Mineral and Mechanical Characterization of Earthen Building Materials from Argentina

/ GISELA SPENGLER (1) JUAN JIMÉNEZ-MILLÁN (2,*), MARÍA-JOSÉ CAMPOS-SUÑOL (2), MARGARITA DO-CAMPO (3)

(1) Instituto de Arqueología, Universidad de Buenos Aires - CONICET. c/25 de Mayo 213 3er piso. 1002, Buenos Aires (Argentina)
(2) Departamento de Geología. Universidad de Jaén. Campus Universitario. Edificio B-3. 23071, Jaén (España)
(3) Instituto de Geocronología y Geología Isotópica, CONICET - UBA. Ciudad Universitaria de Buenos Aires. 1428, Buenos Aires (Argentina)

INTRODUCTION

The use of sediments for the construction of earthen buildings was a technological development used in every continent, from prehistoric times until the present. Earthen building techniques are varied, and they can be classified in three general types: monolithic systems (rammed earth), brickworks (adobe o mudbrick), mixed systems (wattle and daub) and earthen plasters and mortars. Nevertheless, the recognition of archaeological evidence indicative of these kind of buildings is problematical, because this kind of architecture is vulnerable to destruction by weathering, especially by wind and water erosion.

Rainer (2008) emphasized that, in addition to environmental variables, the type of building material is a key factor affecting their composition and deterioration. The presence of swelling clays, hydrolytic weathering of minerals, mechanical erosion produced by rain drops, meteo-climatic factors, and discontinuities produced by the geological materials are among the major causes that produce the physical and chemical deterioration of the earthen architecture.

The determination of texture, plasticity and mineralogy is important to understand the behaviour of earthen building materials (Spengler et al. 2011). However, detailed mineral and petrographic investigations on the earthen building materials from Andean prehispanic cultures are scarces, and over NW Argentine cultures were never carried out. The aim of this contribution is to fill in part this gap. A petrographic classification of the earthen building materials will certainly contribute to understand their weathering and decay processes, and to define parameters for their determination in archaeological contexts.

GEOLOGICAL SETTING

The earthen materials studied are located in NW Argentina (Fig. 1).

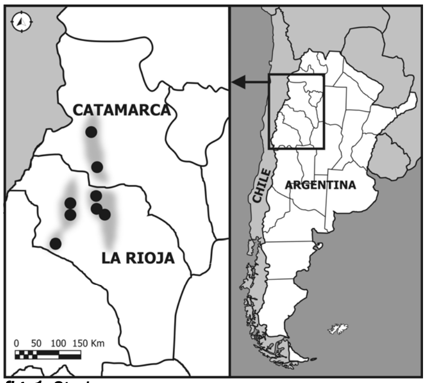

fig. 1. Study area.

From the geological point of view, these archaeological sites were built on materials of several Cenozoic depocenters of the broken-foreland, among Andean foothills and Pampean mountains of Famatina and Velasco segment: the basins corresponding to the Abaucan (Catamarca), Vinchina-Guadancol and Famatina-Antinaco Valleys (La Rioja) (SMLN 2001, Dahlquist et al. 2008).

The fill of Vinchina and Guadancol basins corresponds to several sequences of fluvial, lacustrine and aeolinan systems (Paleocene-Early Eocene to Pliocene) dominated by sandy-shale and sandy-gravel sediments. The Famatina-Antinaco and Abaucan Valleys are surrounded by a series of mountainous ranges belonging to the Famatina Complex comprising crystalline metamorphic basement intruded by diverse Palaeozoic (Ordovician) igneous rocks and containing a Ordovician volcanic record with Ordovician marine sediments interbedded with volcanic rocks.

MINERAL AND PETROGRAPHIC CHARACTERIZATION

Thin section study, X-ray diffractometry (XRD) and SEM-EDS mineral composition of 34 samples from 10 sites were carried out.

According to XRD analysis (powder method), samples are mainly composed by quartz, plagioclase, and variable contents of hematite and mica. Abaucan valley samples sometimes contain subordinate calcite, and less frequently scarce heulandite, dolomite or gypsum. Samples corresponding to Vinchina-Guandacol valleys (La Rioja) sometimes contain K-feldspar and chlorite, and seldom calcite and analcime. In the samples from Famatina-Antinaco valleys hematite is less frequent, sometimes acompanied by K-feldspar, rare gypsum and heulandite. All samples contain diverse clay minerals whose identification was performed on oriented aggregates of the <2μm fraction. The clay fraction of Catamarca samples contain abundant mica, smectite and occasionally subordinate amounts of chlorite and kaolinite. In contrast, samples of La Rioja depict high contents of illite/smectite mixed-layers, and mica in varying proportions.

Detailed petrographic studies emphasize that all the investigated architectural elements consist of a fine-grained groundmass containing lithic and plant fragments.

Lithic fragments chiefly consist of (a) volcanic rocks frequently developing a vesicular texture, (b) banded and foliated metamorphic rocks, (c) feldspar phenocrysts, and (d) very fine-grained quartz-rich sedimentary rocks (mainly sandstone-like). Volcanic fragments are characterized by a highly vesicular texture developed on a high-silica glass matrix with trachytic to rhyolitic composition. Biotite and Ca-amphibole

palabras clave: Materiales arqueológicos, Culturas andinas, Tapial, Adobe, XRD, Petrografía	*key words:* Archaeological materials, Andean cultures, Earthen buildings, XRD, Petrography

* corresponding author: jmillan@ujaen.es

phenocrists are frequently observed included in the glassy matrix. Vesicles show subspherical to elongated morphologies and most of them are filled by zeolites.

