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Systematic sourcing of granite shafts from Gallia Narbonensis and comparison with other western Mediterranean areas

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ABSTRACT

Determining the source quarries for granite shafts in antiquity provides insight into ancient trade routes for such prized materials. We briefly review how non-invasive techniques are currently being applied to address this archeometric task. In specific cases established protocols based on magnetic susceptibility can be integrated with chemical analysis, as demonstrated herein. A systematic inventory and sourcing of granite shafts of presumed antique origin was performed in the region that once formed Gallia Narbonensis. A total of 276 complete shafts or shaft fragments were identified in 21 localities. After fragment pairing hypotheses, they were attributed to at least 174 original shafts. Only four localities (Aix, Arles, Die, Riez) contribute to 54% of the whole corpus. Provenance was determined through visual, magnetic susceptibility and chemical comparison with known antique quarries in Egypt, Turkey, Elba, Corsica and Sardinia. Most of the shafts originated in Turkey (75%), followed by Elba (20.5%). Minor sources are the pink granites of Aswan and Sardinia, as well as grey granite from Corsica, found only in Die. Ambiguity between the Corsican source and the grey Egyptian granite from Mons Claudianus was resolved using portable X-ray fluorescence to determine Sr and Rb contents. As most of the corpus consists of shafts present in medieval to modern contexts, caution is required in interpreting our findings in terms of Ancient Roman architectural and economic choices. Long distance transport of spolia or newly quarried shafts may have occurred after Roman times.

1. Introduction

Granite columns became a major decorative and structural element in monumental architecture during the Roman Empire (DeLaine, 1997), probably due to the influence of Egyptian and other oriental building traditions, superseding the Hellenic and roman Republic preference for white–grey marble and limestone (Russell, 2013). Granite also has some technical and aesthetic advantages: its extreme hardness and mechanical resistance allow carving of long monolithic shafts, their safe transport without breakage and their use in supporting heavy overlying loads better than other types of rocks (e.g. the portico of the Pantheon in Rome). Moreover, granite can take long-lasting mirror polishing to

highlight its colorful, spotted patterns; in contrast, the polished surface of more uniform white–grey marble dulls rapidly when exposed to rain and humidity. The diffusion of polychrome and veined marbles testifies to the imperial preference for colored shafts (Russell, 2013). Note that we use here the quarrying term “granite” in a broad geological sense, i.e. including all types of granitoids.

Although shaft trade was established throughout the Mediterranean basin, only a few source quarries have been identified for granite shafts (Lazzarini, 1992; Williams-Thorpe, 2008; Russell, 2013), with major sources in Egypt (Aswan and Claudianus), Turkey (Troas and Mysia) and the Tuscan islands (Elba and Giglio). Other source quarries for granite shafts in antiquity are known in Corsica, Sardinia and Spain, in

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particular, but these sources show more limited long-distance diffusion according to previous authors (Williams-Thorpe, 2008; Clerbois et al., 2022). This scarcity of sources, despite the quite common occurrence of granite, has been ascribed to various factors: granitic outcrops allowing for the extraction of unfractured blocks up to 8 m long are uncommon; quarries close to the Mediterranean Sea or to large rivers such as the Nile were favoured in order to allow long distance transport by boat, minimizing expensive transport by road; greater skill is required to carve out geometrically perfect shafts than to cut parallelepiped blocks; large quarries were often the personal property of the Emperor and the control of shaft trade was a political issue.

Determining the source quarry of granite shafts found in Roman monuments and of those reused in later periods can help understand trade routes during the imperial period, as they document temporal, regional and local specificities in the selection of sources, and allows researchers to link shafts to their specific monument of origin at a given site. Our survey of some well-preserved Roman cities in Turkey suggests the use of a single source for a given monument. Based on a methodology developed in the last decades, granite shafts sourcing is obtained through visual and petrographic comparison with material from source quarries (e.g. Lazzarini, 1992; Peacock et al., 1994; Antonelli et al., 2010a). Visual identification is sometimes ambiguous, particularly when remains show varying degrees of alteration and conservation, and depends on personal skills and biases. Petrographic characterization through geochemical and mineral analysis in the laboratory is a tedious and destructive process. Researchers have therefore sought to develop suitable non-destructive in situ techniques. In various studies Williams-Thorpe and co-authors used magnetic susceptibility to source Roman granite shafts; they produced a synthesis paper on more than one thousand shafts from numerous regions throughout the Mediterranean area, from the Levant to Spain (Williams-Thorpe, 2008). The same methodology was adopted in this study, as described in the methods chapter. The synthesis by Williams-Thorpe (2008) lacks consistent data from important regions of the Empire such as Gaul, Africa (not counting a few shafts transported from Leptis Magna to England in modern times) and Turkey (apart from Cyprus). Besides limited local studies, the only

attempt to determine granite shaft sources in Gaul is a work by Mazeran (2004), which lacks a systematic quantitative approach. We therefore decided to undertake a systematic study using mainly magnetic susceptibility: this article presents our first results limited to the Narbonensis Province (Fig. 1). Data will be used to compare Gallia Narbonensis to other provinces, and to make site-specific inferences. The problem of the post-Imperial reuse of shafts and the bias this may introduce will be examined, as our corpus seems to contain mostly reused shafts that cannot be easily linked to traceable Roman remains.

2. Materials and methods

The sourcing method derived from Williams-Thorpe (2008) entails the classification of shafts as coarse- or fine-grained grey or pink granites, followed by comparison of their averaged corrected magnetic susceptibility to reference values (see Table 1).

Magnetic susceptibility (K , the ratio between induced magnetization and the inducing weak magnetic field) is a dimensionless bulk physical property that depends mostly on the amount of iron (typically from 1 to 5 wt% FeO) in the material and the mineralogical form of iron (Rochette, 1987). If present in silicates, such as biotite or amphibole, the iron has a weak susceptibility of the order of 10^{-4} SI. If concentrated in oxides (mostly magnetite), K can be much higher, i.e. 2 wt% magnetite corresponds to $30 \cdot 10^{-3}$ SI.

Three main sources of pink granites are known: Aswan in Egypt, Capo Testa and Olbia in Sardinia. Their magnetic susceptibilities overlap in the 2 to $14 \cdot 10^{-3}$ SI range, but Aswan and Sardinian sources are easily distinguished through visual inspection. Aswan granite is foliated and uniformly very coarse grained, with abundant large bright pink feldspars enclosed in a dark matrix, whereas Sardinian sources have an overall much paler color, with less abundant large light pink feldspars enclosed in a fine-grained light gray-pinkish matrix (Fig. 2). K may be used to distinguish between the two Sardinian sources, although some overlap exists (Williams-Thorpe and Rigby, 2006).

Among the more abundant grey granites, two are fine grained with no or rare large feldspars: Elba-Giglio (e.g., Williams-Thorpe and Rigby,

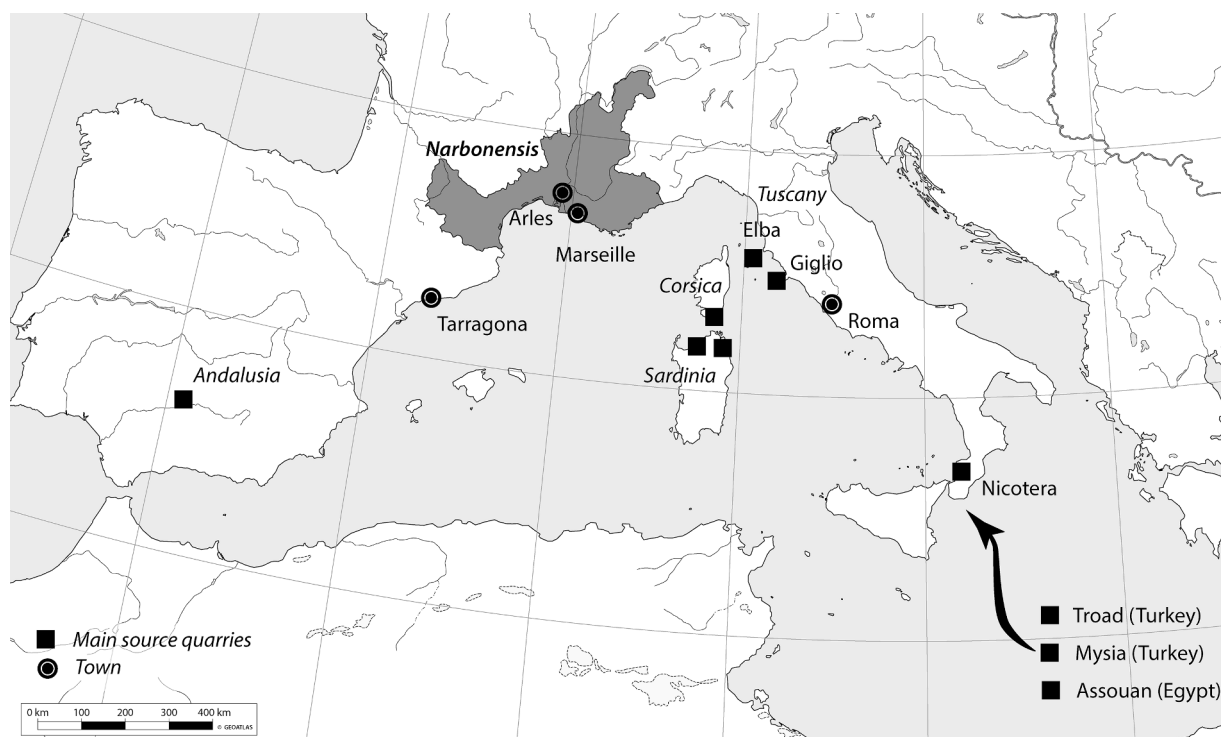


Fig. 1. Map of Mediterranean with Gallia Narbonensis limits in bold, main source quarries and other provinces or cities discussed here.

