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## Refining the high-fidelity archaeointensity curve for western Europe over the past millennium: analysis of Tuscan architectural bricks (Italy)

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1 **Refining the high-fidelity archaeointensity curve for Western Europe over the past**  
2 **millennium: Analysis of Tuscan architectural bricks (Italy)**

3

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19

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21 Western Europe, Past Millennium

22

23 **Abstract**

24 New archaeointensity results were obtained from fourteen groups of baked-brick fragments  
25 collected in and around Pisa (Tuscany, Italy). The fragments were assembled from civil and

26 religious buildings whose dating of construction or renovation, over the past millennium, was  
27 constrained by documentary sources. This collection, analysed using the Triaxe protocol, was  
28 found particularly suitable for intensity experiments, with a success rate of ~84%  
29 corresponding to 276 fruitful specimens associated to 125 independent brick fragments. The  
30 Tuscan data clearly show a peak in intensity at the transition between the 16th and 17th  
31 centuries. They also are in very good agreement and are complementary to a dense dataset  
32 previously obtained in France. Considering the results available within a 700 km radius of  
33 Beaune (between Paris and Pisa), all satisfying a set of quality criteria, a mean geomagnetic  
34 field intensity variation curve was constructed for the past millennium using a newly  
35 developed transdimensional Bayesian technique. This curve, which thus incorporates the new  
36 Tuscan results, allows a better recognition of three intensity peaks (during the twelfth, the  
37 fourteenth, and around AD 1600) in Western Europe. The detail of this curve is a clear  
38 illustration of the centennial-scale resolution that can be achieved using accurate  
39 archaeointensity data.

40

## 41 **1. Introduction**

42 Due to its active volcanoes and particularly rich cultural heritage, Italy can certainly  
43 be viewed as a privileged “playground” for palaeomagnetists to trace back recent variations of  
44 the Earth’s magnetic field. Analysis of lava and pyroclastic flows emitted by Italian volcanoes  
45 has enabled important steps in understanding and describing the main lines of the  
46 geomagnetic directional variations over the past few millennia (e.g. Tanguy et al., 1999, 2003,  
47 2007, 2012; Principe et al. 2004; Arrighi et al. 2006; Vezzoli et al. 2009; Branca et al. 2015a).  
48 Additionally, these studies further allowed re-dating of some lava flows – in the case of  
49 Mount Etna and Vesuvius, these archaeomagnetic constraints were ultimately incorporated

50 for drawing their respective most recent geological map, underlining the potential of such  
51 studies for the comprehension of volcanic edifices (Branca et al. 2015b; Paolillo et al., 2016)

52 On the other hand, during the past 15 years or so, there has been in Italy a dynamic  
53 development of archaeomagnetic research *sensu stricto*. New archaeodirectional data were  
54 acquired from in situ fired structures, which, together with volcanic data, have allowed a  
55 continuous and accurate description of the main lines of the geomagnetic directional  
56 variations in the Italian Peninsula from 1200 BC onwards (see the compilation of Tema et al.  
57 2006 updated in 2011 by Tema, and new results acquired since then: Malfatti et al. 2011;  
58 Kapper et al. 2014; Tema et al. 2016).

59 In contrast, archaeointensity data in Italy remains very few, despite recent progress.  
60 Only 31 results are currently available for a large time interval of eight millennia, with a quite  
61 uneven temporal distribution (Evans 1986, 1981; Aitken et al. 1988; Hedley and Wagner  
62 1991; Hill et al. 2007, 2008; Donadini and Pesonen 2007; Gallet et al. 2009; Tema et al. 2010,  
63 2013, 2016 see also Tema et al. 2011). A few other archaeointensity results were obtained in  
64 Italy, but they mostly relied on archaeomagnetic dating, and for this reason they were not  
65 further considered in this study (e.g. Tema et al. 2015; Principe et al. 2018). Most of the  
66 available results (21) are dated between the 3rd century BC and the 8th century AD, with a  
67 strong concentration of data (12) between 100 BC and AD 100. Three archaeointensity results  
68 were recently obtained for the Early Neolithic period (c. 7500 years ago; Tema et al. 2016),  
69 two results are dated for the 8th century BC and the five remaining results of 31 document the  
70 past five centuries. New archaeointensity data are thus required before a full description of the  
71 geomagnetic field variations in Italy over the past two to three millennia can be achieved.

72 This study aims to contribute to this long-term project with the archaeointensity  
73 analysis of groups of brick fragments collected in and around Pisa. Fourteen brick buildings  
74 dated from between the middle of the 12th century and the end of the 17th century were

75 sampled. From a broader geomagnetic perspective, this study also addresses the issue of the  
76 maximum time resolution of the recording of the geomagnetic field intensity variations  
77 accessible from archaeomagnetic data. This is particularly important as several short-term  
78 (maximum of two centuries) intensity peaks have been proposed over the past millennium in  
79 Western Europe from a dense set of French data (Genevey et al. 2009, 2013, 2016). The  
80 intensity variation rates associated with these peaks are quite strong ( $\sim 0.10 \mu\text{T}/\text{yr}$ ), similar to  
81 the maximum rate observed in the recent field (e.g. Livermore et al., 2014).

82

## 83 **2. Description of the historical baked-brick buildings investigated**

84 Since the Middle Ages, Pisa and its province have been an important area in Tuscany  
85 for ceramic production, particularly using clay from the Arno River and the Serchio River  
86 (Clemente 2015, 2017). Bricks are still produced in Pisa, and numerous buildings made of  
87 bricks were built during the past eight centuries of Pisa's history.

88 Our sampling focused on the baked-brick architectural heritage of the city of Pisa and  
89 its neighbouring territory, encompassing almost five and a half centuries, from the middle of  
90 the 12th century to the end of the 17th century. It thus explores the history of Pisa from its  
91 apogee as a maritime and commercial power to its decline at the end of the 13th century,  
92 followed by a lengthy period under the domination of Florence.

93 We selected a series of fourteen ensembles of bricks based on careful analysis of  
94 available historical and archaeological data, incorporating documentary, iconographic and  
95 cartographic sources. In one case, the year of inauguration was directly inscribed on the  
96 building (Figure 1a,b). All bricks were collected from important buildings commissioned by  
97 the political and/or religious authorities. Even though the year of construction/inauguration of  
98 such buildings do not necessarily correspond exactly to the year of production of the bricks, it  
99 is nevertheless certain that the time lag between their production and their use was very short

100 (most probably less than a year). According to historical and archaeological evidence, the  
101 bricks used were produced specifically for each construction and were not recycled, also  
102 because the quantities of bricks required were extremely high. Furthermore, in order to avoid  
103 the sampling of possibly re-used bricks, we have taken great care to take all our samples from  
104 parts of the walls characterized by homogeneous bricks in terms of colour, aspect, and  
105 dimension. No damaged brick, particularly with traces of burning or chipped portions, were  
106 sampled. In addition, to ensure that the sampled bricks had a size characteristic of the  
107 expected period, we used mensiochronology, a chronological tool based on the temporal  
108 evolution of brick size (e.g. Quiros Castillo 1997). Although this tool requires improvement,  
109 it was observed that the thickness of the bricks gradually decreased from ~6 cm around 1200  
110 to ~4 cm at ~1700 (Quiros Castillo 1997). Furthermore, our selection of sites was dictated by  
111 their accessibility to our sampling (Table 1). This sampling was performed using a portable  
112 driller. Between 10 and 16 cores were taken per group, and the holes were later filled with  
113 tinted mortar in order to restore the visual aspect of the sampled walls as much as possible  
114 (Figure 1c,d,e).

115 Nine groups were collected in Pisa. The two oldest (Pise11 and Pise12) are from the medieval  
116 ramparts built between the middle of the 12th century and the 14th century. These are largely  
117 preserved and still partly surround the historical centre of the city. Drilling was performed on  
118 the same wall located on the edge of the present Scotto Garden (south bank of the Arno  
119 River), where two different phases of construction of the rampart are observed (Gattiglia and  
120 Milanese, 2006). The construction of this medieval wall was initiated in AD 1155 and the  
121 bricks of group Pise12 document this first phase, as confirmed by their thickness, between 6.5  
122 and 7.5 cm, larger than the one observed since. The second, more recent, sampled phase  
123 (Pise11) dates from the first half of the 14th century – i.e., the end of the construction of the  
124 city wall (Quiros Castillo 1997).

125 Two groups were sampled in the Florentine fortress located in the same area of the  
126 Scotto Garden. This large building was erected during the middle of the 15th century (AD  
127 1440), after the end of the Pisan Republic and under Florentine domination (Gattiglia and  
128 Milanese 2006). The first group of samples (Pise10) collected in the Santa Barbara tower  
129 (northern part of the fortress) dates from its construction, whereas the second group from the  
130 Sangallo bastion (Pise09; north-western part near the Florentine bridge over the Arno River,  
131 inside the Corsini building) corresponds to a renovation phase, during AD 1531–1533, which  
132 occurred after a short period of revolt in Pisa and its subsequent reconquest by Florence.  
133 Another group (Pise02) was collected from the Oratory of San Bernardino, which was built at  
134 the end of the 15th century to ward off epidemics of medieval plague (Sodi and Radi 1979).

135 In addition to group Pise09, three other archaeomagnetic groups allow us to document  
136 the 16th century. Group Pise01 was collected from the hydraulic regimentation structure of  
137 the ‘Bocchette’, positioned at the entrance of a canal built during the years of Cosimo I de’  
138 Medici’s government and located a little to the east of the city (Figure 1a,b). This structure  
139 was constructed to divert excess waters of the Arno River towards the Pisan plain, thus  
140 avoiding devastating flooding inside the city (Ciuti 2003). Group Pise08 was sampled in the  
141 important structure of the Medici arsenal, built between 1543 and 1563 on the banks of the  
142 Arno River towards its mouth (Ciuti 2003). Our sampling concerns a well-known renovation  
143 phase carried out few years later in 1588. The third group (Pise06) was sampled in the  
144 structure of the Medici aqueduct, the construction of which was decided upon by Grand Duke  
145 Ferdinando I de’ Medici. This aqueduct provided Pisa with fresh and drinkable water from the  
146 source, located near the little town of Asciano in the Monti Pisani area (Gasperini et al. 2015).  
147 This archaeomagnetic fragment group was collected in a pillar of the terminal segment of the  
148 structure.

149 In Pisa, the 17th century is represented by a group of fragments collected from the  
150 Santo Stefano Dei Cavaleiri church located in the city centre. Although it was founded around  
151 the middle of the 16th century under the direction of Cosimo I de' Medici, some parts of its  
152 external walls are more recent and precisely date to 1683–1691 (Sodi and Renzoni 2003),  
153 where archaeomagnetic group Pise07 comes from.

