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CHARACTERIZATION AND PROVENANCE OF BUILDING MATERIALS FROM THE ROMAN PIER AT SAN CATALDO (LECCE, SOUTHERN APULIA, ITALY): A LITHOSTRATIGRAPHICAL AND MICROPALEONTHOLOGICAL APPROACH

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ABSTRACT

This study deals with the characterization of building materials used in a monumental pier of Roman age, located at San Cataldo, the main coastal harbour of the Roman town of *Lupiae*, modern Lecce (Southern Italy).

In the manufacture of the outer curtains three different lithologies have been recognized, all comprised in Pietra Leccese Formation, which crops out in a broad geographical area of Salento Peninsula. Microfossils recovered from limestone blocks are used to suggest a provenance for the source-rock. Microfossils include planktonic foraminifera characteristic of the upper Miocene (Tortonian-Messinian) foraminiferal MMi11 (*Neogloboquadrina acostaensis* Biozone) and MMi13 (*Globorotalia miotumida* Biozone) biozones. The analysed lithic materials show biostratigraphical characteristics very similar to some samples from Acaya-Strudà zone (some 10 km South-West from the ancient harbour): comparative analysis has been performed, supporting a clear identification of the geological origin of limestone blocks. In hydraulic concrete different lithic materials have been used and mixed with a strong mortar. Macroscopic field observation clearly define that limestone clasts, variable in size, derive from the Pliocene Uggiano la Chiesa Formation, that widely crops out locally at San Cataldo; granular fractions of mortar probably derive from beaches and/or sandy dunes, available in the surrounding area, as well.

KEYWORDS: *Roman pier, Lithostratigraphy, Foraminifera, Limestone blocks, Roman concrete, Southern Apulia.*

1. INTRODUCTION

Microfossils are widely used by geologists in palaeoenvironmental and biochronological reconstructions of sedimentary rock successions. Recently the micropalaeontological method has also been applied in archaeological research, contributing to the characterization of ceramics and artifacts, including building materials (e.g., Wilkinson et al., 2008; Foresi, 2009; Wilkinson et al., 2010; Helama & Hood, 2011; Riquelme et al., 2012). Notwithstanding such potentialities (Quinn, 2008), microfossil studies have rarely been applied in geoarchaeological research of Southern Italy. This contribution reports on a litho-, bio- (based mostly on planktonic foraminifera) and chrono-stratigraphical study of building materials used in a monumental pier of Roman age, located at San Cataldo, the main coastal harbour of the Roman town of *Lupiae*, modern Lecce (Southern Italy). (Figure 1).

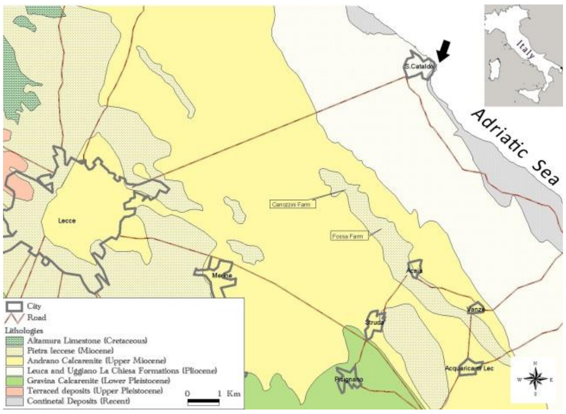

Figure 1. General setting and geological sketch map of the San Cataldo – Lecce area (after Bossio et al., 2006 slightly modified). The black narrow indicates the location of the Roman pier.

The Roman building was already known since the XVI century as part of an ancient harbour. Artistic and very interesting drawings (Figure 2) have been realised during the long phase of planning of a new breakwater (Figure 3) during the 1800s (Sammarco & Marchi, 2012). In addition, archival documents provide detailed descriptions of the ancient remnants, indicating its original overall length of ~150 m, whereas the present surveyed length is ~60 m. The reduction in size was the result of the systematic wrecking of the monument actuated in 1901 (Figure 3) in order to obtain material to be re-used in the construction of the new breakwater, built behind the ancient structure and still partially preserved.

