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PCA Analysis Applied to the Study of the Surface Coating of Stone Monuments in Persepolis

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Abstract

Within an Iranian-Italian archaeological research project on Persepolis (Iran), a diagnostic study was carried out on several stone monuments in view of their conservation. The peculiarity of these monuments is the presence of a white coating which hides the dark grey colour of the stone. Such a coating, never documented so far, was studied on a few micro-samples and then on a much larger number of areas by a portable XRF equipment. PCA analysis was applied to the experimental results and allowed to detect two different types of coating for monuments in function of their age.

Introduction

Persepolis is one of the most representative sites of the Achaemenid Persian empire (6th-4th century BC). It was Darius the Great (522-486 BC) who decided to build this monumental citadel as a huge artificial Terrace, to celebrate the power of his kingdom. The sovereigns who followed Darius further enriched the site with other magnificent, richly decorated, buildings.

In the year 330 BC Alexander the Great reached Fars (Persia) and conquered the city of Pârsa, and then, after four months, set fire to the magnificent buildings on the Terrace. After many centuries of abandon, only in 1931 systematic excavations and studies were initiated by the Oriental Institute, University of Chicago.

In 2008 a 5-year project for Persepolis was launched jointly by Iran and Italy, named "*From Palace to Town* "(Askari Chaverdi & Callieri 2012). One of the important aims of the project was to contribute to the conservation of the stone monuments of the imperial site.

The stone used in Persepolis came from quarries not far from the site. It is a marly limestone of dark gray, almost black colour, , with micro fossils of the Upper Cretaceous period (Guidi et al. 2012) that can be classified as biomicrite with foraminifera (globigerina), algae and bivalves; a very fine dispersion of carbonaceous particles is responsible for the dark grey colour of the stone. Out of the diagnostic activities, special attention was dedicated to the finishing technique of architectural surfaces which appeared to be covered by a reddish earthy deposit. This deposit covers (and partly hide) a white/light-grey layer, much lighter than the colour of the stone core (Fig. 1).

Fig. 1, E staircase of the Apadana Palace: The black colour of the stone is covered by a grayish layer and, in the upper parts of the staircase, by a reddish earthy encrustation

Materials & Methods

A few micro-samples, collected from two different areas, were analysed by XRD and by SEM/EDS on polished cross-sections. The experimental results revealed that a white layer of fluorapatite and calcite is present on the stone surface, below the pinkish encrustation formed by the deposit of earthy dust. Fluorapatite could be obtained from calcined bones. The results obtained on these samples were recently published (Askari Chaverdi et al. 2016).

These totally unexpected results, even if very interesting, were obtained on a too small number of samples to have a real statistical value, therefore, it was necessary to enlarge their number. To have a statistically significant sampling without any damage to the original stone surfaces, an EDXRF

(Energy Dispersive X ray Fluorescence) portable spectrometer was used, alimented by dry batteries, designed by Ars Mensurae, which could be easily used all over the site.

A total of 36 areas were analyzed on different monuments attributed to the different periods of Persepolis.

Experimental results

The experimental results can be summarized as follows: The XRF data, expressed as Number of Counts for a fixed time interval, measured at Low Energy, were given for each sample. The following elements were detected in the various areas, but with different concentration, according to the different monuments: Al, Si, P, S, Cl, K, and Ca. A matrix with 7 columns (variables) and 37 rows (objects) was considered and diagrams with the combination of the 1-2, 2-3, 1-3, loadings components were produced, considering the good regularity of the Scree Plot. As can be seen in Figs 2, 3 and 4

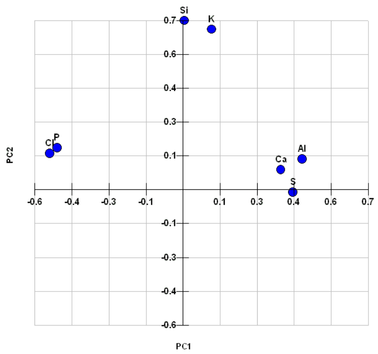

Fig.2, PC1(41.9%)-PC2(26.7%)

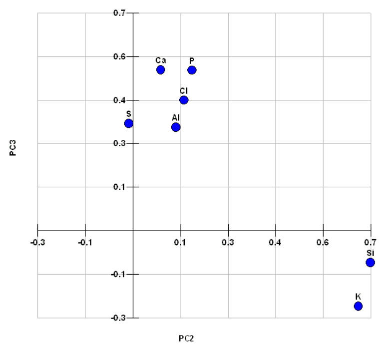

Fig. 3, PC2(26.7%)-PC3(12.7%)

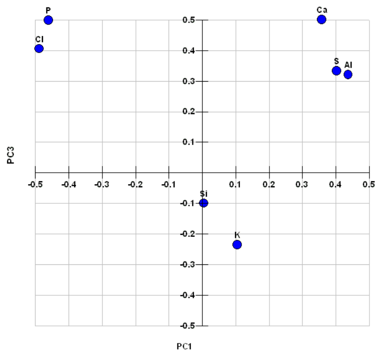

Fig.4, PC1(41.9%)-PC3(12.7%)

the correlation P/Cl is very good; this can be interpreted as the presence of a phosphate containing chlorine. Actually, the XRD performed at first revealed that the white layer of the samples contains Fluorapatite. Fluorine cannot be detected by *in situ* **XRF analysis but it is reasonable now to hypothesize that Fluorine is partially substituted by Chlorine in this white layer. The correlation Ca/S is also good, so indicating that in some other monuments Gypsum was used instead of Fluorapatite to hide the stone black colour. In fact, the monuments where P was detected are different from (and later than) the monuments where gypsum was used. To understand the reason for the observed S/Al and Si/K correlations, a deeper analysis of the experimental data is needed and, perhaps, other analytical techniques which require collecting some samples from the monuments.**

Conclusions

The combined use of XRF spectrometry by a portable equipment and the analysis of the collected data by PCA, allowed to shed light, in a totally non-destructive way, on the coating technique of the Achaemenid stone monuments of Persepolis. This technique was unknown until the study performed within the above mentioned Iranian-Italian archaeological research project.

Acknowledgments

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