154 Five more groups of fragments were collected in the province of Pisa. The first group  
155 (Tosc03) dates from the second half of the 13th century and was sampled in a tower of the  
156 castle of Calcinaia, a small medieval city of the Pisan plain along the Arno River (17 km from  
157 Pisa), that was built and fortified by the Pisans (Alberti and Baldassarri 2004). A second  
158 group (Tosc04) was precisely dated to 1331, as ascertained by archives, and was drilled in the  
159 external wall of the church of Marti in the municipality of Montopoli Valdarno (Febbraro  
160 2006). Finally, three archaeomagnetic fragment groups were also sampled in other segments  
161 of the Medici aqueduct dated to slightly more recent ages (first half of the 17th century) than  
162 group Pise06 located in Pisa, because of later construction and/or a renovation. Group Pise03  
163 comes from the start of the aqueduct (cistern of Ascabo Pisano, Figure 1c), while Pise04 and  
164 Pise05, drilled from the arch, come from intermediate but close segments along its path.

165 A total of 179 cores were drilled from the 14 archaeomagnetic sites described above,  
166 and they were subjected to archaeointensity experiments.

167

### 168 **3. Archaeomagnetic investigation and brick composition**

169 The intensity experiments were carried out using three Triaxe magnetometers housed  
170 at the paleomagnetic laboratory of the Institut de Physique du Globe de Paris (IPGP), of  
171 which one belongs to the Laboratoire d'Archéologie Moléculaire et Structurale (LAMS).

172 The Triaxe protocol has been specially designed to take advantage of the specificities  
173 of this equipment, which allows the three magnetisation components of a small specimen



174 (less than 1 cm<sup>3</sup> in volume) to be measured continuously up to high temperatures, either in a  
175 zero field or in a laboratory field, whose intensity and direction are controlled (Le Goff and  
176 Gallet, 2004).

177 This procedure, derived from the Thellier and Thellier (1959) method, was detailed in  
178 previous papers (e.g. Gallet and Le Goff 2006; Genevey et al. 2009; Hartmann et al. 2010).  
179 Table 2 summarises the five heating and cooling steps involved in the Triaxe procedure,  
180 which are carried out between a low temperature, T1 (between 110 °C and 150 °C), and a  
181 high temperature, T2, chosen such that a large part of the natural remanent magnetization  
182 (NRM) is involved. Here, T2 was fixed between 400 °C and 450 °C, as almost total  
183 demagnetisation was achieved at this temperature.

184 The ancient geomagnetic field intensity is inferred from the series of measurements of  
185 steps #1, #3 and #5 (with increasing temperatures) – more precisely, from the averaging of the  
186 R'(Ti) data computed over the temperature range where the primary component is isolated.  
187 Each R'(Ti) value is equal to the ratio, multiplied by the applied laboratory field intensity,  
188 between the demagnetised fractions of NRM (step #1) and thermoremanent magnetisation  
189 (TRM; step #5) between T1 and Ti, with both fractions being corrected from the thermal  
190 variations of the NRM fraction still blocked at T2 (step #3) (see discussion in Le Goff and  
191 Gallet 2004). When a second component is observed, the R'(Ti) data are computed from a  
192 higher temperature referred to as T1' up to T2.

193 It should be emphasised that this protocol takes into account the anisotropy of the  
194 thermoremanent magnetisation since the laboratory field direction is automatically chosen so  
195 as to induce a TRM parallel to the original NRM (Le Goff and Gallet 2004). Additionally, it  
196 was experimentally observed that the Triaxe protocol allows the cooling-rate effect to be  
197 overcome when the intensity values are derived from the R'(Ti) data. This characteristic was  
198 verified for different archaeological collections of various ages and origins from the Near

199 East, Europe, Russia and Brazil (Le Goff and Gallet 2004; Genevey et al. 2009, 2013;  
200 Hartmann et al. 2010; Hervé et al. 2017; Salnaia et al. 2017). Finally, it is worth noting that an  
201 effect of multidomain grains (if any) would be mitigated with this protocol since the  
202 laboratory magnetisation acquired from T2 is almost a full TRM.

203 The Triaxe results were assessed on the basis of selection criteria presented in  
204 Supplementary Table 1 (see also e.g. Genevey et al. 2016). Firstly, they allow us to judge the  
205 quality of the determination at the specimen level, checking both the directional and intensity  
206 behaviours. Two specimens per fragment must then be successfully investigated, and their  
207 results must agree within a limit of 5%. A mean value is computed at the site level when  
208 deriving from at least three different fragments, and its standard deviation must be less than 5  
209  $\mu\text{T}$  and 10% to be retained. The consistency of the results is thus tested at both the fragment  
210 and group levels. The relevance of these criteria, and those related to the selection of  
211 archaeological artefacts, was *in fine* further tested through the consistency of the intensity  
212 values obtained between sites of similar age.

213 For those groups of fragments successfully analysed for intensity, the magnetic  
214 mineralogy was explored through progressive thermal demagnetisation of three orthogonal  
215 isothermal remanent magnetization (IRM) acquired on cubic specimen (of side 1 cm) in high  
216 (1.5 T), medium (0.4 T) and low (0.2 T) fields (Lowrie 1990). The IRM was imparted using a  
217 MMPM10 pulse magnetiser, while the magnetisation measurements were carried out using a  
218 JR-6 spinner (Agico) magnetometer. One fragment per site was subjected to these  
219 experiments. In addition, magnetic susceptibility measurements were performed for at least  
220 two fragments per site along a heating–cooling cycle between 20 °C and a high temperature  
221 chosen close to temperature T2 considered for the Triaxe experiments (here 400 °C–450 °C).  
222 These experiments aimed to confirm the thermal stability of the magnetic mineralogy on the  
223 same temperature range involved in the intensity analysis. The measurements were performed

224 using a KLY-3 Kappabridge coupled to a CS3 unit (Agico). Note that in our previous studies  
225 (e.g. Hartmann et al. 2011; Genevey et al. 2016), these experiments were systematically  
226 conducted on all the fragments retained in intensity. Here, this has not been the case because  
227 the magnetic susceptibility versus temperature curves were found to be almost identical for  
228 the entire collection (see below).

229 Brick fragments were further analysed in the laboratory of the Archaeological  
230 Superintendence of Florence in order to define their composition. After a first description by  
231 means of a Nikon SMZ800 stereo-microscope, thin sections of about 30  $\mu\text{m}$  were analysed  
232 using a Leitz Ortoluz POL polarising microscope connected to a DIGIMAT image processor  
233 in order to define their petrographic paragenesis and textures, and microanalyses were also  
234 carried out using an FEI Quanta 200 electronic microscope connected to a EDX Edax DX-4  
235 spectrometer in order to explore the chemical composition variability.

236

237

#### 238 **4. Results**

239 One important feature of this collection of brick fragments is its remarkable  
240 homogeneity in terms of paleomagnetic behaviour. This behaviour is characterised by an  
241 almost total thermal demagnetisation of the NRM at relatively low temperatures – i.e., around  
242 400 °C–450 °C, with a single magnetization component isolated from 135°C–220°C up to the  
243 highest temperatures (Supplementary Table 2). This collection also appears to be very  
244 suitable for intensity experiments. Indeed, of the 149 fragments investigated using the Triaxe  
245 magnetometers, only 24 fragments were rejected, leading to a very good success rate of 84%  
246 (Supplementary Table 2). For 11 groups of fragments, this percentage ranges from 80% to  
247 100% at the group level, while it is more modest, between 45% and 55%, for the other three  
248 groups. It is worth noting that these percentages refer to the fragments whose magnetisation

249 was strong enough in relation to the Triaxe sensitivity; 27 fragments were found to be too  
250 weakly magnetised. The retained specimens (Supplementary Table 2) possess a NRM  
251 between 30 and 700  $10^{-8}$  A.m<sup>2</sup> with a NRM below 250  $10^{-8}$  A.m<sup>2</sup> for 90% of the collection. For  
252 14 fragments, failures in intensity experiments were linked to a non-ideal behaviour during  
253 the thermal treatment, as illustrated in Figure 2a by the Tosc04-04B specimen. For this  
254 specimen (and corresponding fragment), the  $R'(Ti)$  data decrease continuously all over the  
255 temperature interval investigated, although only one magnetisation component is observed  
256 (Figure 2b), which prevents the recovery of a reliable intensity of the ancient magnetic field.  
257 By contrast, the Pise04-05A specimen displays an appropriate behaviour for intensity  
258 determination, with quasi-constant  $R'(Ti)$  data observed over the temperature range where the  
259 primary component is isolated (Figures 2a,c). The other reason for rejection is related to the  
260 non-fulfilled coherence test at the fragment level (10 fragments).

261 The very homogeneous magnetic behaviour above is associated with an almost  
262 identical magnetic mineralogy for the whole collection of fragments (at least for the  
263 fragments successfully analysed for intensity). The three-axis IRM curves show a systematic  
264 predominance of low coercivity (<0.2 T) minerals, with unblocking temperatures ranging  
265 from 450 °C to 600 °C, which are likely to be from the magnetite family with impurities of  
266 various contents (Figure 3). The thermal demagnetisation of the 1.5-T IRM also shows the  
267 presence of a small fraction of high-coercivity minerals, likely being hematite. For some  
268 fragments, we observe a fraction of minerals with unblocking temperatures below 200 °C–  
269 250 °C and high coercivity, which probably indicates the presence of epsilon iron oxide, as  
270 recently identified by López-Sánchez et al. (2017, Figure 3). The susceptibility vs temperature  
271 curves, although providing no additional information on the magnetic mineralogy, also  
272 emphasise the homogeneity of the collection, as well as the thermal stability of the magnetic  
273 mineralogy over the temperature range used for intensity determinations (inserts in Figure 3).

274 This consistency in the magnetic response to all the experiments above is most probably due  
275 to the use of the same raw material.

276 A total of 276 specimens associated to 125 brick fragments were successfully analysed  
277 for intensity. This allowed 14 new mean well-defined intensity values (Table 1) to be derived.  
278 This is illustrated in Figure 4, where each panel displays for one group all the results obtained  
279 at the specimen level.

280 The homogeneity of this archaeological collection is further supported by petrographic and  
281 spectrometric measurements. The original clayey material contains silicate debris attributable  
282 to quartz in both single crystal and polycrystalline aggregate forms with a sub-angular to  
283 angular morphology. There is no addition of sandy sediments, as would be the case if the  
284 material source was along the course of the Arno River. The absence of fine silt and of well  
285 rounded clasts also militate against a supply of clay from the small quarries that were active in  
286 Pisa from at least the 13th century (Clemente 2015, 2017). On another hand, it should be  
287 noted that the huge quantity of clay necessary for the construction of the large buildings  
288 studied likely exceeded the resources of these small in-town quarries (Clemente 2015, 2017).  
289 In contrast, the quartz and the other silicate (feldspars, micas) components are typical of  
290 alluvial deposits coming from the eastern part of the Monti Pisani sedimentary succession  
291 (Carratori et al., 1991). The sharpened edges and the clasts typologies suggest a short transport  
292 along small watercourses contributing to the paleo-course of the Serchio River.