Table 1

Magnetic susceptibility, K, for different granite shaft sources mentioned in this paper, either pink (in italics) or grey, listed according to decreasing K in the [Williams-Thorpe \(2008\)](#) database. N is the number of shafts used to compute the mean K (in 10^{-3} SI) and its standard deviation (s.d.). Values obtained in this study after source assignment are listed for comparison. *Note that a few pink shafts possibly from Olbia according to [Williams-Thorpe \(2008\)](#) have K values of 0.23–1.1.

Granite	After Williams-Thorpe (2008)				This study			
	mean K	s.d.	range	N	mean K	s.d.	range	N
<i>Olbia*</i>	9.1	1.0	6.6–14.7	56	9.75	–	9.6–9.9	2
<i>Aswan</i>	6.6	0.9	3.0–8.5	162	5.8	1.1	4.9–7.1	3
<i>Capo Testa</i>	2.8	0.9	1.8–4.3	17	3.1	–	3.1	1
Troad	33.1	5.4	15.4–47.2	345	33.8	4.7	24–48.5	77
Mysia	23.5	2.9	16.6–31.8	165	22.8	3.2	13.4–27	46
Corsica	7.6	0.9	5.8–8.9	23	7.4	2.1	5.0–10.1	5
Claudianus	5.2	2.2	2.1–10.4	104	–	–	–	–
Elba/Giglio	0.17	0.02	0.12–0.24	165	0.16	0.02	0.12–0.22	33



Fig. 2. Field examples of typical visual aspect of the different sources identified in Narbonensis: a) Assouan (Vienne), b) Olbia (Aix), c) Troad (Aix), d) Mysia (Riez), e) Elba (Orange), f) Corsica (Die). Scale indicated with SM30 meter or yellow bar (10 cm long).

2007; note that no attempt was made to distinguish these two nearby sources, hereafter named simply “Elba”) and Mysia (or Kozak Dağ according to [Williams-Thorpe, 2008](#); Marmor Misium of [De Vecchi et al., 2000](#)). Although [De Vecchi et al. \(2000\)](#) distinguish between the two through the identification of a specific mineral (hornblende) and the trace element geochemistry, K measurements allow much easier distinction, as values differ by two orders of magnitude (about 0.2 and $16 \cdot 10^{-3}$ SI for Elba and Mysia respectively). Note that a distinctive feature of the Elba granite is the presence of few large feldspars with black coronas (example in [Fig. 2](#), not always visible on small surfaces).

The most abundant Troad granite (Marmor Troadense, [Pensabene et al., 2018](#)) is quite easily recognized on clean surfaces by the abundance of grey-violet elongated feldspars within a fine-grained matrix and may be confirmed by high K values (on average $33 \cdot 10^{-3}$ SI), the highest among the antique granite sources. However, in the case of weathered or paint-covered surfaces, visual inspection is ambiguous and the K value is decisive in confirming Troad identification. Nonetheless, in road-guards and some church interiors, the distinction between Troad and Mysia may be not straightforward due to overlapping susceptibilities. Still, the combination of magnetic susceptibility and visual inspection limits the

risk of incorrect attribution to either of these two sources. The violet feldspar criterion may not always be used on weathered shafts, as long-term UV exposure turns the violet into grey.

Lastly, several homogeneous coarse-grained grey granite sources are reported. The most famous is named Mons Claudianus (hereafter referred to as Claudianus) because of its abundance in Rome, particularly in the Forum (therefore also called “Forum granite”; Peacock et al., 1994). Due to its characteristic coarse black and white texture, as well as its K value around $5 \cdot 10^{-3}$ SI, it is easily distinguished from the above-mentioned sources, but not from the lesser-known Corsican granite, in the same K range (from Cavallo-San Bainzo islands; Triantafyllou et al., 2021; Wilson, 1988; Clerbois et al., 2022). Note that Thorpe and Rigby (2007) investigated a grey granite in northern Sardinia (Municca quarry), said to be indistinguishable from the southern Corsican quarries (only 12 km north of Municca). Peacock et al. (1994); Williams-Thorpe (2008) suggested that Claudianus could be distinguished from Corsican sources on the basis of its distinct mineral foliation and its pure black and white color, which contrasts with the more varied color palette of the Corsican source (comprising grey and sometimes yellowish zones mixed with black and white crystals). Such criteria must be applied with caution because both are subjective and depend on the quality of the surface; moreover, evidence for foliation depends on the relative orientation of the observation surface. Given the great difference in Rb and Sr trace element compositions, Potts and West (2008) proposed chemical discrimination using portable X-ray fluorescence (pXRF). We therefore also applied this technique to the few shafts in our study of suspected Corsican origin.

Other antique sources reported in the literature are not considered relevant to our study, either because they are reputed to have been mostly used locally in southern Spain (Williams-Thorpe, 2008) or Calabria (Antonelli et al., 2010a) or because they are very rare, highly prized Egyptian colored granites used to produce only small shafts, most of which were found in Rome (Williams-Thorpe, 2008). Although there are no previous reports of a French provenance (for example in the Massif Central), we did not exclude this possibility. We considered for that purpose our past visual and magnetic studies on French granites (e.g. Rochette, 1987; Jover et al., 1989; Gattacceca et al., 2004a). All granite outcrops studied in Gallia have a K value < 0.5 , except rare cases in the high Alps, Brittany and Vosges, which are unlikely to have supplied Narbonensis cities due to their remoteness. During our inventory of Gallia shafts outside the Narbonensis province, we identified several low susceptibility sources very likely from the Massif Central (forthcoming publication). Lastly, we must also mention a known antique quarry of an intrusive rock named esterellite, in Narbonensis, near Frejus, which was used to produce shafts. This rock is not a granite but a bluish grey microdiorite with a porphyry aspect (“porfiro bigio”) that was exported as opus sectile, with only a few shafts reported in Narbonensis and Rome (Mazeran, 2004; Gébara and Morhange, 2010). We will therefore only briefly consider the few esterellite shafts found in the course of this study.

The systematic inventory of shafts in museums and Roman ruins, and of spolia used in later buildings and public monuments was completed through bibliographic search (starting from Mazeran, 2004) and enquiries addressed to museums, local archeological services and academic colleagues working on specific sites. Systematic exploration of favorable sites allowed the detection of numerous previously undescribed shaft fragments, in particular in city streets (e.g., as guard stones), private houses (as pillars or lintels), churches, lapidary deposits, as well as landmarks in private parks or along roads. Care was taken to investigate known Roman cities for which no granite shafts have been reported, so as to check if this absence is due to lack of documentation and poor preservation or to an original lack of granite shafts.

The following information was reported for each shaft fragment: location, diameter (D) and length (L) with a one cm precision, unevenness and magnetic susceptibility (see details below), presence of original top or bottom torus, fracturing, color and visual aspect,

including detailed pictures for references. The sourcing hypothesis was made in situ by combining visual and magnetic criteria, following the procedure described below. Shafts were assigned to a specific “site” corresponding to a present-day city or locality within a radius of 15 km. No attempt was made to name these sites according to a local antique locality due to the above-mentioned predominance of reused shafts. The only exception is the maritime villa of Tauroentum, where one shaft was found during excavations.

Volumic magnetic susceptibility (K) was determined using the SM30 portable instrument, which is more modern and sensitive but has the same overall geometric design as the KT5 used by Williams-Thorpe. The sensor diameter is about 5 cm and probes the material down to a few centimeters in depth: the first centimeter already provides 69% of the total signal (Lecoanet et al., 1999; Jordanova et al., 2003; Gattacceca et al., 2004b). At least three K measurements were obtained by applying the sensor to several cylindrical surfaces, selecting the smoothest possible area. Measurements take about a minute. Relative variability among repeated measurements of the same shaft did not usually exceed 20%. Because the instrument is calibrated for a perfectly flat surface, a correction factor $F (\geq 1)$ was applied to adjust for shaft curvature (i.e. diameter D) and surface unevenness (U), estimated visually in mm. F increases with increasing U and decreasing D. F values are provided in Williams-Thorpe and Thorpe (1993), as well as in the SM30 and KT5 user manuals. For example, the F for a shaft 40 cm in diameter with an unevenness of 0, 1 and 2 mm is respectively 1.10, 1.17 and 1.24. Corrected mean K for a given shaft is thus the averaged raw K measurement multiplied by F and is reported in 10^{-3} SI unit. In three cases we were unable to use the SM30, but we obtained samples of a few tens of grams that were measured in the laboratory using the MFK1 kappabridge. The K value was derived from massic susceptibility using a fixed density of 2.65, typical for granite. These three shafts were found in Arles (two immersed in the Rhone riverbed and sampled underwater at 10 m depth) and Aix (a large shaft set on a 3 m-high pedestal, sampled during its restoration).

