Journal of Physics: Conference Series

PAPER • OPEN ACCESS

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).

To cite this article: P Rochette *et al* 2022 *J. Phys.: Conf. Ser.* **2204** 012037

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).

P Rochette[1,*], C Sciuto[2], S Raneri[3], A Sutter[4], A Rovazzani[4], L. Folco[5], JP Ambrosi[1], V Andrieu[6], J Gattacceca[1], A Hartmann-Virnich[7]

[1] Aix-Marseille Université, CNRS, CEREGE, Aix en Provence, France
[2] University of Pisa, Dept. of Civilizations and Forms of Knowledge, Pisa, Italy
[3] National Research Council, Institute of Chemistry and Organometallic Compounds, , Pisa, Italy
[4] Opera della Primaziale Pisana, OPA, Pisa, Italy
[5] University of Pisa, Dept. of Earth Sciences, Pisa, Italy
[6] Aix-Marseille Université, CNRS, IMBE, Aix en Provence, France
[7] Aix-Marseille Université, CNRS, LA3M, Aix en Provence, France

*rochette@cerege.fr

Abstract. We present a scheme for non-destructive provenancing of granite shafts dating from the Roman to the medieval period using a combination of visual, magnetic, and chemical determinations. Our results on two monumental medieval complexes in Europe, in Pisa and Lyon, shows both oriental provenance, most likely spolia, and shaft from the quarries within the influence zone of the Pisa Republic (Elba, Corsica and Sardinia) that possibly correspond to shafts newly obtained in the quarries, particularly for the large diameter shafts of Ainay in Lyon (from Corsica) and Piazza dei Miracoli (from Elba and Sardinia). pXRF appears to be an efficient way to discriminate Corsican from Egyptian grey coarse grained granite provenance.

1. Introduction

The reuse of Roman spolia in medieval construction has been largely studied, from an archaeological point of view, in various Mediterranean contexts [1]. In particular, the use of granite (sensu lato i.e. including all types of granitoids in the geological sense) for making column shafts is widely attested in the monumental architecture of the Roman Empire as well as in public and religious medieval buildings. A common prejudice in the interpretation of medieval granite shafts is that they are all spolia from Roman monuments, thus allowing to discuss the Roman trade characteristics based on a medieval corpus, neglecting the possibility of medieval quarrying [2]. Several source quarries have been identified, the major ones being in Egypt (Aswan and Mons Claudianus), Asia Minor (Mysia and Troad) and Tuscan islands (Elba and Giglio). Minor quarries with still significant dissemination have been found in Sardinia and Corsica [2-5]. Other sources have been identified, e.g. in Calabria and Spain, but deemed to have limited local usage [2,6]. Granite shaft sourcing has been mostly done through visual comparison with reference specimens and laboratory analysis of samples [7-9]. However, certain provenance attributions are sometimes difficult due to the stone texture itself and possible surface alteration on architectural elements exposed to external agents. For example the

Elba and Mysia types are hardly differentiated, and need a clean surface with well-visible grains and texture, a condition not always fulfilled in shafts found in streets and churches.

Laboratory petrographic and geochemical studies need sampling (large enough to be representative of the centimetric heterogeneity of granites) and are not feasible on a large scale, when studying hundreds of shafts in monumental complexes or relevant architectural structures. However, only systematic studies may provide an unbiased picture of the various determinants involved in granite trade [10]; thus, non-destructive analytical techniques are highly welcomed for non-invasively characterizing large number of shafts, complementing the visual expertise to solve remaining ambiguities and possibly identify anomalies indicating rare or yet unknown sources.

2. Methods

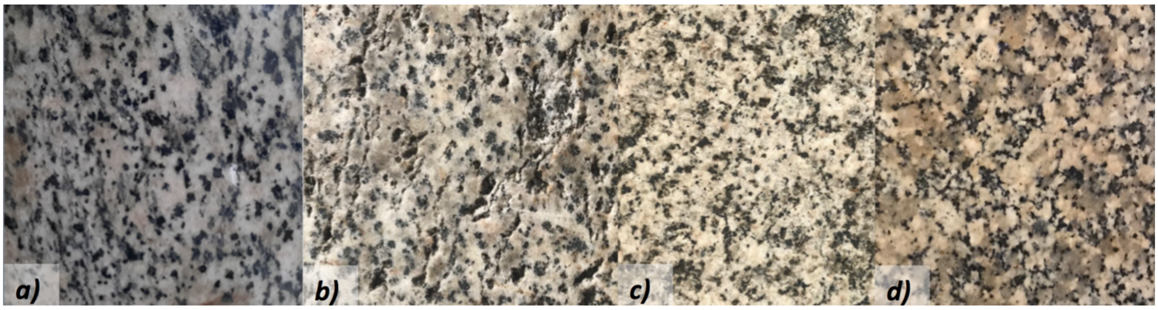

Figure 1: visual examples of coarse grey granite textures observed on shafts studied here; from a) to d): Mons Claudianus in Pisa and Lyon theater, Corsica in Lyon theater and Ainay basilica. Scale is 10 cm height.