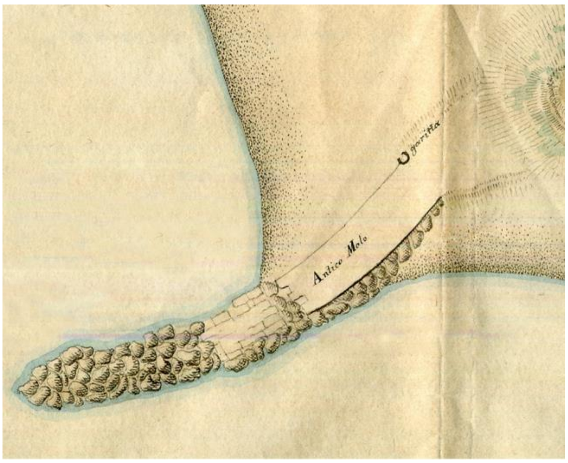

Figure 2 Detail of historical map (1881) showing the original bending shape of the ancient pier (from State Archive of Lecce).

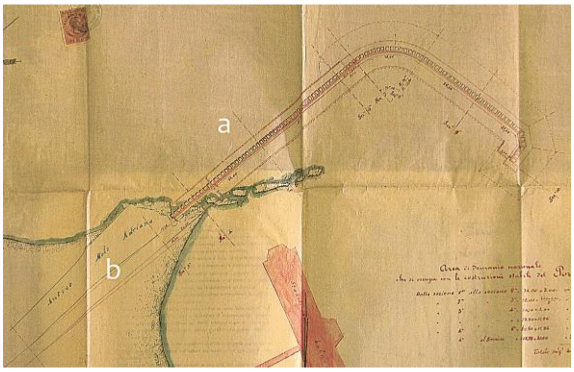

Figure 3. Project plan (1901) of the new L-shaped breakwater (a) built behind the ancient structure (b) (from State Archive of Lecce).

The archaeological remains of the Roman pier (40°23′22″ North 18°18′25″ East) can be actually observed along the beach, 110 m SE from the San Cataldo lighthouse. The monument (Figure 4) shows a compact structure and consists of two outer walls ~15 m distant from each other. The two curtains are made by large squared limestone blocks and filled with hydraulic concrete made with a strong mortar mixed with a local stone aggregate; this aggregate varies in size and composition and is unevenly distributed within the concrete. Certainly, the use of such large blocks was induced by the opportunity to quarry lithic building materials from the surrounding areas. Lithic blocks are used, as well, to realize the mooring rings (Figure 4b) projecting from the inside face of the breakwater.

Figure 4 Some images of the ancient monument showing: a - the inner concrete, b - the southern curtain made by Pietra Leccese blocks and the mooring ring projecting from the inside face of the pier; c- the northern curtain.

Information on the age of the structure substantially derived by historical sources (Pausania 6.19.9, s. Maddoli et al., 1999), which refer to the construction of the pier to the Hadrian's Age (first half of the 2nd c. A.D.). The building technique of the San Cataldo pier can be observed in several other structures of the Mediterranean Basin (Stewart, 1999; Marriner & Morhange, 2007; Brandon et al., 2010), referred to a long stretch of time included between the end of the Hellenistic period and the beginning of Roman Age.

The Roman pier and the harbour of San Cataldo were used until the Middle Age, when San Cataldo was a very active commercial port on the Adriatic coast. A significant trade activity is documented throughout the XVI and the XVII century, mostly to embark the olive oil. When this activity decreased during the XVIII century, the harbour was progressively abandoned.

A new breakwater was built behind the old pier during the first years of the XX century. This new structure is L-shaped, begins at the root of the ancient pier and extends 190 m seaward. It laid on a wide submerged foundation consisting of large-size squared limestone blocks, and it is still well visible in the aerial photographs (Figure 5).