For pXRF we used the Bruker tracer IV in trace element mode with a counting time of 90 s. It shows a sensitivity on Rb and Sr contents of the order of 5 ppm and an analytical spot size of the order of 1 cm. The methodology for such measurements was recently detailed in Triantafyllou et al. (2021). In the case of coarse-grained granite a large number of individual measurements must be averaged (Triantafyllou et al., 2021 suggest 16) to compensate for mineralogical variability at the cm scale. The manufacturer’s calibration was used. To check the validity of this calibration, we compared averaged data obtained on shafts with averaged data obtained on sawn surfaces of rock samples from different quarries (Cavallo Island in Corsica, San Piero in Elba, Okzular in Mysia). We also compared our results with published geochemical data on quarries.

As many of our observations were made on fragments rather than complete shafts, we generated composite shafts from fragments with similar characteristics to achieve statistical significance regarding their original architectural context. We based these reconstitutions on fragments of the same source and similar diameter (within 5 cm), using the maximum shape ratio ($S = L/D$) discussed in the results section, and a maximum of two observed tori. Whenever possible, we considered similarity in K value and texture when fitting broken surfaces, as well as evidence for top and bottom surfaces. Lastly, in order to consider the impact of spolia use, each entry in our catalogue is characterized by a reference to the dating of the archeological context, either imperial, late antique (Christian period, mostly 5–6th century), medieval or modern.

3. Results

a) General results based on magnetic susceptibility

276 granite shaft remains (complete or fragments) were identified in 21 sites from Gallia Narbonensis, not counting isolated countryside finds in the vicinity of Aix and Die (Fig. 3 and Tables 1, 2 and 3). Table 1

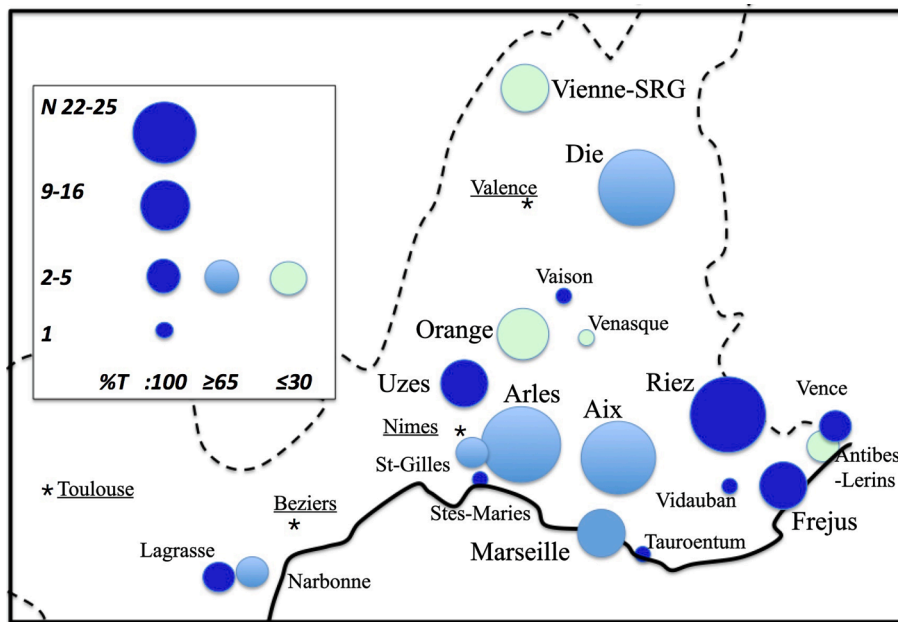


Fig. 3. Map of studied sites with Narbonensis limits (sea shore full line, political frontier dotted line) and granite shafts number represented by circle dimension. Color code corresponds to % of Turkish origin. Sites name with large (small) fonts correspond to shaft number ≥ 9 (≤ 5), while major cities without detected shafts are underlined.

Table 2

Number of granite shafts from the different sources identified at each site or site grouping (ordered by decreasing number of composite shafts). Percentage of Turkish sources and number of fragments (n) are also indicated.

Site	Troad	Mysia	Corsica	Aswan	Elba	Sardinia	N shafts	% Turkish	n frag.
Riez	2	23					25	100	26
Arles	14	5			5		24	79	46
Die	12	3	5		3		23	65	39
Aix	13	5			3	1	22	82	26
Orange	2				14		16	13	43
Marseille	4	8		1			13	92	18
Vienne-SRG	2	1		2	5		10	30	28
Frejus	9						9	100	9
Uzes	8	1					9	100	13
Antibes-Lerins	1				3	1	5	20	7
Narbonne	3					1	4	75	4
Lagrasse	4						4	100	6
Saint Gilles	2				1		3	67	4
Vence	2						2		2
Stes Maries de la Mer	1						1		1
Tauroentum		1					1		1
Vaison la Romaine	1						1		1
Venasque					1		1		1
Vidauban	1						1		1
Total (N or n)	81	47	5	3	35	3	174		276
Total %	47.4	27.5	2.9	1.8	20.5	1.8			

illustrates the good match between source K values (average or range) from this study with those of Williams-Thorpe (2008; see methods section). Table 2 summarizes the number of shafts from each source identified at each site, while Table 3 lists all shaft characteristics.

Note that two site groupings were made in Table 2: Saint-Romain-en-Gal (SRG, with one shaft) is grouped with Vienna, on the other side of Rhone River, while the Abbey of Lerins island (two shafts) is grouped with Antibes, at a distance of 9 km. To achieve statistical significance in terms of initial importation, we attempted to generate composite shafts following the methods presented above; we thus produced a corpus of at least 174 complete shafts. This is a minimum number, as our pairing hypotheses may have grouped fragments from different but nearly identical original shafts. The axial ratios (length over diameter) of shafts with a single piece measured are plotted in Fig. 4. All shafts have a ratio of less than 8.7, except for one shaft with a small diameter that will be

discussed later. We therefore set the upper limit for the axial ratio of composite shafts to 8.7.

Major sites (with >15 shafts) are by order of importance Riez, Arles, Die, Aix and Orange. The first four localities contribute to 54% of the whole corpus. Five sites yielded only one shaft, and five others 2 to 5 shafts. Turkish sources strongly predominate (75%, 2/3 of which from Troad), followed by Elba (20.5%, see Table 2). Besides the overall predominance of Troad, there are some site specificities, with the predominance of Elba in Orange, Antibes-Lerins and Vienne, and of Mysia in Marseille and Riez. Minor sources are pink granites from Aswan (3 shafts in Vienne and Marseille) and Sardinia (3 shafts in Narbonne, Aix and Antibes), as well as grey granite presumably from Corsica based on its lack of foliation and not pure black and white color (5 shafts in Die). No local granite source from Gaul was identified, apart from the Esterel porphyry (4 shafts in Frejus, Lerins, Venasque, with K values of $27.3 \pm$

Table 3

list of composite shafts investigated in Gallia Narbonensis, ordered by sites, with location (in French), internal reference, diameter and height, average corrected susceptibility, number of fragments composing the shaft, source, period (antique, late-antique, medieval, modern: ant, LA, med, mod).

