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Research paper

Assessment of two clayey materials from northwest Sardinia (Alghero district, Italy) with a view to their extraction and use in traditional brick production

B. De Rosa [a], G. Cultrone [b,*]

[a] Dipartimento di Scienza della Natura e del Territorio, Università di Sassari, via Piandanna 4, 07100 Sassari, Italy
[b] Departamento de Mineralogía y Petrología, Facultad de Ciencias, Universidad de Granada, Avda. Fuentenueva s/n, 18002 Granada, Spain

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ABSTRACT

Two clayey raw materials collected in the Porto Ferro and Lago Baratz areas of Alghero in northwest Sardinia (Italy) were used to prepare handmade brick samples that were fired under oxidizing conditions at temperatures ranging between 750 and 1000 °C to evaluate their possible use in the brickmaking industry. Both raw materials are rich in quartz and phyllosilicates but only the sample from Porto Ferro contains calcite. Granulometrically, the sample from Porto Ferro is a silty sand and shows higher plasticity than the clay from Lago Baratz which is classified as a sand. After firing, the samples acquire a red-orange colour and undergo significant mineralogical and textural changes. Phyllosilicate depletion is accompanied by the crystallisation of mullite and, only in Porto Ferro samples, the breakdown of calcite is followed by the formation of gehlenite, wollastonite and anorthite. Optical and electronic microscopic observations revealed that the temper grains are larger and more abundant in the bricks from Lago Baratz than in those from Porto Ferro. As firing temperature increased, pores became ellipsoidal in shape and the matrix became vitrified. The samples from Lago Baratz also show fissures at grain boundaries, which indicate the formation of an extensive network of pores and make these bricks very brittle when fired at low temperatures (750 and 800 °C), so much so that hydric tests could not be performed on them. Bricks produced with the clayey material from Porto Ferro achieved the best results in terms of hydric behaviour, with a reduction in the water absorption capacity, and in terms of compactness, with an increase in ultrasound wave velocity. However, both Porto Ferro and Lago Baratz bricks behaved in similar ways when submitted to the salt crystallisation test, especially at 1000 °C when a sufficient degree of vitrification was reached to ensure high quality samples.

1. Introduction

In ceramic manufacture, a raw material is mixed with water and moulded to give it the shape we want to produce; it is then dried and finally fired. Despite advances in technology the same basic procedure has been used for thousands of years. During this procedure various choices have to be made that have a direct effect on the final product. Two of these, the choice of the raw material and of the firing temperature, are of major importance, as the first affects the type of ceramic that can be produced, while the second influences the quality of the final product (Rathossi and Pontikes, 2010; Warren, 1999). Research has shown for example that the type of clay, the size and amount of temper and the presence of fluxing agents in a raw material will allow the production of a wide range of ceramics from a rough brick to the finest porcelain (Dondi and Fabbri, 2001; Singer and Singer, 1963). Similarly, different firing temperatures alter the mineralogy and the texture of the ceramics in different ways, making them more or less durable (Cultrone et al., 2001, 2004).

In this paper we analyse the granulometry and mineralogy of two clayey materials from northwest Sardinia (Italy). We also study the petrography and physical properties of bricks made with these materials in order to evaluate their durability and potential for use in the brickmaking industry. The idea of studying these raw materials emerged after an archaeological excavation of the Nuragic site of Sant'Imbenia (Porto Conte area, Alghero district, 14th–7th century B.C.) in which ceramic objects were discovered and analysed (De Rosa, 2010). Previous research suggests that these ceramics were produced in the area with locally sourced raw materials (De Rosa et al., 2012). These raw materials are not quarried today but, the petrography of the archaeological findings suggests that they are different from granulometric and mineralogical points of view. This means that the methods used here could also be used to assess the potential for use in brick production of other raw materials with similar characteristics.