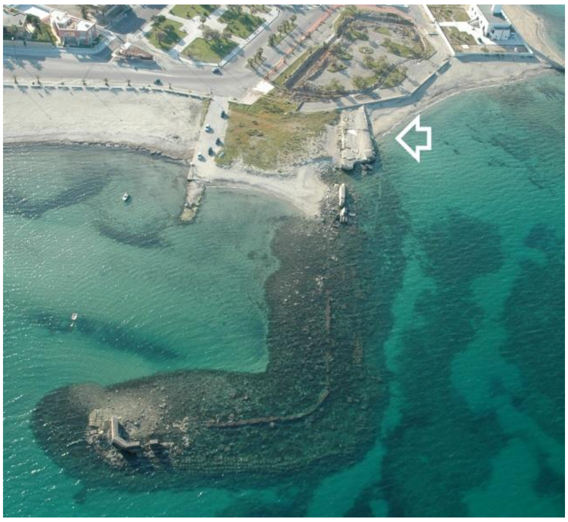

Figure 5 Oblique aerial photograph of the roman pier (arrow) and the modern breakwater (photo: M. Sammarco, 2009).

In order to identify lithological and micropalaeontological features of the lithotypes used in the roman monument, small samples from limestone blocks and from inner concrete have been examined. In particular, microfossil assemblages provide a valid proof for determining the geological provenance of lithic materials.

2. GEOLOGICAL SETTING

The studied roman pier lies along the beach of the village of San Cataldo, located 10 km East of the town of Lecce, along the Adriatic coast. Lithic formations outcropping in the sector east of Lecce, including San Cataldo area, forme a gently folded slight monocline dipping towards East. They are shown in Figure 1 and are listed below in stratigraphic order.

a) Altamura Limestone - compact limestones and dolomitic limestones Cretaceous in age that widely crop out in the north of Lecce.

b) Pietra Leccese - a Miocene (Burdigalian-Messinian) planktonic foraminiferal homogeneous-compact biomicrite cropping out along both the Ionian (Bossio et al., 1992) and Adriatic side of the Southern Apulia (Bossio et al., 1986, 1989a, b, 1991, 1994; Margiotta & Negri, 2005) including the type area of Lecce, where the unit develops its maximum thickness (Bossio et al., 2006; Giudici et al., 2012; Margiotta & Negri, 2004; Mazzei et al., 2009) and Cursi-Melpignano (Foresi et al., 2002; Mazzei, 1994). This formation is typically yellowish in colour, but it changes depending on the mineralogical content: it shows a tobacco brown colour at the base, due to presence of small brown phosphatic nodules, whereas it becomes greenish-yellow upwards, up to intensely green at the top due to its glauconite content. This topmost green part is locally known as "Piromafo".

c) Calcareniti di Andrano – a Messinian formation very widespread in the Lecce area that represents the regression and the closure of the Miocene deposition in the entire Salento. This unit is composed of marly limestone and limestone, grey in colour and rich in fossil shells. The limestone is generally fine-grained and compact; locally it can be medium-grained, porous and friable.

d) Lèuca Formation – the basal Pliocene unit that disconformably covers the Miocene units. It is about ten meters thick and composed of breccia, conglomerate (corresponding to the Miocene Leuca breccia of Bosellini et al., 1999 and Andrano Calcarenite of Ricchetti, 2009) and, subordinately, glauconitic biomicrite (Trubi unit of Bosellini et al., 1999). Breccias and conglomerates are formed by carbonatic heterometric pebbles included in a mainly sandy or marly sandy matrix.

e) Uggiano la Chiesa Formation – a Lower Pliocene unit composed of a basal conglomerate with phosphatic pebbles, covered by a stratified and fossiliferous bio-detritical limestones, with interalyered yellowish calcareous sands.

f) Gravina Calcarenite [according to Ricchetti (2009) and corresponding to Calcareniti del Salento of Bossio et al. (2006)] – bio-detriti climestones and sands locally with abundant fossil shells of the Early Pleistocene.

The sedimentary succession ends with recent deposits sometime terraced, that crop out in the coastal area, both South and West of San Cataldo.

3. METHODS AND MATERIALS

Limestone blocks and mortar employed in the Roman pier of San Cataldo were observed in detail in situ and subjected to laboratory analyses. A detailed macroscopic observation was sufficient for a lithostratigraphic attribution of limestone, but an analytical approach, particularly micropalaeontological, has been necessary to characterize mortars and to define the biostratigraphy of limestones.