Site	Location	Reference	Diameter (cm)	Height (m)	K cor (10–3SI)	N fragments	Source	Period	Shape ratio
Aix	Baptistère St-Sauveur	SS1	57	4.65	0.12	1	Elba	LA	8.1
Aix	St-Mitre (gauche)	SM2	58	2.19	0.10	1	Elba	mod	3.8
Aix	Baptistère St-Sauveur	SS2	62	5.25	0.13	1	Elba	LA	8.5
Aix	Place des Martyrs	CR	37	1.48	18.14	1	Mysia	mod	4.0
Aix	Centre Dir. Archéologie	G2	50	4.15	23.59	1	Mysia	mod	8.3
Aix	Centre Dir. Archéologie	G3	50	4.05	21.97	1	Mysia	mod	8.1
Aix	Cloître St-Sauveur	SS3	52	2.48	21.51	1	Mysia	med	4.8
Aix	Fontaine hôtel de Ville	HV	64	5.12	16.40	1	Mysia	mod	8.0
Aix	La Baronne et Meyrargues	LB1 + MEY	60	3.2	9.58	2	Olbia	mod	5.3
Aix	Centre Dir. Archéologie	S1	32	0.4	33.88	1	Troad	mod	1.3
Aix	Hôtel de Fonscolombe	FC	38	2.6	36.62	1	Troad	mod	6.9
Aix	Musée Granet	G6	45	3.55	33.00	1	Troad	ant	7.9
Aix	Fontaine cours St-Louis	SL	46	3.56	35.17	1	Troad	mod	7.7
Aix	Centre Dir. Archéologie	G4	46	3.57	25.02	1	Troad	ant	7.8
Aix	Centre Dir. Archéologie	G5	46	3.58	38.96	1	Troad	ant	7.8
Aix	Musée Granet	G7	46	3.57	44.54	1	Troad	ant	7.8
Aix	St-Marc-Jaumegarde	SMJ	46	2.05	31.63	1	Troad	mod	4.4
Aix	Musée Granet	G1	47	3.6	31.36	1	Troad	mod	7.7
Aix	Fontaine Bellegarde	BL	47	3.56	38.66	1	Troad	mod	7.6
Aix	Musée du Viel Aix	MVA1 + 2	48	3.5	41.75	2	Troad	mod	7.3
Aix	Fontaine des Augustins	AU	46	3.56	36.14	1	Troad	mod	7.7
Aix	Baptistère St-Sauveur	SS1s + LB2 + St-Mitre	59	4.02	31.80	3	Troad	LA	6.8
Antibes	Musée Picasso	P1	52	0.6	3.14	1	Cabo Testa	mod	1.2
Antibes	composite	A1-P2	40	2.3	0.19	2	Elba	mod	5.8
Antibes	Place Clemenceau	C1	42	2.5	0.14	1	Elba	mod	6.0
Arles	cryptoportiques	CP4	25	1.1	0.16	1	Elba	ant	4.4
Arles	Composite E 40	AL1-CP1-CR6	40	2.35	0.15	3	Elba	ant	5.9
Arles	Composite E 50	AL2-CR13-T8	50	4.08	0.16	3	Elba	ant	8.2
Arles	Composite E 55	RPM-T1	55	3.97	0.15	2	Elba	ant	7.2
Arles	Composite E 60	T4-T7	58	3.9	0.15	2	Elba	ant	6.7
Arles	Composite M 32	CR3-5-8	32	2.48	24.36	3	Mysia	mod	7.8
Arles	Composite M 40	T5-CP5	39	1.8	22.49	2	Mysia	ant	4.6
Arles	Composite M 50	T6-CR10	50	3.72	25.43	2	Mysia	ant	7.4
Arles	Rhône	R1	55	4	27.00	1	Mysia	ant	7.3
Arles	Forum	F2	80	5	22.96	1	Mysia	ant	6.3
Arles	St Trophime	porche	27	3.25	33.35	1	Troad	med	12.0
Arles	Crédit agricole	CA	29	2.33	32.51	1	Troad	ant	8.0
Arles	Exèdre droit	E1 composite	34	2.96	37.97	2	Troad	ant	8.7
Arles	Exèdre gauche	E2	34	2.98	25.33	1	Troad	ant	8.7
Arles	chasse roue	CR11	36	0.5	44.44	1	Troad	ant	1.4
Arles	rue Baléchou	B2 (C4)	40	0.8	25.98	1	Troad	mod	2.0
Arles	Composite T 40a	C2-3-CP2	40	3	33.51	3	Troad	mod	7.5
Arles	Composite T 40b	CR1-2-4-7-9	41	3.05	35.12	5	Troad	mod	7.4
Arles	St Césaire	SC	46	3	38.58	1	Troad	ant	6.5
Arles	Composite T 50	CP3-T9-CR12-GC	48	3.75	31.00	4	Troad	ant	7.8
Arles	Rhône	R2	55	4	46.00	1	Troad	ant	7.3
Arles	chasse roue	CR14	60	0.77	30.96	1	Troad	mod	1.3
Arles	Composite T75	T1-2-3	75	5.2	39.12	3	Troad	ant	6.9
Arles	Forum	F1	80	4	36.61	1	Troad	ant	5.0
Die	musée	M7	23	1.1	5.00	1	Corsica	med	4.8
Die	composite	A2-10-M6-GL	60	4.61	5.60	4	Corsica	med	7.7
Die	composite	A12-14-M1	60	3.01	7.86	3	Corsica	med	5.0
Die	composite	A3-9-13	62	4	10.10	3	Corsica	med	7.2
Die	Clocher 0	C1	63	2.24	8.63	1	Corsica	med	3.6
Die	musée	M11	23	0.92	0.18	1	Elba	med	4.0
Die	extérieur cathédrale	C3	24	1.74	0.13	1	Elba	med	7.4
Die	musée	M9	24	1.74	0.17	1	Elba	med	7.3
Die	Clocher 1	C7	50	3.81	22.98	2	Mysia	med	7.6
Die	composite	A1-4	50	4.1	25.85	2	Mysia	med	8.2
Die	Clocher 1	C4	68	3.34	23.64	1	Mysia	med	4.9
Die	Clocher 1	C6	55	3.16	34.31	1	Troad	med	5.8
Die	Clocher 1	C5	56	3.95	35.56	1	Troad	med	7.0
Die	Clocher 0	C2	60	2.33	25.16	1	Troad	med	3.9
Die	rue	A8	60	1.8	27.59	1	Troad	med	3.0
Die	composite	A6-7-M2-3	64	5.13	34.29	4	Troad	med	8.0
Die	Cimetière	A11	65	4	28.56	1	Troad	med	6.2
Die	Clocher 5	C10	67	5.45	32.79	1	Troad	med	8.1
Die	Clocher 4	C9	67	5.45	33.25	1	Troad	med	8.1
Die	Clocher 6	C11	67	5.45	24.88	1	Troad	med	8.1
Die	composite	A5-M4-8	69	4.93	34.08	3	Troad	med	7.1
Die	musée	M5-privé-4 cantons	69	5.55	32.73	3	Troad	med	8.0
Die	Clocher 3	C8	70	5.45	34.71	1	Troad	med	7.8
Frejus	Baptistère	B6	36	3.05	32.98	1	Troad	LA	8.5

(continued on next page)

Table 3 (continued)

Site	Location	Reference	Diameter (cm)	Height (m)	K cor (10–3SI)	N fragments	Source	Period	Shape ratio
Frejus	Baptistère	B7	36	3.05	34.34	1	Troad	LA	8.4
Frejus	Musée	M1	37	1	29.44	1	Troad	ant	2.7
Frejus	Baptistère	B4	38	3.05	27.32	1	Troad	LA	8.1
Frejus	Baptistère	B5	38	3.05	40.19	1	Troad	LA	8.0
Frejus	Baptistère	B2	38	3.05	24.02	1	Troad	LA	8.0
Frejus	Baptistère	B8	38	3.05	32.29	1	Troad	LA	8.0
Frejus	Baptistère	B3	39	3.05	31.75	1	Troad	LA	7.7
Frejus	Baptistère	B1	41	3.05	36.15	1	Troad	LA	7.4
Lagrasse	composite	C2-D2-3	42	2.73	33.19	3	Troad	med	6.5
Lagrasse	dépôt	D1	44	1.92	43.38	1	Troad	med	4.4
Lagrasse	cloître	C1	48	3	34.87	1	Troad	med	5.2
Lagrasse	cloître	C3	48	2	32.96	1	Troad	med	4.4
Lerins	miliaire	C3	44	1.38	0.16	1	Elba	ant	3.2
Lerins	composite	C2-D1	37	1.7	36.98	2	Troad	med	4.6
Marseille	dépôt	D7	40	1.12	4.95	1	Assouan	mod	2.8
Marseille	Mysia34	D2-D6-D8	34	2.2	20.20	3	Mysia	mod	6.5
Marseille	St-Victor	SV1	42	1.6	17.82	1	Mysia	med	3.8
Marseille	MAM578	D3	43	2.65	22.35	1	Mysia	mod	6.2
Marseille	rue d'Aubagne		50	3.95	24.71	1	Mysia	mod	7.9
Marseille	Génie		50	4.1	22.02	1	Mysia	mod	8.2
Marseille	dépôt	D1-D4-SV2-3	50	4.05	20.00	4	Mysia	med	8.1
Marseille	Borély	B2	53	4	22.95	1	Mysia	mod	7.6
Marseille	parc Puget		54	4.77	15.58	1	Mysia	mod	8.8
Marseille	dépôt	D5	40	1.35	32.83	1	Troad	mod	3.4
Marseille	Borély	B1	41	3.2	31.01	1	Troad	mod	7.9
Marseille	Borély	B3	49	2	32.09	1	Troad	mod	4.1
Marseille	dépôt Salengro	SAL	60	0.3	29.04	1	Troad	ant	0.5
Narbonne	cours d'honneur	CH1	60	0.5	9.88	1	Olbia	med	0.8
Narbonne	Clos Lombarde	CL1	41	2.1	33.66	1	Troad	ant	5.1
Narbonne	horreum	H2	66	4	33.26	1	Troad	ant	6.1
Narbonne	horreum	H1	68	4	30.44	1	Troad	ant	5.9
Orange	T39		39	2.57	0.19	4	Elba	ant	6.6
Orange	T50		50	3.31	0.16	4	Elba	ant	6.6
Orange	dépôt extérieur	D1entier	51	4.12	0.15	1	Elba	ant	8.1
Orange	T54	T54	54	3.77	0.16	3	Elba	ant	7.0
Orange	T54	T54	54	1.49	0.16	3	Elba	ant	2.8
Orange	Théâtre	Retour W	55	4.2	0.14	1	Elba	ant	7.6
Orange	dépôt extérieur	D2entier	58	4.1	0.17	1	Elba	ant	7.1
Orange	T59	T59	59	3.71	0.16	6	Elba	ant	6.3
Orange	T61	T61	61	3.28	0.16	3	Elba	ant	5.4
Orange	4 colonnes	T70	70	5.145	0.16	4	Elba	ant	7.4
Orange	4 colonnes	T71	70	5.145	0.16	4	Elba	ant	7.4
Orange	4 colonnes	T72	70	5.145	0.16	3	Elba	ant	7.4
Orange	4 colonnes	T73	71	5.145	0.16	3	Elba	ant	7.2
Orange	Théâtre	Scène E base	79	1.4	0.14	1	Elba	ant	1.8
Orange	Théâtre	Scène E principal	75	4.6	36.26	1	Troad	ant	6.1
Orange	Théâtre	Scène W	79	5.9	36.53	1	Troad	ant	7.5
Riez	St Maxime	SM1	42	full	22.70	1	Mysia	med	n.d.
Riez	St Maxime	SM2	42	full	27.00	1	Mysia	med	n.d.
Riez	St Maxime	SM3	42	full	20.48	1	Mysia	med	n.d.
Riez	St Maxime	SM3b	42	full	13.35	1	Mysia	med	n.d.
Riez	St Maxime	SM4	42	full	26.14	1	Mysia	med	n.d.
Riez	St Maxime	SM5	42	full	25.35	1	Mysia	med	n.d.
Riez	St Maxime	SM6	42	full	26.88	1	Mysia	med	n.d.
Riez	cathédrale	CA1	48	3.15	26.11	1	Mysia	LA	6.6
Riez	St Maxime	SME + SMP	50	3	26.70	2	Mysia	med	6.0
Riez	cathédrale	CA2	51	1.5	19.89	1	Mysia	LA	2.9
Riez	fontaine	FC	52	full	23.63	1	Mysia	mod	n.d.
Riez	Baptistère	B1	52	4.16	23.83	1	Mysia	LA	8.0
Riez	Baptistère	B2	52	4.16	17.12	1	Mysia	LA	8.0
Riez	Baptistère	B3	52	4.16	22.36	1	Mysia	LA	8.0
Riez	Baptistère	B4	52	4.16	24.14	1	Mysia	LA	8.0
Riez	Baptistère	B5	52	4.16	19.55	1	Mysia	LA	8.0
Riez	Baptistère	B6	52	4.16	21.17	1	Mysia	LA	8.0
Riez	Baptistère	B7	52	4.16	22.52	1	Mysia	LA	8.0
Riez	Baptistère	B8	52	4.16	25.42	1	Mysia	LA	8.0
Riez	Colostre	C1	73	4.85	25.23	1	Mysia	ant	6.6
Riez	Colostre	C2	73	4.85	23.59	1	Mysia	ant	6.6
Riez	Colostre	C3	73	4.85	26.09	1	Mysia	ant	6.6
Riez	Colostre	C4	73	4.85	26.86	1	Mysia	ant	6.6
Riez	chasse roue	CR	42	0.45	35.50	1	Troad	mod	1.1
Riez	Croix rond-point	RP	56	1.3	29.29	1	Troad	mod	2.3
St Romain	dépôt	SRG	35	0.3	0.17	1	Elba	ant	0.9
St-Gilles	Abbaye	AB1	42	3.2	0.14	1	Elba	med	7.7
St-Gilles	composite	D1-2	42	1.25	33.61	2	Troad	med	3.0
St-Gilles	Abbaye	AB2	43	3.2	38.73	1	Troad	med	7.4