Visual expertise can be complemented by less subjective image analysis [11], in particular to identify coarse-grained grey granites (from Egypt, Corsica and Sardinia as well as from Spain and Calabria for the other types), assess the presence of large crystals and their color, as well as the presence of a crystal preferred orientation or a foliation (characteristic of Egyptian granites such as Aswan and Mons Claudianus). Pink granites are easily identified visually, with Sardinian sources being paler and more fine-grained than Aswan granite. For grey granites, an identification scheme has been successfully developed by combining visual characterization and magnetic susceptibility (K) measurements [2]. We will follow this simplified scheme and discuss its drawbacks at the end of the manuscript.

Magnetic measurements allow performing systematic studies of large numbers of shafts, thanks to its rapidity (a representative K measurement made in contact with the shaft takes 5 seconds) and easy discrimination; in fact, it has been observed that K ranges from <0.25 10^{-3} SI for Elba and Giglio to >15 10^{-3} SI for Asia Minor sources, with Mons Claudianus and Corsica sources in the range of 2-9 10^{-3} SI (note that pink granites from Aswan and Sardinia have K in the same range, i.e. 2-10 10^{-3} SI). Among Asia Minor sources, the Troad and Mysia granites are easy to discriminate visually, once Mysia is discriminated from Elba-Giglio by K values. Note that visual discrimination between Elba and Giglio is not straightforward and we preferred to avoid this ambiguity. Among the coarse-grained grey granites with intermediate susceptibility, Corsican and Mons Claudianus types are visually discriminated by the presence of a foliation in Mons Claudianus (although not always obvious, see fig.1 and [2,4,7]).

For a better discrimination between Corsican and Claudianus types, as well as identification of possible outliers from other sources (e.g. Spain, Calabria, etc.), the application of another non-destructive analytical technique is desirable. Portable XRF chemical analysis has been proposed by [12], mainly using Rb and Sr trace elements, and its performance has been more recently investigated [11]. In particular, the application of pXRF may be useful for discriminating between Corsica and Mons Claudianus sources (see fig. 2).

In Pisa, the monumental complex of Piazza dei Miracoli offers a particular context for the investigation of the coeval use of spolia and newly quarried materials through the various phases of construction of the Cathedral, the Baptistery and the Tower, that bear numerous granite shafts [13]. The construction of the cathedral started in 1064, while the worksites for the Baptistery and Tower were initiated in 1152 and 1173, respectively. The basilica of Saint-Martin d'Ainay, in Lyon is one of the most iconic Romanesque architectures in the region [14]. Dedicated in 1107, and built on the remains of late antique structures, the Romanesque building contains materials which represent the persistence of Roman architectural elements in the medieval urban context. Four large granite column shafts in the nave have been documented for this study [15]. We also used data from three shafts from the Roman theater of Lyon.

In Pisa and Lyon, hundreds of granite shafts have been nondestructively characterized; K measurement were carried out by using the SM30 instrument with a 10^{-6} sensitivity, integrating a volume of about 100 cm^3 adapted to the granite grain size; measurements along the shaft are homogeneous with reading varying by less than 20%. Sr and Rb contents have been determined by portable XRF Bruker tracer IV instrument, which shows a sensitivity on Rb and Sr contents of the order of 5 ppm. Analysis of a large number of measurements on different spots (>10, each one taking 2 minutes) were done to overcome the heterogeneity of granite [11] at the scale of the sensor (8 mm) and produce relevant average trace element contents. Measurements spots were chosen randomly on the smooth surfaces available, to obtain an average of the different crystal species. We used the calibration done by Brucker company. To check this calibration we measured using the same protocol two cut slabs from geological samples of Elban (San Piero quarry) and Mysian (Okzular quarry) granites. Our results fit well with the published ICPMS data from these two granite sources (Fig.2).

