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Research paper

Advances in Achaemenid brick manufacturing technology: Evidence from the monumental gate at Tol-e Ajori (Fars, Iran)

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ABSTRACT

This paper deals with the archaeometric characterization of the bricks belonging to Tol-e Ajori Gate, one of the most important excavated sites on the Iranian plateau (Fars, Iran), close to the World Cultural Heritage of Persepolis. The archaeological excavations were carried out between 2011 and 2016 and brought to light a monumental building. The wall of the structure is built with mud and fired bricks sometimes glazed that are very similar to the elements of Babylon's Ishtar Gate.

Several investigations were carried out on the bricks in order to investigate the technology process and to compare their composition with local clays, as potential raw materials collected nearby the archaeological site.

The brick samples were investigated using different analytical techniques (Optical Microscopy, XRD, XRF, SEM-EDX, FT-IR/ATR, TGA, STA and Micro-Raman) to point out differences in chemical and mineralogical composition. Raw clay samples were submitted to XRD, XRF, SEM-EDX and FT-IR/ATR analyses.

A wide homogeneity is present for all the considered bricks: Ca-rich clays with quartz-rich temper were used, this possibly suggesting a common raw material origin. Firing temperatures interval was estimated around 850–900 °C. A multivariate data treatment (PCA and HCA analysis) was applied to the XRF data set acquired for both clays and bricks. PCA suggests that Polvar alluvial clays could be the source raw material for mostly of Tol-e Ajori's bricks and more than one clay deposit was probably used.

1. Introduction

In 2011 the Iranian-Italian Joint Archaeological Mission in Fars with the full support of the Research Institute for Cultural Heritage and Tourism, Islamic Republic of Iran, and of the Iranian Centre for Archaeological Research, started the exploration of Bagh-e Firuzi, 3.5 km West of Persepoli Terrace in Fars area.

The activity concerned two sites, known through previous surface surveys and geophysical surveys carried out by the Iranian-French Joint Archaeological Mission. At one of these sites, Tol-e Ajori - where the excavations are still in course (Fig. 1a) - a monumental building has been discovered, which appears to be of the utmost interest for the evidence it offers of the early settlement in the Persepolis area.

Scientific investigations were carried out on the fired bricks in order

to gather evidence of ceramic technologies, provenance and sources of raw materials.

1.1. Archaeological overview

The Tol-e Ajori building (Fig. 1b) has a rectangular plan and measures 39.07 m (NW-SE) × 29.05 m (NE-SW), oriented from WNW to ESE, with a 20° shift to N from the E-W axis. Its outer perimeter is formed by a massive wall 10.47 m thick, which encloses a rather limited inner room (w. 8.00 m, l. 14.36 m) with low benches along its walls and accessed by two corridors on the NW and SE short sides (w. 4.56 m, l. 12.36 m). In the long stretches, which delimit the inner room, the perimeter wall has proved to be characterized by a mud-brick core c. 5 m thick, encased on its outer and inner sides by two sections in baked

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Fig. 1. a) General view of Tol-e Ajori area; b) Structure facade in trench I, Tol-e Ajori.

bricks, each c. 2.5 m thick. An exceptional feature is seen in the outer facing of the monument, which is in glazed baked clay bricks. The glazed bricks found in situ as well as the fragments of more elaborated glazed and relief bricks found in the various destruction layers give evidence of a rich relief and glazed figural decoration.

As for the function, the two entrance corridors characterize the building as a monumental gate, which in its plan is extremely similar to that of the inner section of the Neo-Babylonian Ishtar Gate of Babylon, albeit in larger dimensions and different from the latter in the use of mud-brick along with baked bricks. The similarity with the Ishtar Gate is not limited to the plan, but extends to building technique and iconography. The results of the study of the decorated bricks show that exactly like the Ishtar Gate of Babylon, the gate of Tol-e Ajori was decorated with very similar glazed bricks. The most interesting remark is not only the similarity of the iconographic motifs, but the exact correspondence between the composition and the individual bricks of the decoration of the two monuments panels (Chaverdi et al., 2014).