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Table 3 (continued)

Site	Location	Reference	Diameter (cm)	Height (m)	K cor (10–3SI)	N fragments	Source	Period	Shape ratio
St-Marie-Mer	église	SMM	45	1.1	31.27	1	Troad	med	2.5
Tauroentum	musée		29	1.2	23.43	1	Mysia	ant	4.1
Uzes	composite	C7a-10a	48	4	18.16	3	Mysia	med	8.3
Uzes	composite	C5-6	30	2	34.56	2	Troad	med	6.7
Uzes	composite	C8a-C10b	47	4	33.30	2	Troad	med	8.5
Uzes	Château	C7b	48	2.6	41.11	1	Troad	med	5.4
Uzes	porche	C2	48	full	48.50	1	Troad	med	n.d.
Uzes	porche	C1	49	full	29.10	1	Troad	med	n.d.
Uzes	porche	C3	49	full	32.51	1	Troad	med	n.d.
Uzes	Château	C9a	49	3.5	32.25	1	Troad	med	7.1
Uzes	porche	C4	50	full	35.35	1	Troad	med	n.d.
Vaison	Eglise		41	3	27.55	1	Mysia	med	8.5
Venasque	baptistère	Int	26	2.27	0.15	1	Elba	med	8.7
Vence	place Gd Jardin	V2	45	2.99	38.40	1	Troad	ant	6.6
Vence	place Godeau	V1	48	2.66	39.50	1	Troad	ant	5.6
Vidauban	extérieur église		35	1.12	27.85	1	Troad	ant	3.2
Vienne	composite	OD2-SE2	49	1.55	7.06	4	Assouan	ant	3.2
Vienne	composite	OD1-TH1	50	3	5.52	4	Assouan	ant	6.0
Vienne	composite	SPi4-5	45	3.9	0.18	2	Elba	ant	8.7
Vienne	composite	SPi6-7	47	4	0.19	4	Elba	ant	8.5
Vienne	composite	DE1-8M	49	3.05	0.18	4	Elba	ant	6.2
Vienne	composite	CY1-3	60	3.4	0.22	4	Elba	ant	5.7
Vienne	St Paul	Spext	40	1.6	22.01	1	Mysia	ant	4.0
Vienne	composite	SPi1-2	44	2.9	29.41	2	Troad	ant	6.6
Vienne	composite	SPi3-TH2	45	2.3	35.32	2	Troad	ant	5.1
non granite									
Frejus	dépôt	SA1	12	0.5	22.62	1	Esterellite	ant	4.2
Frejus	composite	D4-Q1	90	2.3	30.10	2	Esterellite	LA	2.6
Lerins	cloître	C1	37	1.37	30.37	1	Esterellite	med	3.7
Venasque	baptistère	Ext	32	0.42	26.01	1	Esterellite	med	1.3

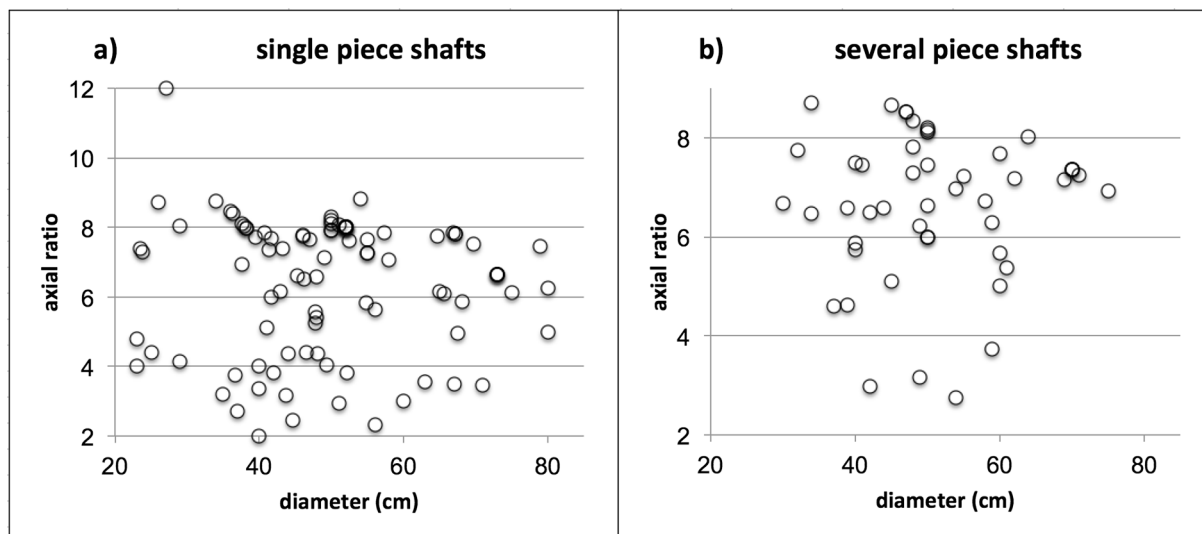


Fig. 4. Axial ratio (length/diameter) versus diameter of shafts measured as single (a) or multiple (b) pieces in our database.

3.7, see Table 3).

b) Corsican granite identification using pXRF

To confirm the identification of Southern Corsica and exclude Claudianus as the source of the coarse-grained composite shafts (5 comprising 13 fragments from Die, all very similar) we determined the Sr and Rb content using pXRF measurements on five fragments from four different locations in Die, for a total of 27 analyses. We compared the resulting average with our pXRF measurements on rock cores sampled on Cavallo Island (Gattacceca et al., 2004a), with pXRF measurements by Triantafyllou et al. (2021) in Cavallo and various nearby islands, as well as in Bonifacio (one column) and Corsica, and with Claudianus data compiled by Potts and West (2008) and reported in Abdel-Rahman (2019). Fig. 5 (based on data summarized in Table 4) shows that, despite a large standard deviation (s.d.) due to the coarse-grained nature of this

facies, the average for Die shafts is consistent with averages for the different Corsican references and differs markedly from the Sr values reported for Claudianus. Although Rb values overlap, they are higher for the Die shafts. Potts and West (2008) results, as well as our pXRF measurements on granite shafts, show that Rb may be systematically underestimated (due to either weathering or the geometric effects of the uneven surface), whereas Sr is estimated more robustly.

