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Geochemical identification criteria for "peperino" stones employed in ancient Roman buildings: A Lapis Gabinus case study

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ABSTRACT

Lapis Gabinus is a durable volcanic stone originally exploited and employed in construction at the ancient Latin city of Gabii. From the second century BCE it was also exported to Rome, where it appears in a series of important monuments, including the Tabularium and the Forum of Augustus. It is a lithified hydromagmatic-surge deposit erupted about 285,000 years ago by the Castiglione Crater, 20 km east of Rome, and is similar in appearance to other local rocks that geologists and archeologists often call "peperino". In the present study we establish geochemical identification criteria to classify this rock and distinguish it from the other "peperini" employed by Roman builders. To this end, we have performed trace-element analyses on 17 samples of Lapis Gabinus collected from outcrops at Gabii, and on 11 samples representative of the other "peperino" stones occurring in the area of Rome. The resulting reference dataset has been employed to construct discrimination diagrams in which the geochemical compositional fields of the different rocks are defined. We then tested this identification method by plotting in these diagrams the trace-element compositions of 16 archeological samples of "peperino" stones collected from the buildings of ancient Gabii and Rome, spanning the sixth century BCE through the first century CE. Our results show that the three most common such stones (Lapis Gabinus, Lapis Albanus, Tufo del Palatino) have distinct trace-element compositions and can be readily distinguished using the proposed discrimination diagrams. This relatively simple and inexpensive identification method can be successfully extended to other archeological research on volcanic materials and employed for wider petrographic purposes.

1. Introduction

For much of the history of Rome, beginning as early as the eighth century BCE, builders quarried the local volcanic rocks that constitute the geologic substrate of the city (Cifani, 2008). These pyroclastic and lava flow deposits erupted during the Middle–Late Pleistocene activity of the Colli Albani and Monti Sabatini volcanic districts (Marra et al., 2011, and references therein). Though their presence in monuments spanning the archaic period through the imperial age has been thoroughly documented by several authors (e.g., Lanciani, 1897; Lugli, 1957; Coarelli, 1974; Cifani, 1994; Heiken et al., 2005; Jackson and Marra, 2006), the identification of the lithological units to which the different lithified tuffs belong has been traditionally based upon visual appearance, including macroscopic and, to a lesser extent, microscopic petrographic features. This is a qualitative approach which requires deep knowledge of the local geology and specific expertise on volcanic petrography and sedimentology, providing a learned, yet subjective judgment. In other words, it does not meet the highest scientific standards, since it lacks one of the basic principles on which modern science is based: verifiability of the data through replicability of results.

Indeed, several of these volcanic rocks display very similar textures, mineralogical assemblages, xenolith occurrence, and color. Furthermore, each eruptive unit is itself characterized by high variability of petrographic features and may exhibit a wide range of colors and compositional fabrics, depending on primary geological factors such as distance from the eruptive vent, morphology, and composition of the substrate, or on secondary processes such as weathering and alteration. These factors sometimes make distinguishing between lithological units problematic. Even efforts relying on more quantitative analyses, like total alkali-silica (TAS) composition and X-ray diffraction, are often insufficient to establish definitively the provenance of a volcanic rock, due to the occurrence of strong alteration processes and to the substantial similarities in the mineralogical assemblages of several different products of the volcanic districts of central Italy (Peccerillo, 2005, and references therein).

It is perhaps because of the similarities between stones, as well as the potential variability within a given deposit, that archeologists often rely on general descriptive terms (e.g. gray granular tuff, red lithoid tuff) in recording ancient Roman stone construction. Such terms can give an idea of the general appearance of a given stone

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block, but they do not designate the particular deposit or quarry location from which it was extracted. Other terms commonly found in the archeological literature, such as "cappellaccio" and "peperino" are similarly vague and can each describe several different volcanic deposits which appear macroscopically similar (as discussed in greater detail below). The ambiguous and confusing terminology that has resulted can thus obscure the underlying geological reality. While in this paper we, especially when describing previous work, of necessity occasionally use these ambiguous names, we encourage the use of formal geological terms, and they are preferred here whenever possible (see Table 1, which collates and correlates the various archeological and geological terms relating to Roman tuffs). The present paper aims to increase our ability to analyze the economy of stone quarrying and construction by testing a quantitative method for accurately determining the specific geological provenance of these volcanic products.

To overcome the difficulty and subjectivity in identifying pyroclastic rocks, a method has been recently developed (Marra et al., 2011) based on the ratio of particular immobile elements (i.e.: Zr, Y, Nb, Th, Ta, TiO_2) which, unlike major elements (e.g.: SiO_2, Na_2O, K_2O, MgO), are considered insensitive to alteration processes. This method has now been successfully applied in several archeological studies (Marra and D'Ambrosio, 2013; Marra et al., 2013; 2014a_Arch).

In the present work, we use this method to establish identification criteria for the so-called "peperini" ("pepper-like stones"), which allow us to attribute a dimension stone to the volcanic rock of origin and to designate it with the correct formational name established in the recent geologic literature (Table 1; Marra et al., 2011, and references therein). The Roman "peperini" include Lapis Gabinus (Peperino di Gabii, or Pietra Gabina), Lapis Albanus (Peperino di Marino, or Peperino Albano), and some varieties of Tufo del Palatino (e.g.: Peperino della Via Flaminia, "Peperino Grigio"; Karner et al., 2001a). Additionally, we also include another volcanic rock whose archeological name, "Sperone", is often incorrectly used as a synonym for Lapis Gabinus (e.g.: Lugli, 1957). The present study is focused in particular on Lapis Gabinus, an extremely hard rock (Jackson et al., 2005) that was employed for the construction of several monuments in Rome (e.g.: the Tabularium, the Forum of Caesar, the Forum of Augustus, the Cloaca Maxima; Lugli, 1957) and that erupted ca. 285 ka ago (Marra et al., 2003) from the hydromagmatic center of Castiglione (De Rita et al., 1988) (Fig. 1).