293 All fragments have in common a red-coloured isotropic matrix due to iron oxidation, as well  
294 as recrystallisation of calcium carbonate during the thermal processes, probably resulting  
295 from the addition of limestone fragments to the clay to increase the porosity of the bricks and  
296 reduce their weight. A fine granulometry is systematically observed in the limestone clasts,  
297 which are present in variable quantities and evenly distributed in the matrix. The  
298 microanalytical investigations show the same qualitative composition. All fragments appear

299 to be made of clayey material fired in furnaces with excess oxygen (oxidising environment) at  
300 temperatures between ~800 °C and ~980 °C. Comparison of the textural and compositional  
301 characteristics of the bricks of Pisa with those of Calcinaia and Marti shows strong  
302 similarities, except for the quantity of the limestone clasts.

303 Based on the results above, we suggest that the bricks used in huge quantity for the  
304 construction of the studied buildings in Pisa were manufactured in the Calcinaia area, where  
305 the presence of brick kilns since the 15th century (Alberti, 2015) is documented, and where  
306 their transport to Pisa was easy thanks to the proximity of the Arno River.

307

## 308 **5. Discussion**

309 Our new data obtained in Tuscany are reported in Figure 5 together with the five other  
310 archaeointensity results available in Italy for the past millennium (Evans 1986; Aitken et al.  
311 1988; Tema et al. 2010, 2013, Tema 2011, see also Figure 6 for their geographical  
312 distribution). Alone, the Tuscan data show a decreasing trend in intensity from the middle of  
313 the 12th century to c. 1500. There was then an increase until the beginning of the 17th  
314 century, followed by a decrease in intensity for about a century. At this stage, it can be noted  
315 that the two other Italian data available for the time period (1500-1700) cannot be easily  
316 reconciled with this variation pattern. This could be the case, however, for the result with the  
317 widest dating interval if its true age would lie at either extremities of that interval. In contrast,  
318 the three most recent data appear in good agreement with the direct measurements and/or the  
319 gufm1 model predictions at Pisa (Jacsikon et al. 2000).

320 Considering the small number of Italian intensity data, Tema et al. (2013) relied on  
321 other data available within a 900 km radius around Viterbo (central Italy) to construct an  
322 intensity variation curve for the Italian peninsula. This curve is composed of two segments,  
323 the ages of which range between 100BC and AD 400, and AD 1300 and AD 1800,

324 respectively. These two intervals are those where the data selected on the basis of quality  
325 criteria are sufficiently numerous. Interestingly, for the period of 1300–1800, the Italian curve  
326 is in fact largely determined from the data obtained in the south of France (e.g. Genevey et al.  
327 2009). For this reason, to compare our new Tuscan data with the other results available  
328 regionally, we preferred to move the reduction site to an intermediate city between Paris and  
329 Pisa and then to integrate into this comparison the data obtained within a 700 km radius  
330 around this new reduction site. Here, we chose Beaune in the Burgundy region, home to the  
331 famous Hôtel-Dieu de Beaune (Figure 6). Note that one of the French data, precisely dated to  
332 the mid-15th century from archival documents, has been obtained from analysis of pavement  
333 tiles from the so-called King’s Room in the Hospices de Beaune (Genevey et al. 2009).

334         At first, we only considered our datasets (Genevey and Gallet, 2002; Genevey et al.  
335 2009, 2013 and this study), as together they form a very homogeneous data collection from an  
336 experimental point of view (i.e., same experimental protocol and selection criteria). Their  
337 geographic distribution is shown in Figure 6 (blue and pink circles), and their intensity values  
338 reduced to the latitude of Beaune are reported in Figure 7a. We observe that they are  
339 remarkably consistent and complementary. The Tuscan data confirm some of the rapid  
340 intensity variations previously observed only from the French dataset (Genevey et al. 2009,  
341 2013, 2016). It is worth recalling that the latter dataset showed that these variations were  
342 characterised throughout the past millennium by three peaks in intensity detected during the  
343 12th century, the second part of the 14th century, and around AD 1600. The Tuscan data  
344 allow us to constrain the intensity maximum at the transition of the 16th and 17th centuries,  
345 with a peak that now appears better defined and more pronounced (Figure 7a). The new result  
346 dated from the middle of the 12th century is also important because it further documents the  
347 peak of intensity observed during this century, in particular the rapid decrease in intensity  
348 between c. 1150 and c. 1250.

349 In a second step, we also reported in Figure 7b all available data obtained within a 700  
350 km radius of Beaune (Figure 6), which fulfil modern quality criteria (as defined by, for  
351 example, Genevey et al. 2016). We only kept data with age uncertainties of less than 100  
352 years, considering that for this recent period of European history, it is possible to access such  
353 accurate dating when the aim is to recover rapid geomagnetic field intensity variations.  
354 Overall, the data available are very consistent. The additional data included here (Chauvin et  
355 al. 2000; Casas et al. 2005; Donadini et al. 2008; Gómez-Paccard et al. 2012) allow, in  
356 particular, a better description of intervals characterised by a decrease in intensity – i.e.,  
357 during the 10th, 15th and 17th centuries.

358 From the data selection above, we constructed a reference intensity variation curve  
359 using the method recently developed by Livermore et al. (2018). This method relies on a  
360 trans-dimensional Bayesian approach that aims to fit a series of linear segments to the data,  
361 the number of which is self-determined by the data themselves. A great asset of this technique  
362 is the minimum regularisation imposed on the fit to the dataset (see discussion in Livermore  
363 et al., 2018). The average curve obtained, and its 95% confidence interval, is shown in Figure  
364 7b. The results are very similar to those previously discussed by Genevey et al. (2016) and  
365 Livermore et al. (2018) using different averaging techniques, which further demonstrates the  
366 robustness of the three intensity peaks observed over the past millennium. Note that this result  
367 is particularly interesting for the attempts to find a correlation (and possible causal link)  
368 between geomagnetic field intensity peaks and cooling episodes in Western Europe as  
369 documented by advances and retreats of alpine glaciers, as well as with fluctuations in the  
370 C14 production rate (Gallet et al. 2005; Genevey et al. 2009, 2013). Furthermore, it is also  
371 worth reminding that the three intensity peaks, now better defined thanks to the new Tuscan  
372 data, are part of a set of five maxima regularly spaced since about 1500 years ago, with a  
373 pseudo period of ~250 years (Genevey et al. 2016; Livermore et al. 2018).



374 Moving away from the area of 700 km around Beaune or Paris, the past millennium in  
375 Europe is well documented by sets of data mainly acquired in northern Germany (Schnepp et  
376 al. 2009), Spain (Gómez-Paccard et al. 2006, 2008, 2012, 2016) and further east in Bulgaria  
377 (Kovacheva et al. 2014). Comparison between, on the one hand, these results and, on the  
378 other hand, the variations predicted in Paris from different global and regional field models  
379 (Pavón-Carrasco et al., 2009, 2014a; Korte et al., 2009; Licht et al., 2013), has already been  
380 widely discussed in our previous publications (Genevey et al. 2009, 2013, 2016; see also in  
381 Pavón-Carrasco et al., 2014b). It should be noted that extending the area around Beaune for  
382 instance to 900 km or 1000 km would lead to a dataset almost identical to that available in a  
383 radius of 1250 km around Paris (Genevey et al., 2016); we recall that in this case, the data  
384 appears significantly more scattered than the dataset available in a 700-km radius, which  
385 results in the smoothing of most of the rapid intensity variations mentioned (see Fig. 7 in  
386 Genevey et al., 2016). Redoing this comparison work would not provide new information  
387 compared to the conclusions of Genevey et al (2016) and for this reason, we chose here to  
388 perform a comparison with a new dataset obtained in Spain (Molina-Cardín et al. 2018).  
389 These authors constructed a new intensity variation curve for the Iberian Peninsula, spanning  
390 the past 3000 years, using both new data and previous results that fulfil a set of quality  
391 criteria, available in a radius of 900 km around Madrid. For the past millennium, this data  
392 selection is essentially different from the one considered around Beaune, even if some data  
393 obtained in France are common to both selections (Figure 6). Let us note that the selection  
394 criteria used by Molina-Cardín et al. (2018) are slightly less restrictive than those used to  
395 select the data reported in Figure 7b (Genevey et al. 2013). The criteria relative to the  
396 intensity methods are the same (Thellier method with pTRM-checks and TRM anisotropy  
397 effect taken into account for artefacts recognized as more anisotropic), but they differ for the  
398 dating uncertainties and data accuracy. In Molina-Cardín et al. (2018), the age uncertainties

399 are required to be of less than 250 years and there is no threshold value relative to the  
400 uncertainty on the intensity mean, whereas, our selection is based on a dating accuracy of less  
401 than 100 years and an uncertainty of less than 15% on the intensity mean. Applying our  
402 selection criteria to the Spanish dataset would have comparatively resulted in the rejection of  
403 13 data, mainly on the basis of the age uncertainties (11 of the 13 data indicated by crosses in  
404 Figure 7c). Regardless of the criteria considered, the data selected around Madrid are  
405 significantly more scattered than those presented in Figure 7b. A mean intensity variation  
406 curve was constructed in Figure 7c using the data selection used by Molina- Cardín et al.  
407 (2018). The dispersion of the data leads to a smooth evolution showing a continuous decrease  
408 between c. 1100 and c. 1850, followed in continuity by the intensity decrease predicted by  
409 gufm1 at Madrid since 1850 (Figure 7c). It should be noted that the very same evolution is  
410 obtained when the Spanish data are selected according to our selection criteria. The same  
411 overall trend is observed from the Beaune dataset, but thanks to a higher coherence between  
412 the results, it allows us to detect the existence of faster intensity variations occurring on the  
413 century timescale (Figure 7b). It therefore seems likely that a reduction of the scatter in the  
414 Madrid dataset would allow the emergence of the same three intensity peaks observed in  
415 France and partly in Italy. From this point of view, the data obtained in France and in Tuscany  
416 indicate that the construction of a mean intensity variation curve with a resolution on a 100-  
417 year timescale is an achievable objective, although it must be acknowledged that this is  
418 clearly a difficult task.

419

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430

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652

653 **Figure and Table captions**

654

655 Figure 1: Examples of Tuscan baked-brick buildings sampled for this archaeointensity study.

656 (a) 'Bocchette di Putignano'. This dike was built in 1558 as indicated on a plaque affixed to  
657 the building (b), which reads 'A PARTV VIRGINIS ANNO M. D. LVIII. CALEN.  
658 NOVEMBRIS' and can be translated as 'November 2nd of the 1558th year since the date  
659 Mary gave birth [to Jesus]'. (c) Cistern of the Medici aqueduct linking Pisa to Asciano Pisa  
660 dated from the beginning of the 17th century. The yellow cross indicates the area selected for  
661 the sampling carried out using drilling. For this site, 12 cores were collected, leaving as many  
662 visible holes (d), which were then filled with tinted mortar to restore the wall as much as  
663 possible (e).