All of these decorated and glazed bricks are produced by firing clay and therefore are altogether similar to the unglazed baked bricks forming the entire portions of the masonry. The fabric has pink, red and cream colours and in a lot of cases the interior (core) and exterior part of bricks have different colours. These bricks can be divided into two general size groups: the larger group measures about $32\text{--}33 \times 32\text{--}33 \times 8$ cm (the measures are uneven), and the smaller group, in which the thickness is the same but the length is approximately half of its width, measures about $32\text{--}33 \times 16 \times 8$ cm, and has been called the “half-size” brick. The existence of the half-size bricks made it possible to lay the bricks in a shifted position course by course. These measurements also correspond exactly to the measurements of Babylonian bricks (Marzahn, 2008).

Actually the mentioned features place our monument in the Early Achaemenid period, and in any case before the construction of the Persepolis Terrace. The Tol-e Ajori Gate appears therefore to have been built in the period between 539 BCE, the year of the Persian conquest of Babylon, and 518 BCE, the presumed beginning of activity on the Persepolis Terrace: more likely during the reigns of Cyrus the Great or Cambyses.

1.2. Geological context

The large alluvial Marvdasht plain is located about 60 km Northeast of the city of Shiraz in Fars province. It is placed in the south east of Zagros fold-and-thrust belt and belongs to the Shahreza-Abadeh-Hambast orogeny belt. The Zagros mountain range is divided into three tectonics zones from the NE to the SW (Stöcklin, 1968, Kehl et al., 2005). The study area is located in the Simply Folded Belt (SFB), which has been studied by many geologists (Falcon, 1974). This region is mainly covered with Mesozoic calcareous deposits and metamorphic rocks (shale, clays and quartzite) from the highlands and the lowlands

of the sedimentary basin. Folded Zagros are located at south-southwest and high Zagros are located in the eastern part of this basin. Khami formation outcropping in the studied area has an upper Jurassic/lower Cretaceous age. This formation is composed of Sormeh, Daryan, Fahliyan and the marly limestone of the Gadvan formations. The other outcropping formations are Kazhdomi formation and Bangestan group which is composed of Sarvak and Ilam formations, and date from upper to late Cretaceous (Quanbari et al., 2014).

Young alluvial of quaternary age that hide the underlying geological structure and tectonic settlement cover the study area. In the Basin of Marvdasht, late Quaternary basin fills consist of loess, loess-like alluvium sediments and fine clay raw materials (Kehl et al., 2005).

According to the map (Fig. 2), clay samples collected in Kooshk, Firuzi and Tol-e Ajori areas are related to holocenic deposits of clay, silt and sand, sometimes with salt (Istakhr) and from massive to thick bedded limestone and silicified clay limestone (Persepolis). Clay samples collected in Pasargadae, Tang-e Bolaghi and Polvar areas are related to holocenic alluvial deposit near the Polvar River.

2. Materials and methods

Thirty-two samples (Table 1, Supplementary Fig. S1) were selected for scientific integrated investigations between many fired bricks' fragments excavated in Tol-e Ajori site. The selected bricks are described in Table 1 in which information concerning archaeological contexts and macroscopic characteristics are included. The bricks' colour ranges between light orange, beige and pale red. The texture is mostly homogeneous and compact without black core. Macroscopically the pore size estimate is about 1–3 mm. On the surface of the bricks, bitumen traces are sometimes still visible.

Colour and structure of the bricks is related to raw materials such as sand and clay, as well as technical procedure such as kiln condition and typology, firing temperature, etc. (Molera et al. 1998).

As no information existed on a possible raw clay provenance, thirty-nine local clay samples were collected nearby the archaeological sites (Table 2, Supplementary Fig. S2). Part of these samples are from local quarries: twelve clay samples were taken from the active quarry of Istakhr, located at northeast of Kooshk, (samples HA; Supplementary Fig. S2a) and nine samples from the still active clay quarry of Kooshk, four samples from the low quarry and five from the high quarry (samples KM; Supplementary Fig. S2b). Other clay samples were collected from some deposits outcropping in the neighboring area: one sample from the area of Tol-e Ajori, in the north of Kooshk (TAJ57), nine samples from Tangh-e Bolaghi (TBPOL 1-9), two samples from the Polvar riverbed near Pasargadae (PPOL 1-2) and six samples from Firuzi near the Polvar river (FIPOL 1-6).

The investigations were performed on all the samples using different analytical techniques to determine the chemical and mineralogical composition of bricks and local clay raw materials.

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