Further proof of the validity of pXRF results is found in our data on Elba and Mysia quarry samples (a surface of about 10 × 10 cm was measured adopting the same protocol used for the shafts). Due to the finer grain-size of these granites, the s.d. on XRF averages are lower than for Corsican granite (Table 4). The averages fit very well with ICPMS ranges reported in de Vecchi et al. (2000) and Gagnevin et al. (2004). We therefore conclude that our pXRF results are robust and that the Die

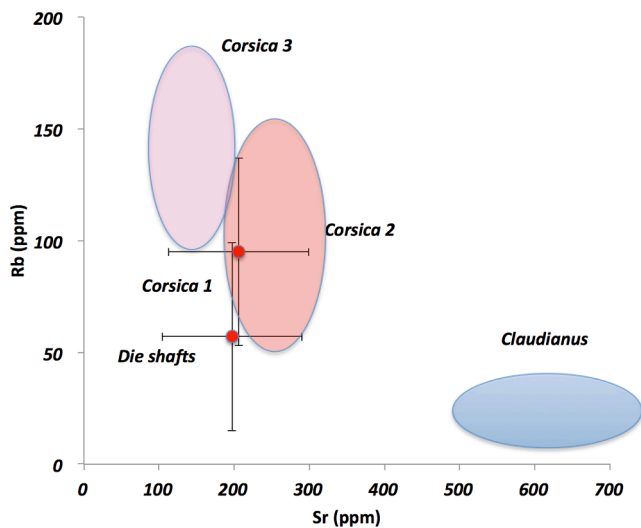


Fig. 5. Average Rb and Sr contents with their s.d. measured by pXRF in Die shafts suspected to come from Corsica, compared to pXRF measurements on rock samples from Corsica made by us (Corsica1) or Triantafyllou et al. (2021; Corsica2), as well as bibliographic data from Potts and West (2008) on Corsica-Sardinia (Corsica3), and from Potts and West (2008) and Abdel Rahman (2019) on Mons Claudianus granite.

Table 4

Sr and Rb contents in ppm for various gray granites; average data with s.d. for our pXRF measurements (Die shafts and quarry samples; N is the number of analyses); range of values reported in the literature.

data	average \pm s.d. or range (ppm) Rb Sr	reference
Die shafts (N = 27)	57 \pm 41 197 \pm 93	This study
Corsica1 (N = 13)	95 \pm 42 206 \pm 75	This study
Corsica2 (pXRF)	60–150 180–290	Triantafyllou et al. (2021)
Corsica3 (ICPMS and XRF)	90–170 120–200	Potts and West (2008)
Claudianus (ICPMS and XRF)	20–45 490–720	Potts and West (2008), Abdel Rahman (2019)
Elba San Piero quarry (N = 12)	246 \pm 30 214 \pm 26	This study
Elba San Piero quarry (ICPMS)	255–276 218–227	Gagnevin et al. (2004)
Mysia Okzular quarry (N = 12)	112 \pm 32 709 \pm 15	This study
Mysia quarries (ICPMS)	105–133 419–712	De Vecchi et al. (2000)

shafts cannot originate in Egypt.

4. Discussion

Our definitive identification of shafts from Corsica in Die, using pXRF to solve the ambiguity with the Claudianus source, may help document the previously overlooked diffusion of this source outside Corsica-Sardinia (but see Clerbois et al., 2022). While Williams-Thorpe (2008) reported this source only in Rome, and a single shaft in Arezzo, our discovery of Corsican shafts in Die, as well as in Lyon and Pisa in another study (Rochette et al., 2021), suggests that this source was more widely exported than previously thought.

Comparison with other western Mediterranean areas (data from Rodà et al., 2012; Williams-Thorpe, 2008, and preliminary observations reported briefly herein) highlights the specificities of granite trade (Fig. 6). In Tarragona our observations confirm the overwhelming predominance of Troad shafts (Rodà et al., 2012), although one Mysia shaft was observed, as well as two of unknown provenance. In Corsica, we observed 12 shafts in Mariana, all from Elba, which can be considered a

local source. In Maghreb, our cursory observations in northern Tunisia, as well as published data from Djemila in Algeria (Antonelli et al., 2010b), indicate a strong predominance of Turkish sources. Egyptian granites are abundant only in Rome (followed by Turkish sources), an indication that they were more highly prized. Outside Rome, local sources are dominant in Andalusia and Tuscany, as well as Sardinia and Corsica, whereas Turkish sources are predominant in Narbonensis, Tarragona and Maghreb only.

Histograms of shaft diameter for Troad, Mysia and other sources are presented in Fig. 7. Most shafts diameter range from >30 to <70 cm. Compared to histograms presented in Williams-Thorpe (2008; their Fig. 6), the same major modes appear at around 40 and 60 cm. Histograms are quite different for the different sources: comparison between Fig. 7 a) and b) may suggest that Mysia was specialized in 50–70 cm diameter shafts, whereas Troad produced more 40–60 cm shafts. This may partly explain the choice of Mysia versus Troad for a given architectural project: ordering a shaft diameter of 50 instead of 40 cm may have determined the preference for the Mysia rather than the Troad source.

The abundance of shafts per site yields some unexpected results: unlike the major cities of Arles and Aix, the smaller Riez and Die were not expected to rank among the top four sites with over 20 shafts because of their presumed rather limited historical and geographical importance. This may be because these relatively remote cities with limited modern development lost fewer shafts through the ages with respect to large cities along the Rhone River or the Mediterranean coast. Nevertheless, the fact that Die and Riez are among the four localities with shaft >70 cm diameter (together with Arles and Orange), indicates a specific monumentality. However, some major historical sites yield either no granite shafts, like Nîmes, Béziers, Toulouse and Glanum, or very few shafts, like Narbonne and Vaison-la-Romaine. These cities may have suffered particularly intense spoliation, with export of shafts to other sites (e.g. the shafts of Lagrasse Abbey may have come from Narbonne), or may not have made use of granite shafts from the beginning. This may be linked to the secondary rank of the city (case of Glanum and Vaison), or cultural peculiarities, such as an emphasis on local or Hellenistic cultures (case of Nîmes?).

Most shafts from Narbonensis are found reused in late Antiquity (12.3%), medieval (32.7%) or modern settings (21.1%). Reuse started during the imperial period (two engraved milestones found in Lerins and Vidauban; one shaft fragment partly cut to generate 2 cm-thick slabs, e.g. for opus sectile near Die, although their attribution to antiquity is uncertain), then in late Antiquity in Christian baptisteries (Aix, Riez, Frejus, Venasque, see Guyon, 2005), but mostly in the Middle Ages, when spolia was used in Romanesque-style churches and abbeys (Arles, Die, Lagrasse, Lerins, Riez, St Gilles, Saintes-Maries-de-la-Mer, Vaison). Medieval reuse was partly for structural purposes (e.g., pillars supporting the bell tower of Die cathedral), but mainly for decorative purposes, in church choirs or porches (Hartmann Virnich, 2000), as pillars for basins, etc. An interesting case is the 27 cm-diameter Troad shaft in the porch of Saint-Trophime Church in Arles: it bears no end torus, has a constant diameter and has an exceptionally high axial ratio (Fig. 4). This implies that it was thinned from an antique shaft of larger diameter, likely for the purpose of following medieval style, characterized by shafts thinner than the Roman standard (Vergnolle, 1998). Modern reuse was observed in castles and private properties (Aix, Die, Uzès), street monuments (Aix, Antibes, Marseille, Vence), road guards (Arles and Riez) and even artistic installations (Picasso Museum in Antibes).