664

665 Figure 2: Examples of favourable (Pise04-05A) and unfavourable (Tosc04-04B) magnetic  
666 behaviour for intensity determination. (a) Diagram showing the evolution of the  $R'(Ti)$  data  
667 over the temperature range investigated. (b) and (c) Corresponding thermal demagnetisation  
668 diagrams. Only one magnetisation component is observed in both cases. For the specimen  
669 Pise04-05A, the  $R'(Ti)$  data are almost constant and their mean provides a reliable intensity  
670 value. The decrease in the  $R'(Ti)$  data over the entire temperature range observed for the  
671 specimen Tosc04-04B indicates a varying proportionality between the NRM and TRM  
672 fractions, thereby invalidating the possibility of recovering the ancient magnetic field  
673 intensity for this brick fragment.

674

675 Figure 3: Characterisation of the magnetic mineralogy. Typical example of thermal  
676 demagnetisation of three-axis IRM acquired in fields of 1.5, 0.4 and 0.2 T. The inserts show  
677 the low field susceptibility vs temperature curves for the corresponding fragments  
678 (heating/cooling in black/grey).".

679

680 Figure 4: Intensity results obtained for four groups of brick fragments. Each curve in the  
681 different panels represents the evolution of the  $R'(Ti)$  data for one specimen over the  
682 temperature range considered for intensity determination. There are 80 determinations,  
683 corresponding to as many specimens, represented here. This figure makes it possible to assess  
684 the consistency of the results obtained at the fragment and group levels

685

686 Figure 5: New archaeointensity data obtained in Pisa and its neighbouring territory, and their  
687 comparison with the other archaeointensity results available in Italy for the past millennium,  
688 the direct measurements and the intensity values expected in Pisa from the gufm1 model  
689 (Jackson et al. 2000) from 1850 onwards. All data were reduced to the latitude of Pisa.

690

691 Figure 6: Geographical distribution of the Italian archaeointensity data (pink circles, the new  
692 Tuscan data; purple squares, previously acquired data), the dataset previously acquired in  
693 France and Belgium (blue points; Genevey et al. 2009, 2013) and the other data selected  
694 (green squares) within 700 km around Beaune (purple circle) and within 900 km around  
695 Madrid (yellow circle; Molina-Cardín et al. 2018).

696

697 Figure 7: Archaeointensity variations in Western Europe over the past millennium as inferred  
698 from different data selections (a) New Tuscan data, together with other results previously  
699 acquired in France and Belgium (Genevey and Gallet 2002; Genevey et al. 2009, 2013) and  
700 from direct measurements (<http://www.bcmf.fr/>). (b) Intensity data fulfilling quality criteria  
701 and available within 700 km around Beaune, and mean geomagnetic field intensity variation  
702 curve, and its 95% confidence envelope, computed from this dataset using the AH-RJMCMC  
703 algorithm developed by Livermore et al. (2018). The computational parameters are as  
704 follows:  $\sigma_{\text{move}} = 200 \text{ yr}$ ,  $\sigma_{\text{change}} = 15 \mu\text{T}$ ,  $\sigma_{\text{birth}} = 8 \mu\text{T}$ ,  $\sigma_{\text{ages}} = 5 \text{ yr}$ ,  $\beta = 20$ ,  $K_{\text{max}}=80$ , with a chain

705 length of 50 million samples and intensity priors of 30  $\mu\text{T}$  for the minimum and 100  $\mu\text{T}$  for  
706 the maximum (see details in Livermore et al., 2018). Following Genevey et al. (2008), the  
707 datum obtained by Casas et al. (2005) marked by ‘\*’ was decreased by 5% to account for the  
708 cooling-rate effect, which was not evaluated in this study. (c) Intensity data selected by  
709 Molina-Cardín et al. (2018) for a region of 900 km around Madrid and the corresponding  
710 mean intensity variation curve computed using the same method as in (b) and with the same  
711 computational parameters except for the intensity priors set at 25  $\mu\text{T}$  for the minimum and 95  
712  $\mu\text{T}$  for the maximum. Note that the time-order relationship existing for two datasets was taken  
713 into account in these estimates. The symbol “x” indicates the thirteen data that would not have  
714 been retained if the same selection criteria as in Figure 7b had been chosen. The intensity  
715 values expected in Madrid since 1850 from the gufm1 model (Jackson et al. 2000) are also  
716 exhibited.

717

718 Table 1: New mean archaeointensity values obtained from the fourteen Tuscan groups of  
719 architectural brick fragments analysed in the present study. ‘location’ indicates the city where  
720 the brick fragments were sampled. Note, however, that the study carried out on the  
721 composition of the bricks suggests the same production area around Calcinaia (43.68°N ;  
722 10.61°E). ‘# Group’ indicates the archaeomagnetic identification number of each group; ‘N  
723 Frag. (n Spec)’ gives, respectively, the number of fragments and specimens retained to  
724 estimate a mean; ‘ $F \pm \sigma F$  ( $\mu\text{T}$ )’ corresponds to the mean value obtained at the sampling site  
725 with its standard deviation in  $\mu\text{T}$ . Its reduction at the latitude of Beaune (47.02°N) is given in  
726  $\mu\text{T}$  in the last column.

727

728 Table 2: Sequence of the five series of measurements involved in the Triaxe intensity  
729 protocol. The measurements are carried out every 5° C (Le Goff and Gallet, 2004).

730

731 Supplementary Table 1: Summary of the selection criteria used to retain the intensity results  
732 at the specimen, fragment and group levels.

733

734 Supplementary Table 2: Intensity results obtained at the specimen level and mean values  
735 obtained at the fragment level. ‘Tmin-Tmax’: Interval of temperature involved for the  
736 intensity computation. ‘Flab’: Intensity of the laboratory field in  $\mu\text{T}$ . ‘NRM T1 (T1)’  
737 column: Percentage of magnetisation fraction with unblocking temperatures larger than T1 (or  
738 T1’). ‘Slope R’: Slope of the straight line computed from the R’(Ti) data between Tmin and  
739 Tmax. ‘F Triaxe’: Intensity values obtained at the specimen level in  $\mu\text{T}$ . ‘F Triaxe mean value  
740 per fragment  $\pm \sigma F$ ’: Mean intensity value obtained at the fragment level with its standard  
741 error when computed from 2 values or its standard deviation when computed from 3 values.  
742 \*: (n1/n2/n3) indicates successively the number of fragments collected, the number of  
743 fragments whose magnetization was strong enough relative to the Triaxe sensitivity and the  
744 number of fragments retained to estimate a mean value at the group level.



a)



b)



c)



d)



e)



Figure 1.

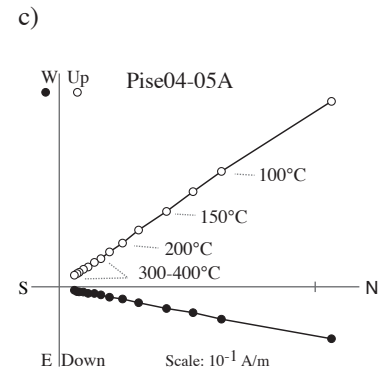
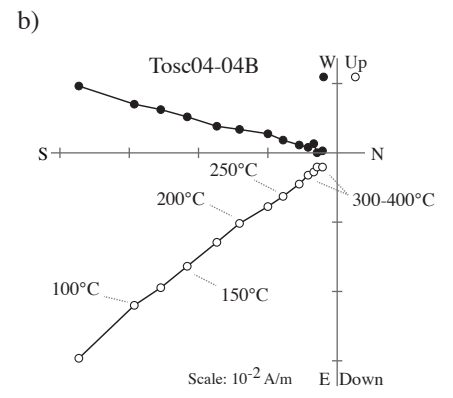
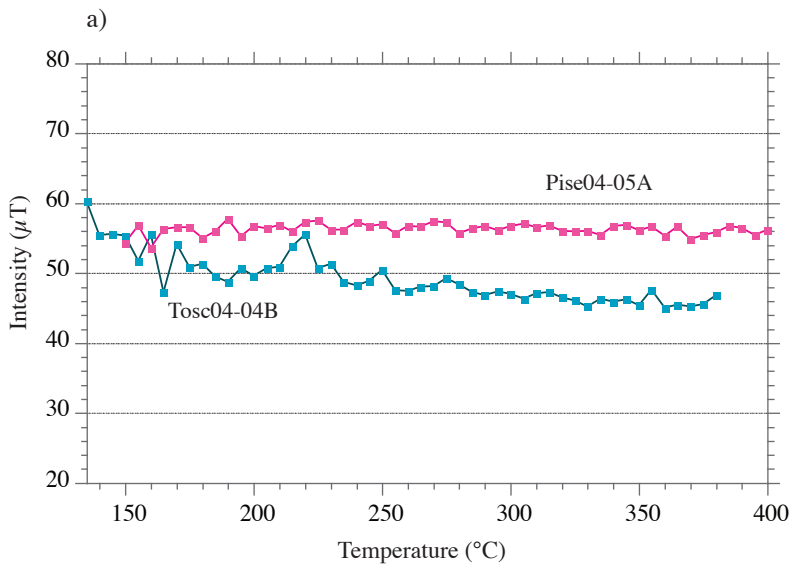


Figure 2.