There is ample evidence of ceramic production using local clays in this part of the island over a wide chronological period. It has been demonstrated that ceramic products formed part of the daily lives of the

* Corresponding author. Tel.: +34 958 240077; fax: +34 958 248535.
E-mail address: cultrone@ugr.es (G. Cultrone).

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inhabitants of villages such as Sant'Imbenia, Barnaldu and Palmavera among others, from at least the Neolithic Age, if not earlier (Colombi, 2010; Moravetti, 1992). Recent studies have revealed the trade in Sardinian ceramics in the Mediterranean Basin during the first millennium B.C. (Fundoni, 2009; González de Canales Cerisola et al., 2006). Later on, the Romans manufactured ceramics in the Porto Conte area and in the Turris Libisonis colony along the sea coast near Porto Torres (Carboni et al., 2012). There is also evidence of ceramic production in the Alghero (Milanese, 2013) and Sassari areas (Rovina and Fiori, 2013) in the Middle Ages.

According to the data supplied by the Italian Association of Brick Manufacturers (ANDIL, http://www.laterizio.it/), Sardinia today has a low brick production level (229,702 tonnes in 2011, less than 3% of total national production) compared to other regions in Italy, one of Europe's biggest brick manufacturers (Dondi, 2011). There are only five registered factories in Sardinia out of 170 in the whole country, some of which are located in the south of the island where tertiary clay sediments are quarried (Strazzera et al., 1997). Another important production centre is the Campidano plain of Oristano in mid-western Sardinia where terracotta vessels, roof tiles and bricks are produced (Annis, 1985). Quarries in northern Sardinia typically contain Quaternary colluvial clays derived from silty–sandy–conglomeratic sediments (Dondi et al., 1999a). The most common bricks produced in the area are hollow bricks characterized by low porosity and pore size and low resistance to frost (Dondi et al., 1999b). Despite the fact that brick production on the island is currently low, several studies have highlighted the potential of northwest Sardinia for ceramic production (Ligas et al., 1997; Oggiano and Mameli, 2012).

Although most brick production today is performed by extrusion (Lassinantti Gualtieri et al., 2010; Sánchez, 2001), as is the case in Sardinian factories (Dondi et al., 1995), in this paper we will be considering traditional handmade brick manufacture. This is because of the demand from architects and builders for special, non-standard bricks (with varying sizes, shapes and finishes), which are generally used in the construction of traditional-style country houses and in the restoration of historical buildings (Bajare and Svinka, 2000; Trevelyan and Haslam, 2001; Warren, 1999). Handmade brick production has an additional advantage over industrially produced extruded bricks in that it offers greater flexibility in terms of the numbers of bricks produced, so enabling savings in raw materials (Trevelyan and Haslam, 2001).

There are various differences between traditional and extruded bricks: in traditional bricks more water is used during the moulding process, the preferred orientation of laminar minerals is less pronounced and, above all, the final product is more porous (Álvarez de Buergo Ballester and González Limón, 1994; Singer and Singer, 1963). This last aspect makes traditional bricks more prone to decay. Particular attention must therefore be paid to the tests measuring physical parameters such as the compactness, water absorption and durability of the fired bricks. However, lower physical parameters with respect to extruded bricks should not necessarily be seen as a synonym of defective or of low quality products. In fact, the hydric, porometric and mechanical parameters of handmade bricks often closely resemble those of bricks used in our Cultural Heritage (Esbert et al., 1997) and are therefore more compatible with them than extruded bricks. The use of compatible materials in restoration work is crucial to avoid further damage to the monuments (Elert et al., 2003). Although stone is the most commonly used material in Sardinia's historical monuments, there are some fine brick buildings in Siligo and Fertilia (Sassari district) and, of course, in mainland Italy. We therefore believe our results will be of interest to those working in the restoration and traditional construction sectors.