During the field work one hundred and nineteen limestone blocks have been mapped. Six representative samples from limestone blocks, three mortar samples from the inner concrete and two mortar samples from the outer curtains have been collected. The samples have been treated to obtain washing residues and thin sections, aimed to realise micropalaeontological (particularly planktonic foraminifers) and facies-mineralogical analyses, respectively. Thin sections of limestone have been prepared with classic method; mortar samples were made cohesive before processing, through inclusion in resin. Samples for micropalaeontological analyses have been disaggregated gently boiling the dried sediments in aqueous solution of hydrogen peroxide and after washed through a 63 μm sieve. Dried washing residues have been analysed through a stereomicroscope at maximum magnification of 100X. A number of 100-200 specimens of planktonic foraminifera were randomly picked up and a semi-quantitative evaluation of the abundance of the taxa was carried out in order to perform biostratigraphic attributions based on the Iaccarino et al. (2007) zonal scheme. Macroscopic visual observation of lithological characters of inner concrete was sufficient to certainly attribute the stone aggregate to a specific lithostratigraphic unit, making redundant further analyses.

Finally, the comparison of our results with the dataset presented in several published studies has been essential to suggest the geological provenance of the materials.

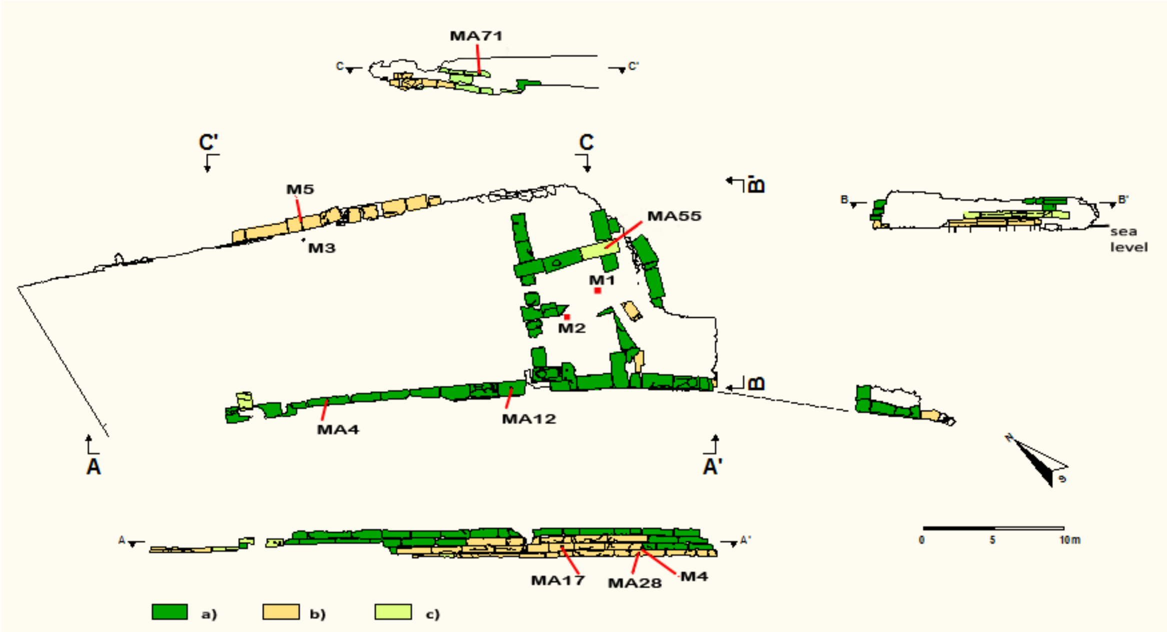

Figure 6 Distribution of the three varieties of miocenic Pietra Leccese Fm. recognised in the roman pier: a) greenish limestone (Piromafo variety); b) straw yellow compact limestone, containing rare granules of glauconite; c) slightly glauconitic whitish-greenish limestone. In red, locations of collected samples.