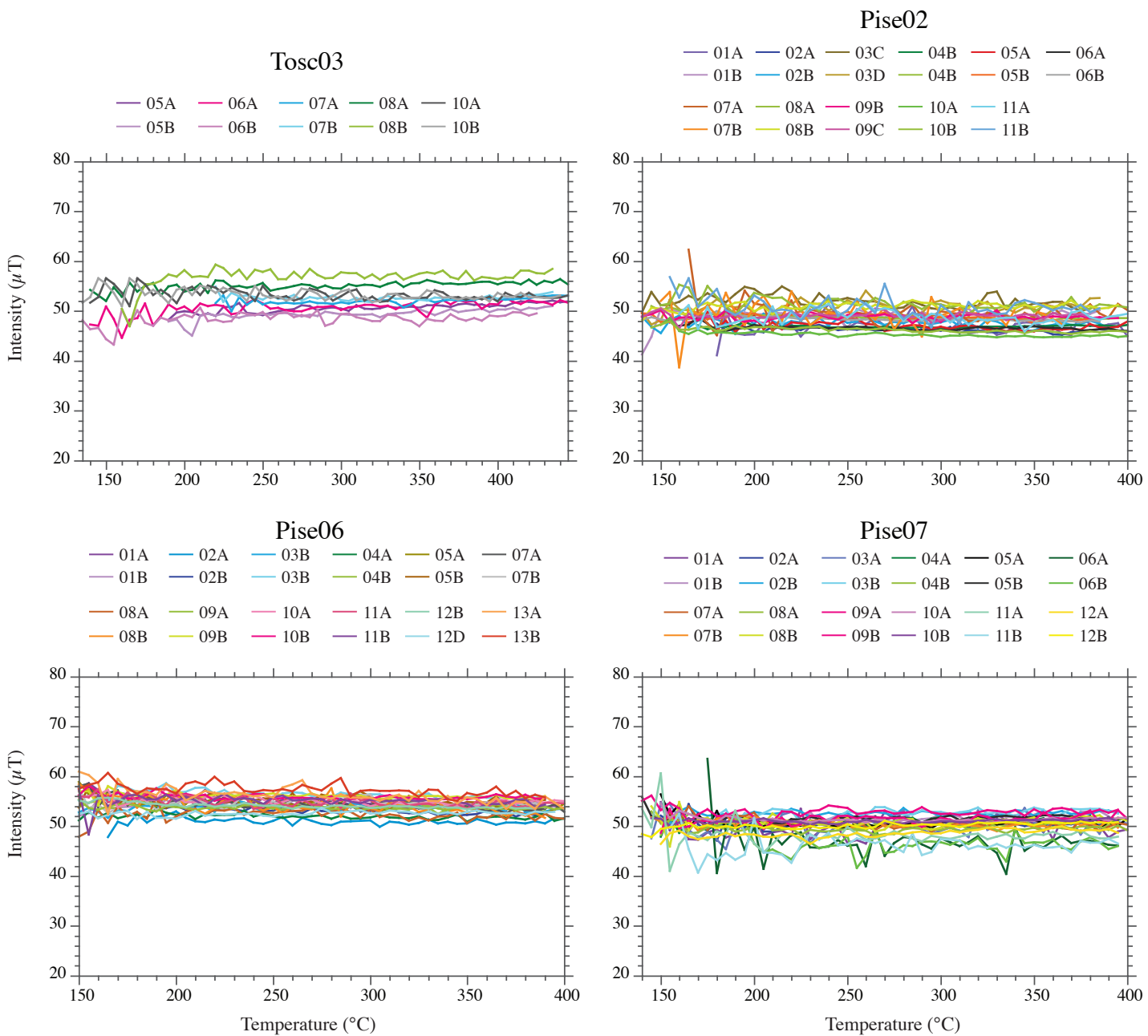


Figure 4.

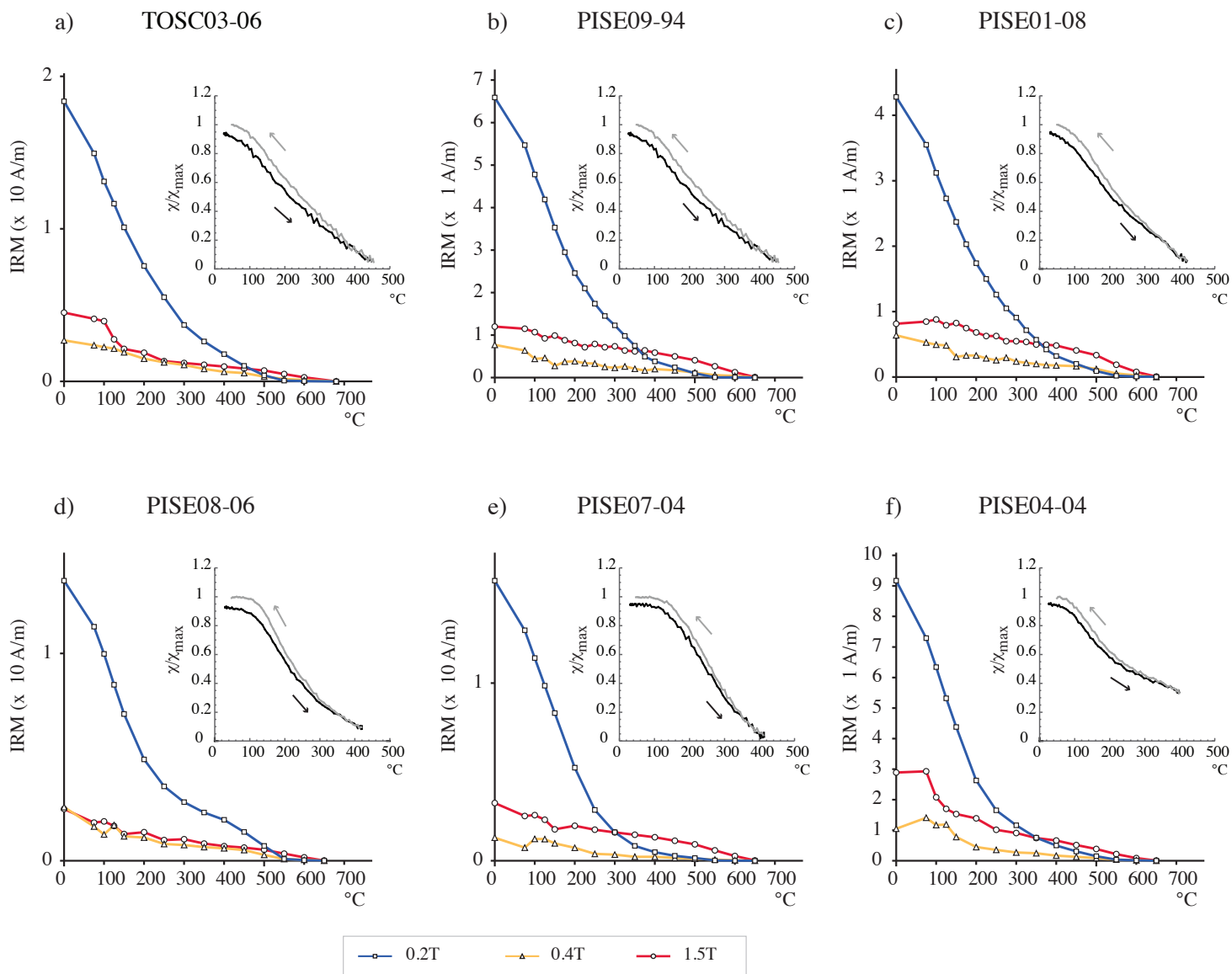


Figure 3.

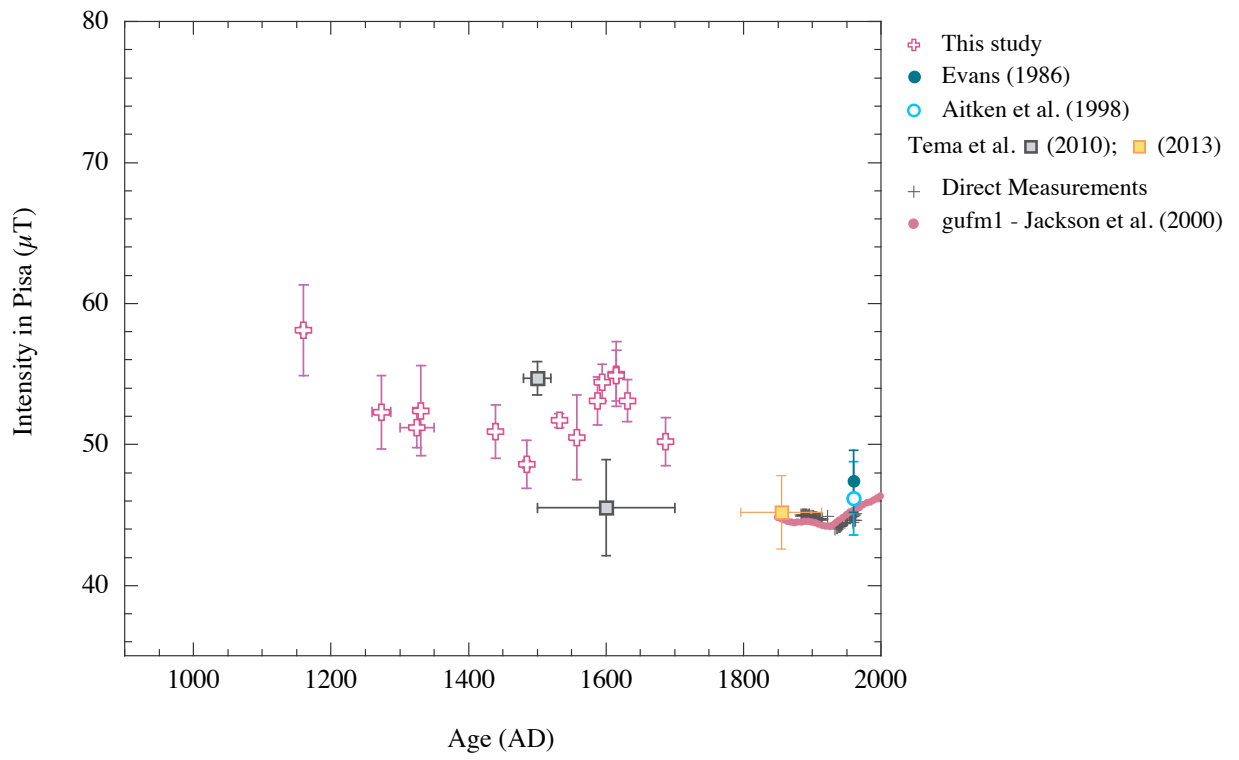


Figure 5.