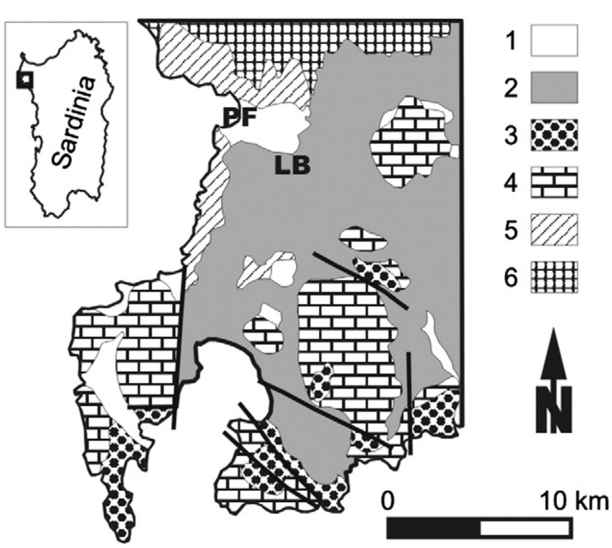

Fig. 1. Geological map of the area near Alghero (Sardinia, Italy) where the raw materials from Porto Ferro (PF) and Lago Baratz (LB) were collected. Legend: 1) alluvial, eolian and littoral sediments (Holocene); 2) conglomerates, sand and mud deposits in river terraces (Pleistocene); 3) limestones and marls of sub-littoral environment (Cretaceous); 4) dolomitic and bioclastic limestones and marls (Lias-Malm); 5) red-violet silty clays, micaceous and quartz-rich sandstones known as "Buntsandstein" (Upper Permian–Lower Triassic); and 6) Metasandstones and phyllites, terrigenous sedimentary rocks of uncertain age. Black lines indicate discontinuities. From Carmignani (2001), modified.

2. Materials and methods

2.1. Materials provenance and geology of the area

Two raw materials for ceramic production were collected from the Alghero district (northwest Sardinia) in the Porto Ferro (PF) and Lago Baratz (LB) areas.

The PF samples come from an area near the Bay of Porto Ferro (coordinates: 40°41'36.90''N; 8°11'56.72''E), a natural inlet about 2 km long, bordered to the south by twenty-metre high dunes that separate it from the Lago Baratz. The raw material is reddish-brown and very plastic. The LB was sampled near the only natural lake in Sardinia, the Lago Baratz (coordinates: 40°40'46.42''N; 8°13'38.06''E). It was formed at the end of the Würm Glaciation Stage and is characterized by significant seasonal variations in water levels (Alba, 2009). The raw material is almost brown and slightly plastic, with an earthy texture. The geology of the area consists mainly of Mesozoic layers, which rest on Quaternary deposits related to alluvial fans and/or flat braided channels, and wind dune fields from the Würm Glaciation Stage (Fig. 1) (Cassinis et al., 1996). The Triassic is mainly composed of dolostones and aeolian sandstones with carbonate cement, dolomitic marls, chalk marls and clay with foraminifera and continental facies, consisting of the typical red Buntsandstein sandstone. The Jurassic and the Cretaceous deposits consist of platform carbonates: mainly dolostones, limestones and marl. On the top, there are outcrops of volcano-sedimentary successions and lacustrine deposits from the early Oligocene–Miocene (Cita Sironi et al., 2006).

Geomorphologically, the study area is made up of level to sublevel land used above all for agriculture. Judging by the geographical extension of the outcrops from where the raw materials were sampled, both PF and LB reserves appear to be vast. Slightly further to the north, similar sediments with large reserves are used in the brickmaking industry and abandoned areas are reused in a sustainable way as controlled landfills (Dondi et al., 1995).

2.2. Sample preparation process

The samples were prepared manually, by disaggregating the raw materials and adding the amount of water needed to soften the clayey mass and remove excess air. The mass was then placed in a wooden prism-shaped mould which had previously been lined with sand to prevent the clay from sticking to the walls. The mould dimensions were $24.4 \times 11.5 \times 4$ cm. After 4 days, the samples, still moist, were removed