We can question the implicit assumption of previous authors (e.g. Williams-Thorpe, 2008) that the corpus is not biased by post-Roman importation of spolia. The use of spolia in new buildings called for the transport of these materials, sometimes over long distances. The inscriptions on the two identical shafts in Vence suggest they are spolia transported from Marseille, 150 km away, during the imperial period. In medieval France, the two red porphyry columns observed in Le Puy

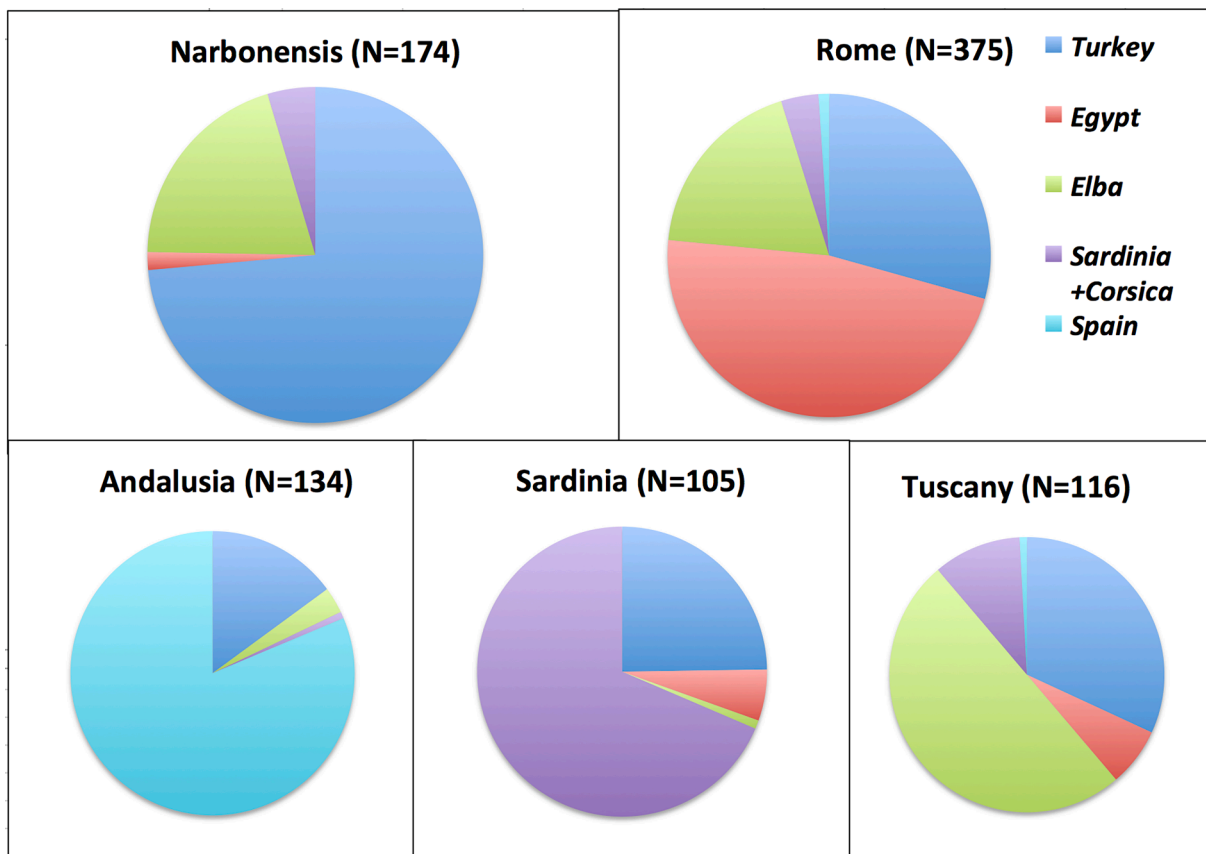


Fig. 6. Pie diagrams of granite shaft sources in Narbonensis compared to Andalusia, Rome, Sardinia, Tuscany after Williams-Thorpe (2008).

Cathedral were likely brought from Rome by a pope – possibly Callixtus II – in the 12th century (Malgouyres, 2011). The transport of numerous shafts from Ravenna and Rome to Aachen ordered by Charlemagne in the 9th century is also noteworthy (Peacock, 1997). There are other examples of such long-distance transport in the modern period: shafts from Leptis Magna in Libya were spoliated repeatedly during the 17th century on behalf of the kings of England and France (Laronde, 1995; Williams-Thorpe, 2008). The medieval columns in Aachen were spoliated during the French Revolution, and Napoleon used them to decorate the Louvre Palace in Paris (Peacock, 1997). Later, the aristocratic taste for antiquity and ancient Rome led to the documented importation of materials to northern France (our work in preparation) from Italy, Egypt and the Maghreb. Such overseas imports likely explain the presence in the Marseille history museum collection of a perfect cylinder of Aswan granite, of obvious modern cut and size, serving as a statue pedestal. No documentation accompanies this item, but it was part of the decor of a castle furnished for Louis Borely, who traded with Egypt at the end of the 19th century.

When interpreting our corpus in terms of Roman architecture in Narbonensis, it is also important to bear in mind that shafts used in medieval monumental works may not have been spolia but extracted at the time from granite quarries. Medieval granite shaft production is demonstrated in Elba (Clerbois et al., 2022; Zecchini, 2018), and the numerous shafts observed in Pisa that measure over 1 m in diameter and were sourced from Elba were identified as ‘likely’ Pisan by Williams-Thorpe (2008; see also Rochette et al., 2021).

Fig. 7c shows a different diameter distribution for non-Turkish sources (predominantly Elba, followed by Corsica-Sardinia and a few Aswan), with significantly smaller (≤ 35 cm) and larger (≥ 60 cm) diameters with respect to Turkish sources. A similar spread is observed in Tuscany, where Elba and Corsica-Sardinia shafts abound (Fig. 6 of Williams-Thorpe, 2008). This may indicate that a significant proportion

of shafts (particularly those in the small diameter range, as exemplified by St Trophime in Arles) were produced in medieval times, both in Narbonensis and Tuscany. Most of the materials in our corpus with a diameter < 30 cm were found in medieval contexts.

5. Conclusions

A systematic inventory and sourcing of granite shafts of presumed antique origin was performed in the former territory of Gallia Narbonensis. 276 complete shafts or shaft fragments were identified and attributed to at least 174 original shafts from 21 localities. Only four localities (Aix, Arles, Die, Riez) contribute to 54% of the whole corpus. Sourcing was performed through visual, magnetic susceptibility and trace element comparison with known antique quarries in Egypt, Turkey, Elba, Corsica and Sardinia. Turkish sources (Troas and Mysia) are predominant (75%), followed by Elban ones (20.5%). Minor sources are the pink granites of Aswan and Sardinia, as well as grey granite from Corsica, found only in Die. No local sources (e.g. from Massif Central granites) were identified, apart for the esterellite microdiorite (“porfiro bigio”). Ambiguity between the Corsican source and the grey Egyptian granite from Mons Claudianus was resolved using portable X-ray fluorescence to determine Sr and Rb contents. Corsican granite may have been more widely exported than previously thought.

Compared to other western Mediterranean provinces – except Rome, where Egyptian granites dominate – Gallia Narbonensis, with its dominance of Turkish sources and lack of local sources, shows similarities to Tarragona and Maghreb. In contrast, local sources are predominant in the provinces of Andalusia, Tuscany, Corsica and Sardinia. Our study will enable local archeologists to formulate hypotheses about the monuments of origin for the reported shafts, and about the specificities of each site in terms of adopted granite sources.

As most of the corpus consists of shafts present in medieval to

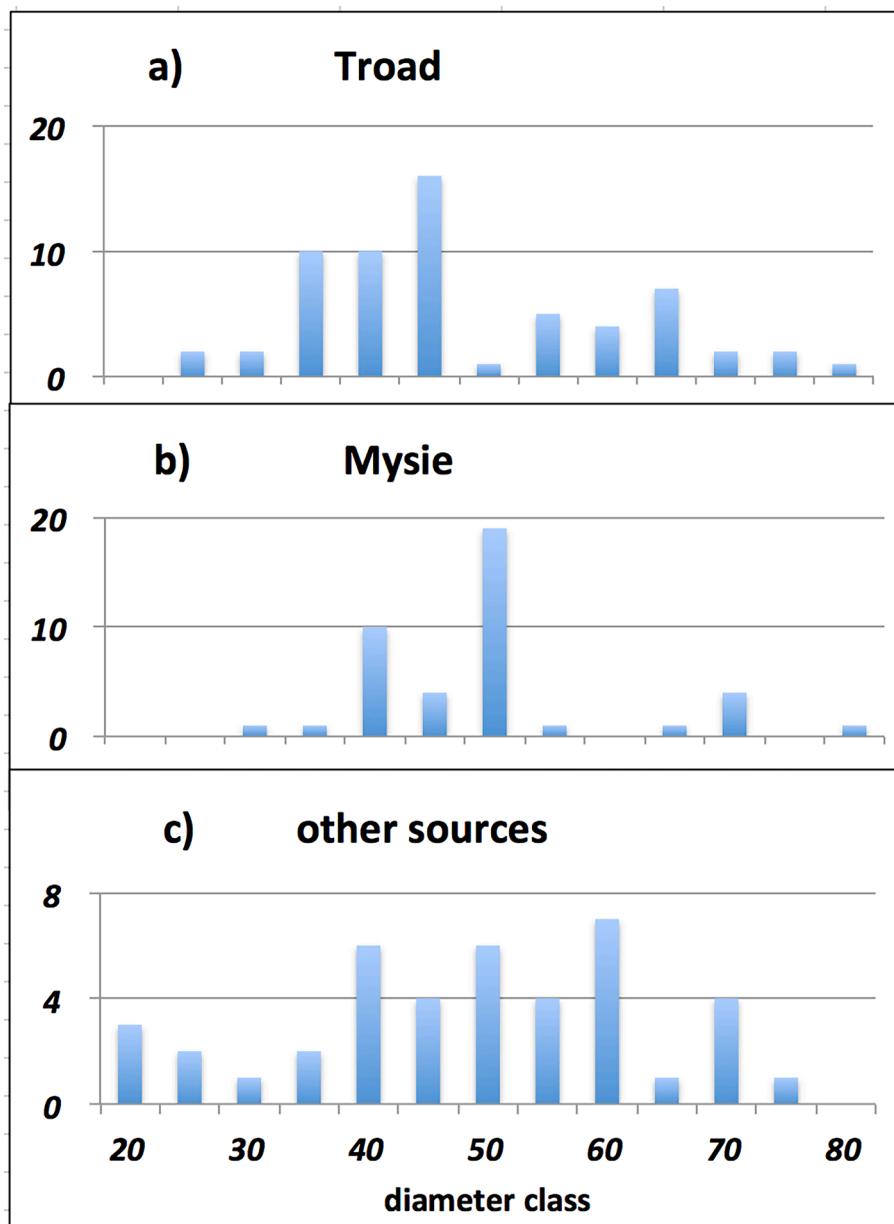


Fig. 7. Histograms of shaft diameters for different sources in our study: a) Troad, b) Mysie, c) others (mostly Elba).

modern contexts, caution is required in interpreting our findings in terms of Roman architectural and economic choices. Long-distance transport of spolia or newly quarried shafts may have occurred after the Roman period. Further study is required, particularly on shafts used or reused in medieval constructions, as reported in the case of Romanesque churches in Pisa and Lyon (Rochette et al., 2021). This systematic study should also be extended to the rest of Gaul, as well as the entire western Mediterranean, where the published granite shaft corpus is rather incomplete.