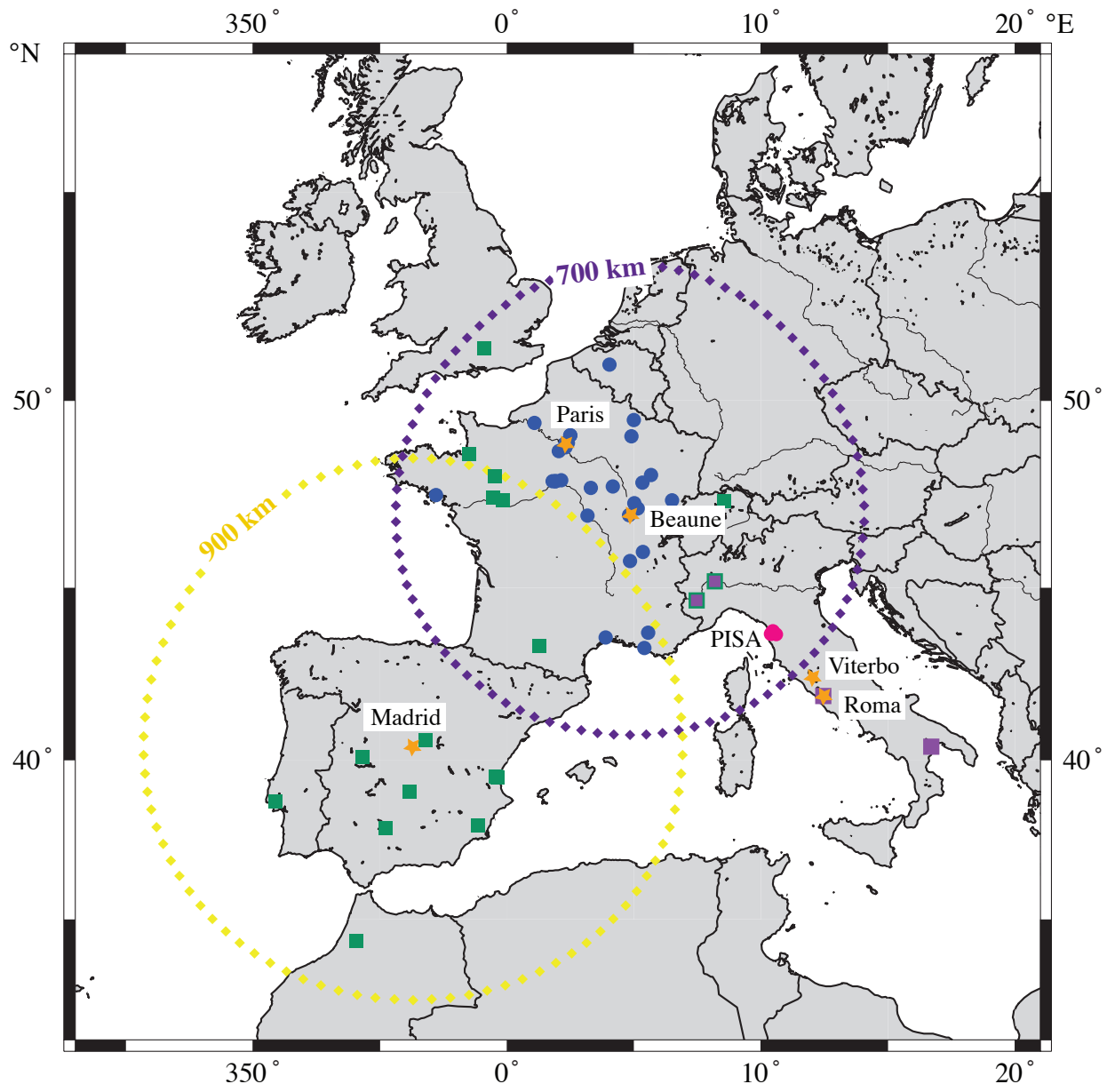


Figure 6.

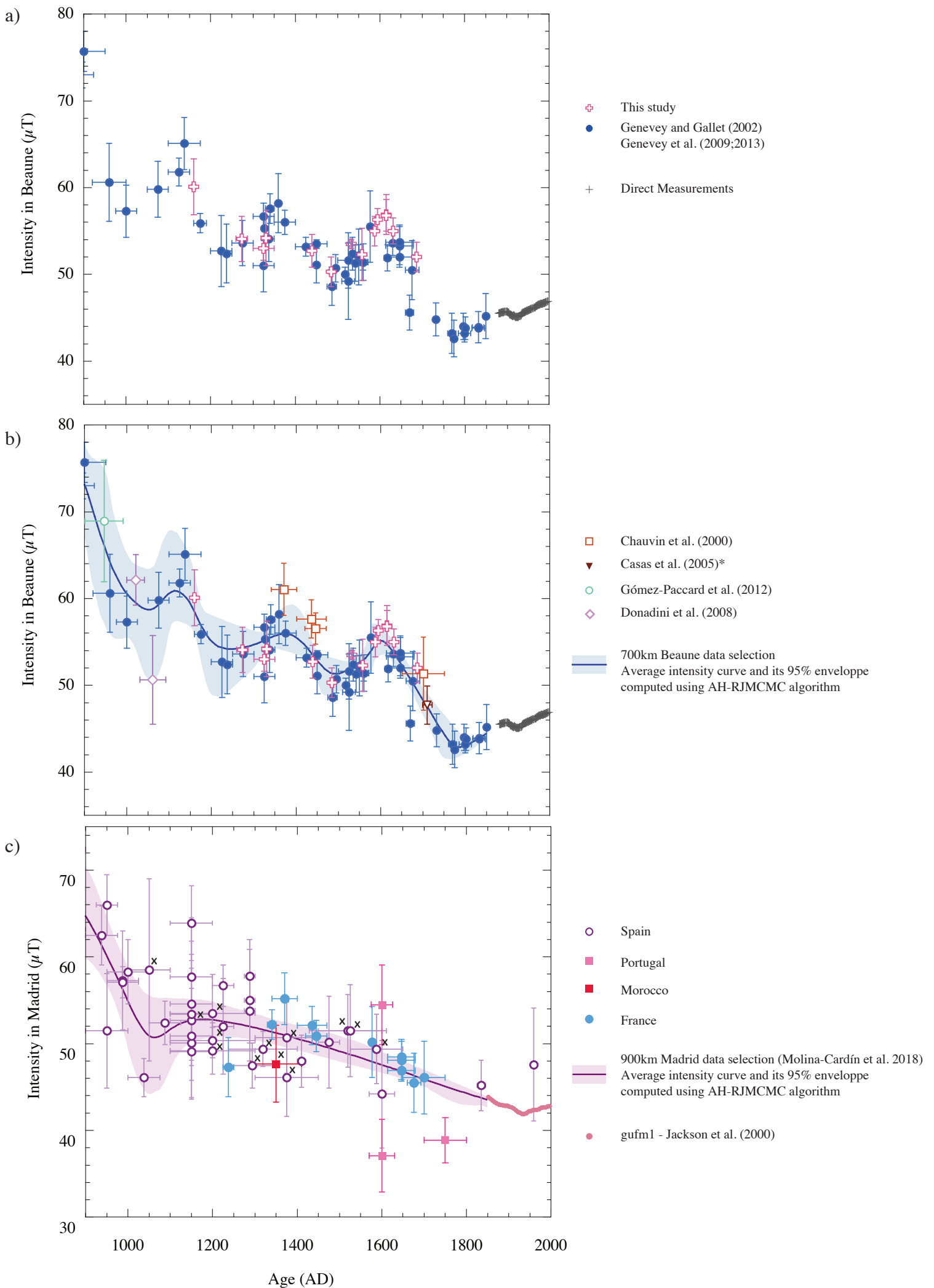


Figure 7.

Location	# Group	Age (A.D.)	Sampled baked-brick buildings	N Frag. (n Spec.)	F ± σF (μT)	at Beaune (μT) (47.02°N; 4.84°E)
Pisa (43.71°N ; 10.40°E)	Pise12	1155-1165	Medieval walls - Scotto Garden	N = 10 (n = 29)	58.1±3.2	60.2
	Pise11	1300-1350	Medieval walls - Second phase - Scotto Garden	N = 4 (n = 12)	51.2±1.4	53.0
	Pise10	1440	New citadel - Santa Barbara tower	N = 15 (n = 30)	50.9±1.9	52.7
	Pise02	1479-1490	Oratory of San Bernardino	N = 11 (n = 22)	48.6±1.7	50.3
	Pise09	1531-1533	New Citadel - Sangallo bastion	N = 5 (n = 15)	51.7±0.5	53.5
	Pise01	1558	Bocchette di Putignano	N = 3 (n = 9)	50.5±3.0	52.3
	Pise08	1588	Medici shipyard (Arsenal)	N = 6 (n = 12)	53.1±1.7	55.0
	Pise06	1595	Medici Aqueduct - Arch	N = 12 (n = 24)	54.4±1.3	56.3
	Pise07	1683-1691	Santo Stefano dei Cavalieri church - Extension of the church	N = 12 (n = 24)	50.2±1.7	52.0
Asciano Pisano (43.75°N ; 10.47°E)	Pise03	1613-1617	Medici Aqueduct - Cistern	N = 10 (n = 20)	55.0±1.8	56.9
	Pise04	1613-1617	Medici Aqueduct - Pillar	N = 9 (n = 22)	54.9±2.3	56.8
	Pise05	1632	Medici Aqueduct - Pillar	N = 13 (n = 26)	53.1±1.6	55.0
Calcinaia (43.68°N ; 10.61°E)	Tosc03	1260-1287	Del Castello tower	N = 5 (n = 10)	52.3±2.6	54.1
Marti (43.65°N ; 10.74°E)	Tosc04	1331	Santa Maria Novella church	N = 10 (n = 21)	52.4±3.2	54.3

Table 1.



Step

#1	Heating	from T1	to T2	in zero field	=> Demagnetization of the NRM
#2	Cooling	from T2	to T1	in zero field	
#3	Heating	from T1	to T2	in zero field	=> Control of the thermal variation on the magnetization fraction remaining unblocked at T2
#4	Cooling	from T2	to T1	in field	=> Acquisition of a laboratory TRM parallel to the NRM
#5	Heating	from T1	to T2	in zero field	=> Demagnetization of the laboratory TRM

Table 2.

■ Specimen level	•Thermal demagnetization	=> Well defined primary component isolated between $T_{min} \geq T1$ and $T_{max} = T2$
	•Intensity determination	=> Performed on the temperature range $[T_{min}-T_{max}]$ , where the primary component is isolated
		=> Percentage of magnetization fraction with unblocking temperatures larger than $T_{min} \geq 50\%$
		=> Slope of the straight line computed between the $R'$ values at $T_{min}$ and $T_{max} \leq 10\%$ This tests the constancy of the $R'(T)$ ratios on the $[T_{min}-T_{max}]$ temperature range considered
■ Fragment level		=> At least n specimens $\geq 2$
		=> Standart error (or standard deviation when $n \geq 3$ ) around the mean $\leq 5\%$
■ Site level		=> At least N fragments $\geq 3$
		=> Standart deviation around the mean $\leq 5\mu T$ and $\leq 10\%$