3. Results

In Piazza dei Miracoli a total 133 shafts were determined among which 110 in the Cathedral, the only ones not measured being in the upper exteriors of the Cathedral. 45.9% of the 133 studied shafts appear to come from Elba-Giglio (table 1), including all shafts from the Tower and most shafts from the Baptistery. Adding on that Corsica and Sardinia sources, 57.2% of shafts come from the area of direct regional influence of the medieval republic of Pisa and may be considered, at least in part, to be newly quarried for the monuments, rather than spolia. Oriental sources, most probably spolia, have been identified as Asia Minor (30.8% with nearly equal contributions from Mysia and Troad) and Egypt (10.5%, mostly Aswan). Only two shafts from Mons Claudianus were found, one in the Cathedral gallery and one in the pulpit of the Baptistery. The two pulpits at the Cathedral and Baptistery used four shafts from Egypt (including one red porphyry), two shafts from Mysia and two from Corsica.

Table 1: number of granite shafts from the different sources identified in Piazza dei Miracoli

source	Elba-Giglio	Sardinia (pink)	Corsica (grey)	Troad	Mysia	Aswan (pink)	Mons Claudianus	Others (Spain?)
N	61	12	3	22	19	12	2	2

An alternative to the above hypothesis of newly quarried shafts is that raw or unfinished shafts, left in the quarries or by the docks on the seashore in Roman time, could have been recycled in medieval constructions. Even today, a number of these leftovers can be observed near ancient quarries, on land or under water [3,5]. The hypothesis of the shipping of antique quarry leftovers to Pisa might also be referred to in two inscriptions on the cenotaph for Buscheto, one of the Cathedral's architect (Fig.3). According to these medieval epigraphs, column shafts of enormous weight were retrieved from the bottom of the sea. Though they were so heavy that they could hardly be shipped by sea, the architect Buscheto managed to lift them with pulleys. The inscriptions celebrate the talent of the architect in finding a solution for recovering the shafts in the sea. It may refer to the recovery of (partly) drown shafts on the shore near the quarries, although we acknowledge that a more classic interpretation of this text is that the shafts were recovered from a shipwreck. However, to further ground the hypothesis that the cathedral's shafts were at least partly newly extracted in quarries for the purpose of the monumental medieval architecture, we can list the following arguments:

- all large diameter (96 to 114 cm) shafts documented in the Cathedral and Baptistery, for a total of 24 shafts, come from Elba-Giglio and Sardinia. Such large diameter shafts (with length around 7,5 m, i.e. about 16 tons), in this quantity, would be difficult to obtain all together from a single spolia emporium as they can be found mostly in Rome and Eastern Mediterranean [2]. Moreover, we might suppose that the big and intact column shafts present in the Rome area had been already reused in situ by the 11th century;
- contrary to spolia, the surfaces of the suspected newly quarried medieval shafts are not polished, and bear mark of axes and toothed axes. This surface treatment is consistent with other stone working techniques typical of Medieval age in the same buildings. Some of them have not been totally finished (a detachment surface can be observed) and bear rough quarrying toolmarks.

In Pisa, three shafts are interpreted as originating from Corsica and two, somewhat similar looking (apart from the foliation), from Mons Claudianus. Note that these shafts were not characterized by [2]. Two anomalous lithologies were observed in the cathedral: a pink fine grained one, with K and texture compatible with Mysia, as well as two coarse grained grey granite eventually fitting the description of the Spain II and III type of [2].

In Lyon 6 shafts of likely Corsican origin were identified (two in the Fourvière Roman theater and four in the Romanesque basilica of Ainay). pXRF results (average on >10 measurements on spots spread over tens of cm) do confirm, based on Sr and Rb contents, that this identification is correct (Fig. 2). One Claudianus shaft (already mentionned in [18]) was also positively confirmed in the Lyon Theater using this technique. Reference values from Corsica and Claudianus were obtained from our sampling on Cavallo island, and [11,12,16]. In Pisa we studied using pXRF three shafts presumed from Corsica, Mons Claudianus and Mysia (? the pink facies), and their Sr, Rb average contents also fits reference values. pXRF allows an easy discrimination between Corsican and Claudianus shafts, despite biases linked to the shaft surface roughness and weathering. pXRF data on shafts, in particular Rb values, are often lower than reference or geological sample data, but the separation between Claudianus and Corsica fields is large enough to overcome this bias.