Declaration of Competing Interest

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

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References

- Abdel-Rahman, A.M., 2019. Geochemistry, age and origin of the Mons Claudianus TTG batholith (Egypt): insight into the role of Pan-African magmatism in uniting plates of Gondwana. *Geol. Mag.* 156 (06), 969–988. <https://doi.org/10.1017/S0016756818000304>.
- Antonelli, F., Lazzarini, L., Cancelliere, S., 2010a. ‘Granito del Foro’ and ‘granito di Nicotera’: petrographic features and archaeometric problems owing to similar appearance. *Archeometry* 52, 919–936.
- Antonelli, F., Lazzarini, L., Cancelliere, S., 2010b. On the white and coloured marbles of the Roman town of Cuicul (Djemila, Algeria). *Archeometry* 52, 575–596.

- Clerbois, S., Mattielli, N., Triantafyllou, A., Brkojewitsch, G., 2022. The Roman Granite Quarries in the Tyrrhenian Sea during the Imperial Period: a Technological Study. *Marmora*, (in press).
- DeLaine, J., 1997. The baths of Caracalla. A study in the designs, construction and economics of large-scale building projects in imperial Rome. *JAT*, Suppl. 25. Portsmouth, Rhode Island.
- De Vecchi, G., Lazzarini, L., Lünel, T., Mignucci, A., Visonà, D., 2000. The genesis and characterisation of 'Marmor Misium' from Kozak (Turkey), a granite used in antiquity. *J. Cult. Heritage* 1 (2), 145–153.
- Gagnevin, D., Daly, J.S., Poli, G., 2004. Petrographic, geochemical and isotopic constraints on magma dynamics and mixing in the Miocene Monte Capanne monzogranite (Elba Island, Italy). *Lithos* 78 (1-2), 157–195.
- Gattacceca, J., Orsini, J.-B., Henry, B., Rochette, P., Rossi, P., Cherchi, G., 2004a. Late-Hercynian tectonic environment revealed by anisotropy of magnetic susceptibility of Hercynian granitoids from Southern Corsica and Northern Sardinia. *Geol. Soc. London* 161, 277–289.
- Gattacceca, J., Eisenlohr, P., Rochette, P., 2004b. Calibration of in situ magnetic susceptibility measurements. *Geophys. J. Int.* 158 (1), 42–49.
- Gébara, C., Morhange, C., 2010. Fréjus (Forum Julii): Le Port Antique / The Ancient Harbour. *J. Roman Archaeol.*, Suppl. 77, 152 pp, Portsmouth Rhode Island.
- Guyon, J., 2005. Les premiers édifices de culte chrétiens. In: 15 ans d'archéologie en Provence-Alpes-Côte d'Azur, pp. 118–199.
- Hartmann Virnich, A., 2000. Le rôle des matériaux antiques en réemploi dans la sculpture monumentale antiques en Provence romane: l'exemple d'Arles et de Saint-Gilles-du-Gard. *Revue Archéol. Narbonnaise* 33 (1), 288–292.
- Jordanova, D., Veneva, L., Hoffmann, V., 2003. *Stud. Geophys. Geod.* 47, 403–418. <https://doi.org/10.1023/A:1023736111156>.
- Jover, O., Rochette, P., Lorand, J.P., Maeder, M., Bouchez, J.L., 1989. Magnetic mineralogy of some granites from the French Massif Central: origin of their low field susceptibility. *Phys. Earth Planet. Inter.* 55, 79–92.
- Laronde, A., 1995. Claude Le Maire et l'exportation des marbres de Lepcis Magna. *Bull. Soc. Nationale Antiquaires France*, année 1993 (1), 242–255.
- Lazzarini, L., 1992. Des pierres pour l'éternité, les granits utilisés dans l'antiquité classique. *Le Marbre dans l'Antiquité, Les Dossiers d'Archéologie* 173, 58–67.
- Lecoanet, H., Leveque, F., Segura, S., 1999. Magnetic susceptibility in environmental application: comparison of field probes. *Phys. Earth Planet. Inter.* 115, 191–204.
- Malgouyres, P., 2011. Dévotion mariale et faveur pontificale. A propos des colonnes de porphyre du portail occidental de la cathédrale du Puy. *Bull. Soc. Nat. Antiquaires de France, Années 2004* (1), 335–338.
- Mazeran, R., 2004. Les granitoïdes employés en décoration dans les monuments romains et paléochrétiens du sud-est de la France. In: Lorenz J. et Gely J.-P. Gely (dir.) *Carrières et constructions en France et dans les pays limitrophes CTHS 2001*, p. 219–230.
- Peacock, D.P.S., Williams-Thorpe, O., Thorpe, R.S., Tindle, A.G., 1994. Mons Claudianus and the problem of the 'granito del foro': a geological and geochemical approach. *Antiquity* 68 (259), 209–230.
- Peacock, D.P.S., 1997. Charlemagne's black stones: the re-use of Roman columns in early medieval Europe. *Antiquity* 71 (273), 709–715.
- Pensabene, P., Domingo, J.Á., Rodà, I., 2018. The distribution of Troad Granite columns as evidence for reconstructing the management of their production, *ASMOSIA XI*, (Split 2015). *Split* 2018, 613–620.
- Potts, P.J., West, M., 2008. Portable X-ray fluorescence spectrometry: Capabilities for in situ analysis. *R. Soc. Chem.* 291.
- Rochette, P., 1987. Magnetic susceptibility of the rock matrix related to magnetic fabric studies. *J. Struct. Geol.* 9 (8), 1015–1020.
- Rochette, P., Sciuto, C., Raneri, S., Sutter, A., Rovazzani, A., Ambrosi, J.P., Andrieu, V., Gattacceca, J., Hartmann-Virnich, A., 2021. Non-destructive magnetic and chemical characterization of granite column shafts traded in the Mediterranean area: the case of Piazza dei Miracoli in Pisa (Italy) and Basilica of Saint-Martin d'Ainay in Lyon (France). *Metrology for archaeology and cultural heritage congress*, Milano.
- Rodà, I., Pensabene, P., Domingo, J.Á., 2012. Columns and Rotae in Tarraco made with granite from the Troade, *ASMOSIA IX*, (Tarragona 2009). *Tarragona* 2012, 210–227.
- Russell, B., 2013. *The Economics of the Roman Stone Trade*, Oxford.
- Triantafyllou, A., Mattielli, N., Clerbois, S., Da Silva, A.C., Kaskes, P., Claeys, P.h., Devleeschouwer, X., Brkojewitsch, G., 2021. Optimizing multiple non-invasive techniques (PXRF, pMS, IA) to characterize coarse-grained igneous rocks used as building stones. *J. Archaeol. Sci.* 129, 105376. <https://doi.org/10.1016/j.jas.2021.105376>.
- Vergnolle, É., 1998. La colonne à l'époque romane. *Réminiscences et nouveautés. Cahiers de Civilisation Médiévale* 41 (162), 141–174.
- Williams-Thorpe, O., 2008. A thousand and one columns: observations on the Roman granite trade in the Mediterranean area. *Oxford J. Archaeol.* 27 (1), 73–89.
- Williams-Thorpe, O., Rigby, I.J., 2006. Roman granites of Sardinia: geochemical and magnetic characterization of columns and quarries, and comments on distributions in the Mediterranean area. *Marmora* 2, 83–112.
- Williams-Thorpe, O., Rigby, I.J., 2007. Roman granite columns in Elba, Giglio and Tuscany: a contribution to provenancing and distribution studies. *Marmora* 3, 77–106.
- Williams-Thorpe, O., Thorpe, R.S., 1993. Magnetic susceptibility used in non-destructive provenancing of Roman granite columns. *Archaeometry* 35 (2), 185–195.
- Wilson, R.J.A., 1988. In: *Classical Marble: Geochemistry, Technology, Trade*. Kluwer Academic Publishers, pp. 103–112.
- Zecchini, M., 2018. Il granito dell'Elba nell'antichità. *Fronti di cava, statue, colonne*. <https://www.academia.edu/37854100/>.