Fragment	Specimen	T <sub>min</sub> -T <sub>max</sub>	F <sub>Lab</sub>	NRM T1 (T1')	Slope R'	F <sub>Triaxe</sub>	F <sub>Triaxe</sub> mean value per fragment ± σF
		(°C)	(μT)	(%)	(%)	(μT)	(μT)
<b>Pise12, Pisa, Medieval walls, [1155-1165] AD, (12/11/10)*</b>							
Pise12-02	Pise12-02A	165-390	50	79	4	57.3	58.6±1.2
	Pise12-02C	160-395	55	82	-2	59.3	
	Pise12-02D	155-395	55	84	-2	59.3	
Pise12-03	Pise12-03A	170-370	50	79	-3	60.0	61.3±1.8
	Pise12-03B	165-405	55	80	-6	60.6	
	Pise12-03C	170-400	60	78	0	63.3	
Pise12-04	Pise12-04A	155-390	50	80	-3	62.0	61.8±0.5
	Pise12-04B	155-395	55	77	0	61.2	
	Pise12-04D	140-395	55	84	-3	62.2	
Pise12-05	Pise12-05A	150-390	50	71	-3	59.0	60.3±1.4
	Pise12-05B	150-390	55	71	-2	61.8	
	Pise12-05C	140-395	55	81	-2	60.1	
Pise12-06	Pise12-06A	150-390	50	72	1	52.2	52.7±0.5
	Pise12-06E	155-395	55	76	-6	53.2	
Pise12-07	Pise12-07A	150-385	50	81	-3	57.6	58.2±0.5
	Pise12-07B	150-395	55	84	-3	58.5	
	Pise12-07C	150-395	60	86	-2	58.5	
Pise12-09	Pise12-09A	170-385	50	70	-1	59.5	59.5±0.8
	Pise12-09B	145-360	55	62	1	58.7	
	Pise12-09C	140-395	55	79	-1	60.3	
Pise12-10	Pise12-10A	150-385	50	74	-2	59.3	59.5±1.4
	Pise12-10C	150-395	55	77	-1	60.9	
	Pise12-10E	150-395	55	74	4	58.2	
	Pise12-11A	150-400	50	67	-5	57.3	
Pise12-11	Pise12-11C	140-395	55	71	0	55.0	55.9±1.2
	Pise12-11D	140-395	55	71	-2	55.5	
	Pise12-12A	150-390	50	87	-1	52.2	
Pise12-12	Pise12-12B	150-375	55	89	-2	52.9	53.1±1.0
	Pise12-12C	150-390	55	87	-1	54.2	
	<b>Pise11, Pisa, Medieval walls, [1300-1350] AD, (14/9/4)*</b>						
Pise11-01	Pise11-01A	150-400	50	75	1	50.7	50.9±0.2
	Pise11-01C	155-390	50	66	-4	50.9	
	Pise11-01D	160-395	50	63	-4	51.1	
Pise11-02	Pise11-02A	135-390	50	77	-5	52.5	53.0±1.0
	Pise11-02B	140-385	50	75	-9	52.4	
	Pise11-02D	135-390	50	74	-4	54.2	
Pise11-06	Pise11-06A	165-390	50	70	-3	48.7	49.6±1.0
	Pise11-06B	135-390	50	75	-1	50.6	
	Pise11-06C	150-390	50	74	-4	49.5	
Pise11-11	Pise11-11A	150-390	50	73	2	51.7	51.4±1.5
	Pise11-11B	150-400	50	83	2	49.8	
	Pise11-11C	155-390	50	74	-6	52.8	
<b>Pise10, Pisa, New citadel - Santa Barbara Tower, 1440 AD, (16/15/15)*</b>							
Pise10-01	Pise10-01A	150-400	50	76	1	51.9	52.7±0.8
	Pise10-01B	150-400	50	78	-4	53.5	
Pise10-02	Pise10-02A	170-400	50	74	-9	50.5	50.1±0.4
	Pise10-02B	170-385	50	76	-2	49.7	
Pise10-03	Pise10-03A	150-400	50	75	2	51.3	51.8±0.5
	Pise10-03B	150-400	50	74	-1	52.3	
Pise10-05	Pise10-05A	150-400	50	77	-4	52.7	53.1±0.4
	Pise10-05B	150-390	50	78	-5	53.5	
Pise10-06	Pise10-06A	165-400	50	76	-6	51.5	51.8±0.3
	Pise10-06B	165-390	50	76	-4	52.0	
Pise10-07	Pise10-07A	180-400	50	68	-2	51.0	51.6±0.6

Pise10-08	Pise10-07B	180-390	50	75	-3	52.2	
	Pise10-08A	175-385	50	75	5	52.2	52.3±0.1
	Pise10-08B	175-390	50	80	4	52.3	
Pise10-09	Pise10-09A	150-390	50	79	5	47.1	47.8±0.7
	Pise10-09B	150-390	50	77	-4	48.5	
Pise10-10	Pise10-10A	165-395	50	83	-6	47.6	48.8±1.2
	Pise10-10B	165-390	50	77	-6	50.0	
Pise10-11	Pise10-11A	155-400	50	80	-1	45.7	46.7±1.0
	Pise10-11B	155-385	50	78	-3	47.7	
Pise10-12	Pise10-12A	180-390	50	72	-5	48.4	49.6±1.2
	Pise10-12B	150-395	50	79	-3	50.7	
Pise10-13	Pise10-13A	150-395	50	73	-9	52.3	52.2±0.1
	Pise10-13B	150-390	50	80	-5	52.1	
Pise10-14	Pise10-14A	150-400	50	78	0	52.8	53.1±0.3
	Pise10-14B	150-390	50	80	0	53.3	
Pise10-15	Pise10-15A	150-395	50	75	-3	52.0	51.4±0.7
	Pise10-15B	150-390	50	75	-2	50.7	
Pise10-16	Pise10-16A	150-395	50	76	-4	50.9	51.1±0.2
	Pise10-16B	150-390	50	75	-1	51.2	

**Pise02, Pisa, Oratory of San Bernardino, [1479-1490] AD, (12/12/11)\***

Pise02-01	Pise02-01A	180-400	50	73	0	46.9	48.0±1.1
	Pise02-01B	140-385	50	80	3	49.0	
Pise02-02	Pise02-02A	180-400	50	85	-2	46.2	46.9±0.7
	Pise02-02B	140-395	50	82	-2	47.6	
Pise02-03	Pise02-03C	135-380	50	67	-4	51.9	51.4±0.6
	Pise02-03D	135-385	50	68	1	50.8	
Pise02-04	Pise02-04A	170-420	50	95	1	46.9	47.9±1.0
	Pise02-04B	145-400	50	94	-4	48.9	
Pise02-05	Pise02-05A	165-420	50	85	-3	47.0	47.9±0.9
	Pise02-05B	140-385	50	83	-2	48.8	
Pise02-06	Pise02-06A	160-410	50	91	-1	46.6	47.5±0.9
	Pise02-06B	140-385	50	91	-2	48.4	
Pise02-07	Pise02-07A	165-400	50	78	-2	49.7	49.6±0.2
	Pise02-07B	150-365	50	80	-2	49.4	
Pise02-08	Pise02-08A	150-400	50	57	-5	51.1	51.0±0.1
	Pise02-08B	140-395	50	75	-2	50.9	
Pise02-09	Pise02-09B	140-395	50	82	0	48.8	48.9±0.1
	Pise02-09C	135-385	50	82	0	49.0	
Pise02-10	Pise02-10A	150-400	50	89	-4	45.3	45.8±0.5
	Pise02-10B	145-400	50	89	-3	46.2	
Pise02-11	Pise02-11A	160-400	50	67	-2	48.9	49.9±1.0
	Pise02-11B	155-385	50	70	-5	50.9	

**Pise09, Pisa, New Citadel - Sangallo bastion, [1531-1533] AD, (12/5/5)\***

Pise09-02	Pise09-02A	150-400	50	68	-7	50.3	51.1±1.1
	Pise09-02B	170-400	50	68	-6	52.4	
	Pise09-02C	150-405	50	71	2	50.6	
Pise09-04	Pise09-04A	180-465	50	84	2	50.2	51.6±1.3
	Pise09-04B	185-400	50	82	-7	51.9	
	Pise09-04D	175-390	50	80	-7	52.7	
Pise09-08	Pise09-08A	155-410	50	83	-7	52.8	51.9±0.9
	Pise09-08B	150-400	50	83	-1	51.1	
	Pise09-08C	150-405	50	87	-3	51.9	
Pise09-10	Pise09-10A	150-410	50	79	2	50.9	52.5±1.4
	Pise09-10B	150-390	50	79	-2	53.3	
	Pise09-10C	150-405	50	82	0	53.2	
Pise09-12	Pise09-12A	150-410	50	94	-3	49.9	51.5±1.4
	Pise09-12B	150-390	50	76	-4	52.5	
	Pise09-12D	150-395	50	87	-5	52.2	

**Pise01, Pisa, "Le Bocchette di Putignano", 1558 AD, (10/3/3)\***

Pise01-07	Pise01-07A	175-400	50	60	0	46.7	47.1±0.4
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	Pise01-07B	175-445	50	70	5	47.1	
	Pise01-07C	175-450	50	70	4	47.4	
Pise01-08	Pise01-08A	150-400	50	70	-4	50.7	51.3±1.1
	Pise01-08B	140-395	50	74	-3	52.5	
	Pise01-08C	175-395	50	72	-5	50.6	
Pise01-10	Pise01-10A	150-400	50	72	2	51.8	53.0±1.1
	Pise01-10B	140-395	50	69	4	53.1	
	Pise01-10D	155-395	50	69	-1	54.0	

**Pise08, Pisa, Medici shipyard (Arsenal), 1588 AD, (15/11/6)\***

Pise08-03	Pise08-03A	155-400	50	80	-6	54.9	55.1±0.2
	Pise08-03B	160-395	50	78	-1	55.2	
Pise08-04	Pise08-04A	150-400	50	76	2	52.0	52.6±0.6
	Pise08-04B	145-385	50	79	1	53.2	
Pise08-05	Pise08-05A	135-390	50	82	-9	50.6	51.0±0.4
	Pise08-05B	135-390	50	84	-5	51.3	
Pise08-06	Pise08-06A	150-400	50	79	-1	54.9	54.8±0.2
	Pise08-06B	145-385	50	82	6	54.6	
Pise08-08	Pise08-08A	150-395	50	61	-6	51.8	51.4±0.4
	Pise08-08B	150-420	50	70	-7	51.0	
Pise08-11	Pise08-11A	150-390	50	82	1	53.4	53.6±0.2
	Pise08-11B	145-385	50	81	0	53.8	

**Pise06, Pisa, Medici Aqueduct - Arch, 1595 AD, (15/15/12)\***

Pise06-01	Pise06-01A	150-400	55	84	-4	54.8	54.6±0.2
	Pise06-01B	150-390	55	81	0	54.4	
Pise06-02	Pise06-02A	165-400	55	83	-1	50.9	52.1±1.2
	Pise06-02B	165-390	50	81	-5	53.3	
Pise06-03	Pise06-03A	150-400	55	80	0	53.7	55.1±1.4
	Pise06-03B	150-390	55	82	-3	56.4	
Pise06-04	Pise06-04A	150-400	55	85	-2	51.9	52.9±1.0
	Pise06-04B	150-390	55	86	-2	53.9	
Pise06-05	Pise06-05A	150-400	55	81	-4	54.7	55.1±0.4
	Pise06-05B	150-390	55	80	-1	55.4	
Pise06-07	Pise06-07A	150-400	55	86	0	54.5	54.6±0.1
	Pise06-07B	150-390	55	85	-1	54.7	
Pise06-08	Pise06-08A	150-400	55	83	0	52.3	53.3±1.0
	Pise06-08B	150-390	55	80	-7	54.2	
Pise06-09	Pise06-09A	150-400	55	84	-1	53.8	55.0±1.2
	Pise06-09B	150-390	55	83	-2	56.1	
Pise06-10	Pise06-10A	150-400	55	80	-3	55.1	55.5±0.4
	Pise06-10B	150-390	55	86	-2	55.9	
Pise06-11	Pise06-11A	150-400	55	79	-4	54.9	55.0±0.1
	Pise06-11B	150-390	55	82	-1	55.1	
Pise06-12	Pise06-12B	150-385	55	88	-3	54.1	53.3±0.8
	Pise06-12D	150-395	55	93	1	52.5	
Pise06-13	Pise06-13A	150-400	55	81	-7	56.2	56.8±0.6
	Pise06-13B	150-390	55	82	-5	57.4	