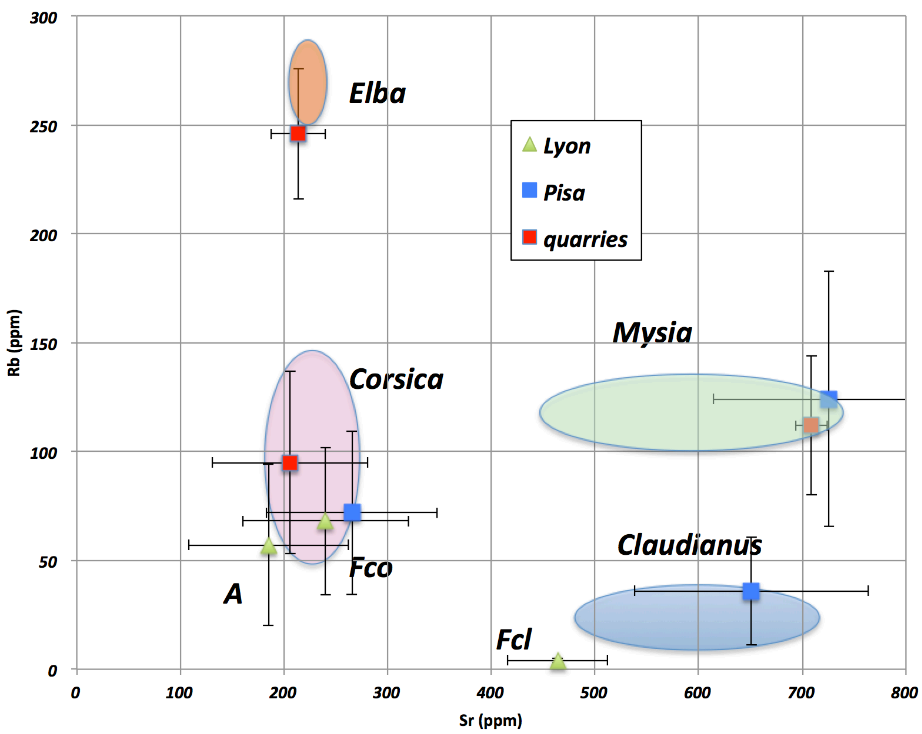

Figure 2. Rb versus Sr fields for Corsica, Mons Claudianus, Mysia and Elba sources after [8,11,12,16,17], in pink, blue, green and orange ellipses, respectively. Our average pXRF data with s.d. on geological samples of Cavallo island, Mysia and Elba are plotted as red squares with their s.d.; shafts from Lyon appear as green triangles: Ainay (A four shafts) and Fourviere theater, averaging separately data from the two Corsican shafts (Fco) and from one Claudianus shaft (Fcl). Three shafts from Pisa cathedral were also studied using pXRF (blue squares), allowing to confirm Corsica, Mons Claudianus and Mysia (?pink facies) provenances.

Table 2: reference and our pXRF Sr and Rb data in ppm for Corsica and Mons Claudianus (MC) shafts (average and s.d. for our pXRF measurements with N as number of measurement spots, range for reference data)

	MC [12-16]	Corsica [11]	Ainay	Theater Corsica	Theater MC	Pisa MC	Pisa Corsica	Pisa pink Mysia?	Cavallo island
N	-	-	16	8	5	12	12	12	13
Sr	490-720	180-290	185±77	240±80	464±48	726±111	266±83	726±111	206 ±75
Rb	20-45	60-150	57±37	68±34	4±1	36±25	72±38	124±59	95 ±42

Figure 3: inscriptions in the façade of Pisa cathedral

By analogy with the case of large shafts in Pisa, the 108-cm-diameter Ainay shafts, which are by far the largest found in France, may possibly be interpreted as newly quarried shafts or unused leftovers from the antique quarry in Corsica, rather than spolia from a Roman temple as discussed in [15]. A particularity of the Ainay shafts is that they seem to be derived from two halved original columns based on their short length (about 4.3 m).

According to [5], the Corsican quarries on Cavallo and nearby islands (San Bainzo, Lavezzi) have not been reused in Middle Age, contrary to quarries in Sardinia and Elba. [19] noted that grey granite very similar to the Corsican one (in visual aspect and K value) has been quarried on the Sardinian side of the strait of Bonifacio (e.g. Municca, only 15 km from Cavallo). Further investigations are thus needed to exclude that our identification of "Corsican" shaft source does not in fact include Sardinian quarries of grey granite. In the present study we followed the simplified scheme of [2,19]: shafts identified as Sardinian or Corsican are the ones bearing large pale pink feldspars or not, respectively. Support for this assumption can be found in the fact that reported evidences for ancient quarrying are more robust in the Corsican sites than in the Sardinian grey granite sites [5,19].

4. Preliminary conclusions

The study presents a wide analysis of granite shafts provenance in different medieval architectures. The application of fast and non-destructive analytical protocols to the determination of granite sources can secure ambiguities on source assignment using visual expertise alone and help shedding a light on stone procurement systems and materials supply on working sites.