Metamorphic rocks fragments show a characteristic compositional banding. The compositional banding is the most conspicuous microscopic feature of these fragments defining a foliation probably produced by pressure solution. The banding consists of the alternation of biotite-rich layers and quartz-rich layers several mm thick.

Subeuhedral alkali feldspar phenocrysts are frequently found in the groundmass of the earthen elements. A characteristic perthitic texture is developed with wormy and ribboned Na-plagioclase exsolutions. Big fragments of very fine-grained quartz-rich sedimentary rocks can also be frequently observed in the studied materials which are very difficult to distinguish from the surrounding groundmass.

The fine-grained groundmass generally shows an intergranular texture scarcely oriented, and consists of small fragments of minerals included in the bigger lithic fragments. Unfortunately, the fine mineral size strongly limited the microscopic observation of the groundmass in which clay minerals are also widespread.

PHYSICAL AND MECHANICAL PROPERTIES

From a granulometric point of view, most of the samples contain less than 30% of clay fraction and a variable proportion of silt and sand. Rammed earth materials are predominantly more richer in sand (around 50% of sand fraction) than in adobe (around 35% of sand fraction). Two groups of mudbricks can be identified: Abaucán Valley mudbricks are richer in sand than those from Vinchina Valley.

Density values of mudbricks (average 1.73 g/cm^3) are commonly higher than those of rammed earth (average 1.59 g/cm^3). On the other hand, the lowest values of plasticity are found in rammed earth materials (below 9%), while mudbricks usually exceed 10%.

Compressive and flexural strength (CS and FS) were tested, values of CS from adobes are higher (between 14 and 16 kg/cm^2) than those of rammed earth (between 10 and 12 kg/cm^2). FS values for rammed earth are below 5 kg/cm^2, while many adobes depict higher values. These test could not been performed for wattlle and daub (and earthen plasters) because quantity and coherence of samples were insufficient.

DISCUSSION AND CONCLUSIONS

The petrographic study has revealed that volcanic lithic fragments are especially abundant in the archaeological sites from the Abaucan Valley. Volcanic fragments can also be found in the archaeological sites from the Famatina Valley but they are almost absent in earthen materials from the Vinchina and Gudancol Valleys.

The presence of important outcrops of Tertiary and Ordovician volcanic rocks in the mountains surrounding the Abaucan and Famatina Valley indicate the source areas for the Quaternary materials deposited in these valleys, which were used as raw materials for the earthen building materials found in these archaeological sites. Earthen building materials from the Famatina Valley are rich in metamorphic rock fragments, although this kind of fragments can be also found in several samples from the Guadancol Valley. This composition can be related with the outcrops of metamorphic rocks in the surrounding reliefs from Pampean mountains (Famatina-Antinaco Valleys) and Greenville (Guadancol) basements.

Sedimentary rocks are the main component of the lithic fragments observed in the Vinchina-Guadancol Valleys archaeological sites. These archaeological sites were build on Quaternary deposits which source areas are made of sedimentary formations containing fine-grained sandstones rich in quartz and clay minerals.

Grain size is related to the raw materials used but also to the type of building technique. The finest grain sized materials are those made with the sediments from the Vinchina Valley. Concerning the building technique, finer grain size materials were selected to make earthen plaster than in mudbricks and rammed earth.

Other physical and mechanical properties of earthen materials are more controlled by the building technique than by the raw materials. The higher flexural strength of adobes arises from their fiber and clay content. The technological properties of earthen building materials should be mainly controlled by the proportion of clay- versus sand+silt-sized material, but also by the kind and relative proportion of high plasticity clays in raw material, and also to the natural fiber content.

ACKNOWLEDGEMENTS

Financial support was provided by the research group RNM-325 of the Junta de Andalucía, and project UBACyT F086 of Universidad de Buenos Aires. This research was conducted by a PhD Scholarship of CONICET and a postgraduate Scholarship of AUIP.

REFERENCES.

Rainer, L. (2008): Deterioration and Pathology of Eathen Architecture, In: Terra Literature Review. An Overview of Reasearch in "Earthen Architecture Conservation". E. Avrami, H. Guillaud, M. Hardy, eds. The Getty Conservation Institute, Los Ángeles (USA), 45-61.

SMLN (2001): Provincia de La Rioja - Suelos, In: Establecimiento de Datos de Calidad Ambiental. Programa de Asistencia Técnica para el Desarrollo del Sector Minero Argentino. Secretaría de Minería de La Nación (Argentina).

Spengler, G., Do Campo, M., Ratto, N. (2011): Caracterización de materiales constructivos en tierra mediante estudios de laboratorio. in: "La arqueometría en Argentina y Latinoamérica" S. Bertolino, S. Cattaneo, A. Izeta, eds. Universidad Nacional de Córdoba (Argentina), 311-321.

*Dahlquist, J.A., Pankhurst, R.J., Rapela, C.W., Galindo, C., Alasino, P., Fanning, C.M., Saavedra, J., Baldo, E. (2008): New SHRIMP U-Pb data from the Famatina Complex: constraining Early-Mid Ordovician Famatinian magmatism in the Sierras Pampeanas, Argentina. Geologica Acta, **6**, 319-333.*