**Pise07, Pisa, Santo Stefano dei Cavalieri church, [1683-1691] AD, (12/12/12)\***

Pise07-01	Pise07-01A	150-400	45	76	2	49.9	50.8±0.9
	Pise07-01B	150-390	50	78	4	51.6	
Pise07-02	Pise07-02A	150-390	45	86	0	50.3	51.4±1.1
	Pise07-02B	150-395	50	82	1	52.5	
Pise07-03	Pise07-03A	145-400	45	74	1	50.2	51.4±1.2
	Pise07-03B	170-395	50	81	2	52.6	
Pise07-04	Pise07-04A	150-400	50	86	3	50.8	50.6±0.3
	Pise07-04B	145-395	50	87	-2	50.3	
Pise07-05	Pise07-05A	150-400	50	85	-2	50.8	51.2±0.4
	Pise07-05B	140-395	50	85	0	51.6	
Pise07-06	Pise07-06A	175-395	50	81	-5	46.8	46.6±0.3
	Pise07-06B	190-395	50	81	0	46.3	
Pise07-07	Pise07-07A	150-400	50	79	-4	50.5	50.5±0.1

	Pise07-07B	145-395	50	80	-2	50.4	
Pise07-08	Pise07-08A	150-400	50	84	0	49.4	50.2±0.8
	Pise07-08B	145-400	50	82	1	51.0	
Pise07-09	Pise07-09A	150-400	50	82	2	51.4	52.2±0.8
	Pise07-09B	140-395	50	82	0	52.9	
Pise07-10	Pise07-10A	150-390	50	89	-1	51.3	51.2±0.2
	Pise07-10B	145-395	50	90	1	51.0	
Pise07-11	Pise07-11A	140-395	50	82	-3	48.2	47.2±1.1
	Pise07-11B	155-385	50	70	1	46.1	
Pise07-12	Pise07-12A	150-395	50	88	4	48.5	49.3±0.8
	Pise07-12B	140-395	50	90	3	50.1	

**Pise03, Asciano Pisano, Medici Aqueduct - Cistern, [1613-1617] AD, (12/11/10)\***

Pise03-01	Pise03-01A	155-420	50	78	1	54.4	55.0±0.6
	Pise03-01B	150-400	50	78	-4	55.6	
Pise03-02	Pise03-02A	150-400	50	73	4	53.9	55.2±1.3
	Pise03-02B	150-385	50	75	-2	56.4	
Pise03-03	Pise03-03A	150-400	55	80	0	54.2	54.1±0.1
	Pise03-03B	150-385	55	80	1	54.0	
Pise03-05	Pise03-05A	150-400	55	79	-1	56.0	56.5±0.5
	Pise03-05B	150-385	55	74	-2	56.9	
Pise03-06	Pise03-06A	150-400	55	81	0	54.9	55.8±0.9
	Pise03-06C	150-380	55	82	-3	56.6	
Pise03-07	Pise03-07A	150-400	55	81	-1	54.4	55.7±1.3
	Pise03-07B	145-385	55	80	-3	57.0	
Pise03-08	Pise03-08B	135-385	55	80	0	57.5	58.1±0.6
	Pise03-08C	135-380	55	79	2	58.7	
Pise03-09	Pise03-09A	150-400	55	78	-2	52.6	52.4±0.3
	Pise03-09B	150-385	55	78	2	52.1	
Pise03-10	Pise03-10A	150-400	55	87	-5	53.1	52.1±1.1
	Pise03-10B	150-390	55	87	-2	51.0	
Pise03-11	Pise03-11A	150-400	55	72	1	54.7	54.7±0.0
	Pise03-11B	150-390	55	79	2	54.7	

**Pise04, Asciano Pisano, Medici Aqueduct - Pillar, [1613-1617] AD, (12/11/9)\***

Pise04-01	Pise04-01A	150-400	55	93	-2	51.6	53.0±1.2
	Pise04-01B	140-390	55	89	1	53.7	
	Pise04-01D	140-380	55	93	2	53.8	
Pise04-02	Pise04-02A	150-400	55	81	-3	51.2	52.4±1.2
	Pise04-02B	170-390	55	84	-3	53.6	
Pise04-04	Pise04-04A	150-400	55	81	1	54.2	55.5±1.3
	Pise04-04B	140-390	55	87	1	56.8	
	Pise04-04C	140-395	55	84	-1	55.6	
Pise04-05	Pise04-05A	150-400	55	85	0	56.3	56.9±1.0
	Pise04-05B	140-390	55	82	-3	56.4	
	Pise04-05D	150-385	55	88	0	58.1	
Pise04-06	Pise04-06A	170-390	55	80	-5	49.8	50.5±0.7
	Pise04-06B	150-395	55	83	-3	51.1	
Pise04-07	Pise04-07A	160-400	55	82	-4	56.5	56.8±0.2
	Pise04-07B	165-390	55	79	-5	56.9	
	Pise04-07C	165-395	55	82	-4	56.9	
Pise04-10	Pise04-10A	150-400	55	79	2	55.9	56.5±0.6
	Pise04-10B	150-390	55	84	-1	57.1	
Pise04-11	Pise04-11A	150-400	55	80	0	54.8	55.7±0.9
	Pise04-11B	150-390	55	86	-2	56.5	
Pise04-12	Pise04-12A	150-400	55	88	-5	55.8	56.6±0.8
	Pise04-12B	150-390	55	88	-3	57.4	

**Pise05, Asciano Pisano, Medici Aqueduct - Pillar, 1632 AD, (14/13/13)\***

Pise05-01	Pise05-01A	150-400	50	76	-1	53.0	52.9±0.1
	Pise05-01B	150-370	50	77	-2	52.8	
Pise05-02	Pise05-02A	150-400	50	87	2	50.5	51.0±0.5
	Pise05-02B	150-400	50	83	1	51.5	

Pise05-03	Pise05-03A	150-400	50	79	-4	52.8	53.4±0.6
	Pise05-03B	150-380	50	75	-6	53.9	
Pise05-04	Pise05-04A	150-400	50	81	-4	55.3	54.3±1.1
	Pise05-04B	150-380	50	82	-4	53.2	
Pise05-05	Pise05-05A	150-400	50	89	2	51.1	52.0±0.9
	Pise05-05B	150-385	50	89	-1	52.9	
Pise05-06	Pise05-06A	150-400	50	80	0	51.2	52.1±0.8
	Pise05-06B	150-385	50	80	1	52.9	
Pise05-07	Pise05-07A	150-400	50	83	0	54.3	55.0±0.7
	Pise05-07B	150-390	50	82	-2	55.6	
Pise05-09	Pise05-09A	150-400	50	84	3	54.9	55.5±0.6
	Pise05-09B	150-390	50	84	0	56.1	
Pise05-10	Pise05-10B	140-385	50	88	-3	53.4	53.3±0.1
	Pise05-10C	140-385	50	84	-3	53.2	
Pise05-11	Pise05-11A	150-400	50	81	-1	54.6	54.9±0.3
	Pise05-11B	160-390	50	79	-2	55.1	
Pise05-12	Pise05-12A	175-375	50	68	4	51.2	50.6±0.7
	Pise05-12B	170-390	50	75	-7	49.9	
Pise05-13	Pise05-13A	135-380	50	72	-6	50.9	52.1±1.2
	Pise05-13C	140-380	50	73	1	53.3	
Pise05-14	Pise05-14A	150-395	50	79	4	52.4	53.7±1.3
	Pise05-14B	150-385	50	80	-1	55.0	

**Tosc03, Calcinaia, Castle - Medieval Tower, [1260-1287] AD, (11/10/5)\***

Tosc03-05	Tosc03-05A	190-445	50	78	5	50.7	50.1±0.7
	Tosc03-05B	190-435	50	79	-6	49.4	
Tosc03-06	Tosc03-06A	140-445	50	81	7	50.6	49.6±1.1
	Tosc03-06B	135-425	50	82	3	48.5	
Tosc03-07	Tosc03-07A	220-445	50	70	3	52.0	52.4±0.4
	Tosc03-07B	220-435	50	75	0	52.7	
Tosc03-08	Tosc03-08A	140-445	50	75	4	55.1	56.0±0.9
	Tosc03-08B	160-435	50	72	5	56.8	
Tosc03-10	Tosc03-10A	140-445	50	84	-3	53.3	53.3±0.0
	Tosc03-10B	150-435	50	75	-3	53.2	

**Tosc04, Marti, Santa Maria Novella church, 1331 AD, (12/11/10)\***

Tosc04-02	Tosc04-02A	170-400	55	71	-4	49.0	48.3±0.7
	Tosc04-02B	155-380	55	66	-7	47.6	
	Tosc04-02E	155-395	55	70	-2	48.3	
Tosc04-03	Tosc04-03A	155-400	55	85	-3	46.1	47.1±1.0
	Tosc04-03B	135-380	55	86	-2	48.1	
Tosc04-05	Tosc04-05A	140-395	55	86	2	55.1	55.9±0.8
	Tosc04-05B	140-390	45	86	-4	56.6	
Tosc04-06	Tosc04-06A	140-395	55	85	4	52.1	53.0±0.9
	Tosc04-06B	140-390	55	81	-5	53.9	
Tosc04-07	Tosc04-07A	140-395	55	89	-2	55.1	55.3±0.2
	Tosc04-07B	140-390	55	89	-5	55.4	
Tosc04-08	Tosc04-08A	140-395	55	82	-1	54.1	54.3±0.2
	Tosc04-08B	135-380	55	81	1	54.5	
Tosc04-09	Tosc04-09A	140-395	55	81	2	48.1	48.8±0.7
	Tosc04-09B	135-380	55	82	-1	49.5	
Tosc04-10	Tosc04-10A	140-395	55	85	2	53.5	54.6±1.1
	Tosc04-10B	145-380	55	83	-4	55.7	
Tosc04-11	Tosc04-11A	140-395	55	83	4	54.8	55.1±0.3
	Tosc04-11B	140-380	55	85	2	55.3	
Tosc04-12	Tosc04-12A	140-395	55	79	4	50.3	51.4±1.1
	Tosc04-12B	140-390	55	77	-1	52.4	