In Pisa, the large-scale monumental worksite, active for about two centuries, benefitted from both long-distance transport of spolia, e.g. [20], as well as medieval procurement in the quarries surely encouraged by the Pisan privileges on the granite sources in western Mediterranean islands. Instead of actually newly quarried shafts one may also hypothesize that raw or unfinished shafts left in the quarries or on the seashore in Roman time, have been recycled for the medieval constructions. The case of Lyon seems to suggest a similar dynamic, supporting the idea that ancient quarries in Corsica, Elba or Sardinia could have been used also for the procurement of granite shafts during the Middle Ages. This hypothesis remains to be verified with further research and is not exclusive of the use of spolia from the same sources.

In both cases, the application of an integrated study of stone-working techniques, architectural phases and stone provenance could help highlighting stone supply networks and the specific economy of the worksite.

Acknowledgments:
The University of Pisa Visiting Fellow Programme supported PR's field work in Italy. The authorities of Ainay basilica and Fourviere theater in Lyon are thanked for their help.

References

[1] De Lachenal, L., 1995. Spolia: uso e reimpiego dell'antico dal III al XIV secolo. Vol. 24. Longanesi.
[2] Williams-Thorpe, O., 2008. A Thousand and One Columns: Observations on the Roman Granite Trade in the Mediterranean Area. Oxford Journal of Archaeology 27, 73-89.
[3] Poggi, D. and Lazzarini, L., 2005. Il granito sardo: Cave e cavatura, usi, diffusione e aspetti archeometrici. Marmora 1, 49-68.
[4] Wilson, R.J.A., 1988. Ancient granite quarries on the bocche di Bonifacio. N. Herz and M. Waelkens (eds.), Classical Marble: Geochemistry, Technology, Trade, 103-112. by Kluwer Academic Publishers.
[5] Clerbois, S. et al., 2021. The Roman Granite Quarries in the Tyrrhenian Sea during the Imperial Period: a Technological Study. Marmora, (in press).
[6] Antonelli, F., Lazzarini, L. and Cancelliere, S., 2010. 'Granito del Foro' and 'Granito di Nicotera':petrographic features and archaeometric problems owing to similar appearance Archeometry 52, 919-936.
[7] Peacock, D. P. S., Williams-Thorpe, O., Thorpe, R. S. and Tindle, A. G., 1994. Mons Claudianus and the problem of the 'granito del Foro': a geological and geochemical approach. Antiquity 68, 209-230.
[8] De Vecchi, G., Lazzarini, L., Lünel, T., Mignucci, A., Vison, D., 2000. The genesis and characterisation of 'Marmor Misium' from Kozak (Turkey), a granite used in antiquity. Journal of Cultural Heritage 1, 145-153.
[9] Antonelli, F., Lazzarini, L., Cancelliere, S., 2010. On the white and coloured marbles of the Roman town of Cuicul (Djemila, Algeria). Archeometry 52, 575-596.
[10] Russell, B., 2013. The Economics of the Roman Stone Trade, Oxford.
[11] Triantafyllou, A., Mattielli, N., Clerbois, S., 2021. Optimizing multiple non-invasive techniques (PXRF, pMS, IA) to characterize coarse-grained igneous rocks used as building stones. Journal of Archaeological Science 129,105376 DOI: 10.1016/j.jas.2021.105376
[12] Potts, P.J., West, M., 2008. Portable X-ray fluorescence spectrometry: Capabilities for in situ analysis. Royal Society of Chemistry, 291 pages.
[13] Tedeschi Grisanti, Giovanna. 1995. «Il reimpiego di materiali di età classica». In *Il Duomo di Pisa*, a cura di Alessandro Peroni, 153–64. Modena: Panini.
[14] Reynaud, J.-F., Bryon, P.-A., Richard, F., Riche, D. Lyon., 2016 L'église romane de Saint-Martin d'Ainay. De l'abbaye à la basilique. Editions lyonnaises d'art et d'histoire, Les amis de Saint-Martin d'Ainay, Lyon.
[15] Fellague D, 2016. La difficulté de datation des monuments : à propos des monuments de Lugdunum, en particulier ceux considérés comme hadrianiques », Revue archéologique de l'Est, tome 65, http://journals.openedition.org/rae/8792
[16] 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. Geological Magazine 156, 969–988. https://doi.org/10.1017/S0016756818000304.
[17] 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, 157-195.
[18] Mazeran, R., 2005. 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, 2005, p. 219-230.
[19] 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.
[20] Peacock, D. P. S., 1997. Charlemagne's black stones: the re-use of Roman columns in early medieval Europe. Antiquity 71, 709-715.