4. FIELD AND LABORATORY DATA

4.1 Macroscopic characters

Lithic blocks employed in the outer walls are made of a homogeneous and compact limestone, generally yellowish in colour, but sometimes tobacco brown or greenish. In addition, limestone shows abundant microfossil content, when observed through a hand lens. These characteristics surely indicate that the limestone squared blocks were quarried from the Pietra Leccese Formation. Moreover, based on the colour of the limestone, the different lithofacies of this formation have been recognized, also reconstructing a specific organization the blocks, which are stacked by following the original stratigraphy of the formation (Figure 6). The blocks employed in the lower parts of the walls are commonly represented (Figure 7a) by a straw yellow compact limestone, containing rare granules of glauconite, skeletal fossils and diffuse trace fossils (37% out of the total). These blocks are covered by others (13% out of the total) composed of slightly glauconitic whitish-greenish limestone (Figure 7b) with sparse common fossils (mainly pectinids). The upper part of the structure generally present greenish limestone and the glauconitic granules are locally concentrated in dark green lenses. These last blocks (Figure 6c) are marked by concentrations in fossil bivalve shells (mainly *Neopycnodonte, Flabellipecten*, and *Amusium*), with subordinate phosphatic moulds, pteropods, and brachiopods, mixed with small apatitic nodules (a few millimetres to 2-3 cm in size). Widespread bioturbation (abundant horizontal burrow trace fossils) can be observed. All these characteristics indicate that this last lithology corresponds to the “Piromafo” variety (50% out of the total) of the Pietra Leccese Fm.

The clasts used in the concrete (Figure 7d) show different size, varying in the interval from some centimetres to 15-20 cm and are made mainly of whitish biodetritical limestone with fossil shells and subordinately by violet compact micritic limestone. These lithological features permit indubitably to refer the clasts of the inner concrete to the Pliocene Uggiano la Chiesa Formation. The clasts are mixed with a strong mortar characterised by a reddish colour with whitish and yellowish shades.

Figure 7 Detailed view of the blocks employed in the roman pier: a) compact whitish-yellowish biomicrite (southern curtain); b) slightly glauconitic whitish-greenish biomicrite with sparse pectinids (southern curtain); c) greenish biomicrite with fossils and horizontal tubular bioturbations (inner concrete); d) biodetritic limestone rich in gastropods and bivalves (inner concrete).

4.2 Microscopic characters

All samples of collected mortars show very similar characteristics (Table I). The washing residues are composed mainly of a sandy clastic fraction and a low content of microfossils, a portion of not disaggregated original mortar is also present.

Rare benthic foraminifera (*Ammonia beccarii* and *Elphidium crispum*), as well as rare remains of bryozoans, barnacles, echinoids, molluscs, ostracods and serpulids constitute the microfossil association. In particular, the remains of echinoids are represented by large spine fragments, with original pigment still well preserved, and it can be assumed that they belong to the species *Paracentrotus lividus*.

As regards inorganic fraction, some crystals are dark green / blackish in colour and they stand out with respect to the remaining part of the residue, which is clear in colour. These are crystals of olivine and pyroxene, which have a certain volcanic origin probably correlated to the recent Sicilian volcanic activity or to Monte Vulture (South Appennine) volcanic complex (Margiotta et al., 1983; Zezza, 1969). However, more precise information about this topic can be obtained only through further specific analysis. All clasts, including fossil fragments, are well polished and rounded and show dull surfaces.

Two mortar samples , collected from the outer walls and from the inner concrete, have been examined also in thin section, and they confirm the results obtained by the analysis on the washing residues. In particular, both samples have a mud-supported texture, with large portions involved in evident oxidation processes, highlighted by the brownish colour (Figure 8a). The clasts of medium-coarse grain size are strongly fractured and this is particularly evident in the quartz crystals of the mortar of the hydraulic concrete (Figure 8b). This fracturing is due to mechanical stress occurred during the preparation of mortar or after its emplacement. In fact, all the larger crystals, regardless their type, display this feature, and this excludes it was an original character of the material.