2. The "peperino" stones

Several different lithological units appearing in outcrops in the area of Rome have been described under the conventional name of "peperino" in the archeological and geological literature (Table 1; see Karner et al., 2001a for a review). This term derives from the Italian word for pepper and applies to all the pyroclastic-flow deposits characterized by lithified, granular texture and gray color, in which white and black lithic inclusions, as well as abundant feldspar and pyroxene crystals resembling peppercorns, occur (Fig. 2). It is thus a general term that does not specify a particular deposit or quarry location. We describe here the various stones conventionally labeled as "peperino" which are included in our analysis, while also drawing attention to the terminological confusion generated by the proliferation of archeological and geological terms (see Table 1).

The most typical "peperini" are two hydromagmatic-surge deposits erupted by the Castiglione Crater and by the Albano Crater, 285 ka and 36 ka ago, respectively: "Peperino di Gabi" and "Peperino di Marino" (also "Peperino albano") (Marra et al., 2003; Freda et al., 2006). These pyroclastic deposits formed extremely hard rocks, known also by the archeological names Lapis Gabinus and Lapis Albanus (Lugli, 1957) (Fig. 2a, b). "Peperino" has also been used to describe both Tufo del Palatino and the Grottarossa Pyroclastic Sequence (Karner et al., 2001a) (Fig. 2c, d), which are reported in the literature with the generic name of "Peperino Grigio" (e.g.: Ventriglia, 1971) or with the similarly generic archeological name "cappellaccio" These rocks present an appearance similar to Lapis Albanus and Lapis Gabinus, but with a less lithified character. However, an extremely hard facies of Tufo del Palatino (Fig. 2e) crops out in Grottarossa north of Rome (Karner et al., 2001a); this was previously considered to be a product of the Monti Sabatini activity and is known in the literature as Peperino della Via Flaminia (Mattias and Ventriglia, 1970). In this context, it is also important to note that Tufo del Palatino is a geological, and not geographical, term, and outcrops are not limited to the Palatine hill.

Another volcanic dimension stone used during the Fascist period to restore several Roman monuments (e.g. the Colosseum, the Theatre of Marcellus) is so-called "Sperone" (Fornaseri et al., 1963). This is a deposit of welded volcanic scoriae forming a portion of the Tuscolano-Artemisio caldera rim, near the town of Tuscolo (Fig. 1), where it was used to build the local amphitheater in the second century CE (Coarelli, 1981). The name "Sperone" is improperly used as a synonym for Lapis Gabinus by Lugli (1957) ("Pietra a Sperone"), generating significant confusion. However, "Sperone" has well distinguished macroscopic petrographic features with respect to tuffs (including those described as "peperino"), being an aggregate of rounded, sub-centimeter sized, poorly vesicular scoriae, resembling a scoriaceous lava rather than a pyroclastic-flow or hydromagmatic-surge deposit (Fig. 2f). Indeed, "Sperone" is a clast supported deposit, which lacks the fine ash matrix characteristically occurring in the "peperini".

De Rita and Giampaolo (2006) attributed the large blocks of tuff employed by the Roman builders in the walls of the Colosseum to "Sperone" from Tuscolo; Jackson and Marra (2006) interpreted this rock to be a less welded, zeolitized facies of the scoriae deposit, and called it Tufo di Tuscolo. However, a study in progress (D'Ambrosio

Table 1
Nomenclature of the most common peperino rocks of the Roman region.

Correct geological name	Proposed archeological name	Other archeological name	Other geological names
Peperini			
Peperino di Marino, Peperino Albano, Albano Unit 6 (1, 2)	Lapis Albanus (6)	*Peperino* (6)	*Villa Doria Unit* (9)
Peperino di Gabi, Hydromagmatic-surge deposit of Castiglione (3)	Lapis Gabinus (6) (italian: Pietra Gabina)	*Pietra Sperone*, *Asperone* (6)	
Tufo del Palatino (4)	Tufo del Palatino	Cappellaccio (6)	*Tufo Granulare* (*Grigio*), *Peperino Grigio*[10]; *Peperino della* Via *Flaminia* [11]
Grottarossa Pyroclastic Sequence (5)	Grottarossa Pyroclastic Sequence	Cappellaccio	*Tufo Granulare* (*Grigio*)
Welded scoria-fall deposit of the Tuscolano-Artemisio Sperone	Sperone	*Sperone Tuff* (7) *Tufo di Tuscolo*(8)	*Lava Spero* (12)

In italics, the archeological and local geological names which use should be avoided in order to eliminate confusion due to redundant and/or misleading appellation. The term "Cappellaccio" should be considered as a supplementary attribution to indicate the typical, laminated facies of Tufo del Palatino and Grottarossa Pyroclastic Sequence, as opposed to the Peperino della Via Flaminia, strongly lithified facies.
(1) Freda et al., 2006; (2) Giaccio et al., 2007; (3) Marra et al., 2003; (4) Marra and Rosa, 1995; (5) Karner et al., 2001a; (6) Lugli, 1957; (7) De Rita and Giampaolo, 2006; (8) Jackson et al., 2005; (9) De Benedetti et al., 2008; (10) Ventriglia, 1971; (11) Mattias and Ventriglia, 1970; (12) Fornaseri et al., 1963.