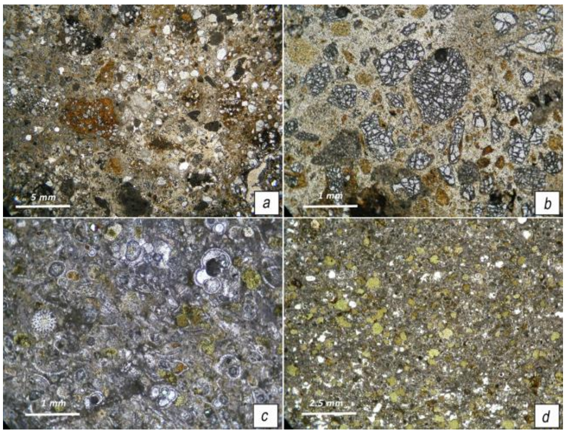

Figure 8 Pictures from thin section - plane polarized light: a – sample M3, mortar, the brownish areas indicate the presence of oxidation processes; b – sample M3, mortar of inner concrete. The quartz grains are well-rounded and strongly fractured; c – sample MA 17, Pietra Leccese from the outer walls, biomicrite characterised by abundant foraminiferal test, especially of planktonic species; d - sample MA 12 Pietra Leccese from the outer walls, intensely glauconitic biomicrite. The granules green and brown in colour are glauconite and phosphatic nodules, respectively.

Six samples of limestone blocks have been collected: two samples from the compact yellow limestone (MA17, MA28), two from the intensely green (MA4, MA12) and two from the whitish-greenish limestone (MA55, MA71). All samples have shown to be particularly resistant to washing operations and the residues were characterized by abundant not disaggregated fraction. As regards micropalaeontological fraction, few remnants of fish, echinoids and rare ostracods have been observed, but the characterizing component is provided by foraminifers, which are of planktonic and benthic type; both groups are represented by a large number of species and individuals.

Generally, the specimens show a medium-poor preservation, and their classification is often hampered by carbonate encrustations, which mask the distinctive characteristics of the species. When the presence of carbonate encrustations is very marked, semi-quantitative abundance estimation is inhibited, and it is just possible to indicate the presence/absence of each species (Tab. 1). However, for the case in question, this aspect did not prevent the biostratigraphic analysis, performed with a good confidence, and the relative biozone determinations. Two samples have been also observed in thin section. Both are classified as a biomicrite rich in foraminifera (Figure 8c). Among the crystalline clasts, granules green and brown in colour are common, respectively corresponding to glauconite and phosphatic nodules (Figure 8d).

From a biostratigraphic point of view, the presence of some diagnostic taxa, such as *Neogloboquadrina atlantica praeatlantica*, *N. acostaensis* (changes in coiling direction of the test are also relevant in neogloboquadrinids), *Globigerinoides obliquus extremus* and *Globorotalia conomiozea*, allowed us to refer all samples to the zonal interval MMi11-MMi13 of the adopted zonal scheme, all biozones referred to the Tortonian-Messinian chronostratigraphic interval (Figure 9).

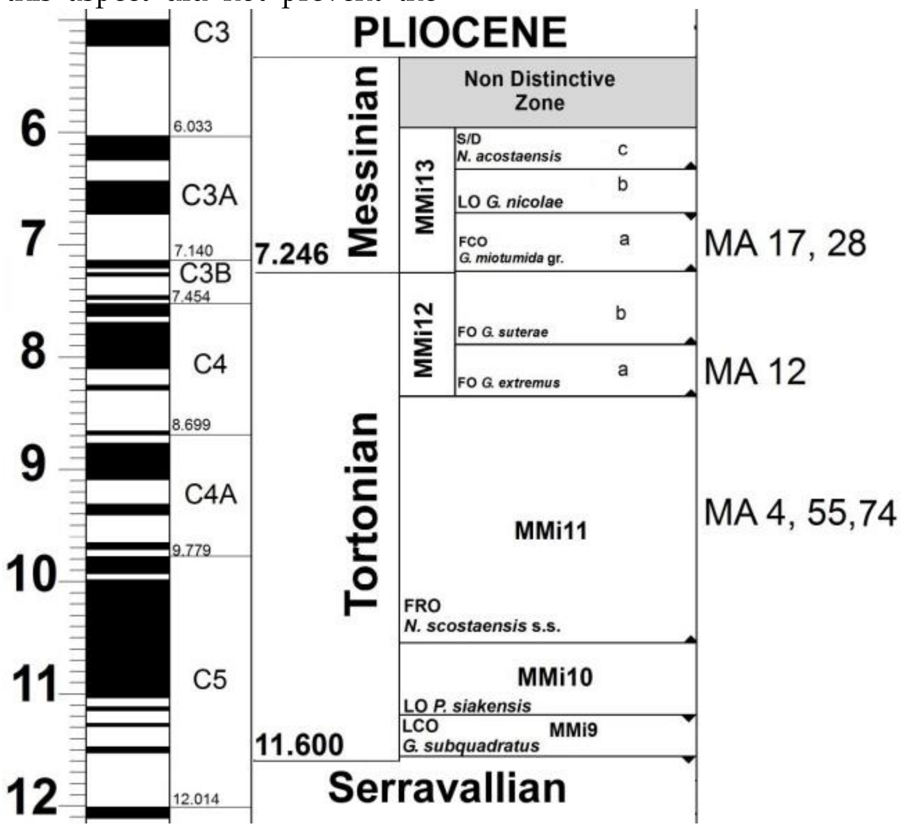

Figure 9 Bio-chronostratigraphic reference of the samples collected in the Pietra Leccese blocks of the Roman Pier. The position of the samples within the biozone is just as an indication (modified from Iaccarino et al., 2007).

Notes	Provenance	Sample	Planktonic Foraminifera																								Benthic Foraminifera				Other						
			D. altispira	G. bulloides	G. falconensis	G. glutinata	G. bollii	G. obliquus obliquus	G. obliquus extremus	G. quadrilobatus	G. sacculifer	G. trilobus	G. dehisens	G. nepenthes	G. woody-decoraperta	G. menardii	G. miotumida	G. miozea	G. conomiozea	G. scitula	N. acostaensis	N. praeatlantica	O. bilobata	O. suturalis	O. universa	T. quinqueloba	Ammonia beccarii	Elphidium crispum	Hanzawaia boueana	Peneroplis planatus	Bryozoans	Barnacles	Echinoids	Molluscs	Ostracods	Fish remains	Serpulids
Mortar from inner concrete		M1																									R						R	R			RR
Mortar from inner concrete		M2																									R	R					RR	R			
Mortar from inner concrete		M3																									R						R	R			
Mortar outer walls		M4																									R	R		R			R	R			
Mortar from outer walls		M5																										R	RR	R	RR	RR	R	R	RR		
Intensely glauconitic Pietra leccese - outer wall	Roman pier	MA 4		X		X		X		X		X	X		X						X	X											R			R	
Intensely glauconitic Pietra leccese - outer wall		MA12	X		X			X	X	X					X					X	X			X		X							X			X	
Pietra leccese - outer walls		MA17		C		R	R	A	R	C	R	R		R	C				R	R	?R	R	R	R	R	R							R			R	
Pietra leccese - outer walls		MA28		X			X	X		X		X			X	X	X			X	X			X		X									X		
Slightly glauconitic Pietra leccese - outer walls		MA55	R	R	R			C		A		A	R					R				C		R		R							R			R	
Slightly glauconitic Pietra leccese - outer walls		MA71	R		R	R	C	A		R	R	C		R	A							R		R		R							R			R	
Intensely glauconitic Pietra leccese		AC5					C	A	R	C	R	R		R	A		R		R		R	R	R	R	C	A											
Intensely glauconitic Pietra leccese		AC4		R		R	C	A	C	R	R			R	A	R	R		R		C	R	R	R	C	A											
Intensely glauconitic Pietra leccese	Acaja section	AC3		R		R	C	A	C	C		R			A	R	R		R		R	R		R	C	A											
Intensely glauconitic Pietra leccese		AC2					C	A	R	R				R	C				R	C	C				C	A											
Intensely glauconitic Pietra leccese		AC1		A	R	C	C	C	C	R	R			C	A	R	R		R	R	R		R	R	C	A											

Table I Distribution of the fossil rests in the micropalaeontological samples from the Roman pier and caja section. RR: very rare, R: rare, RC: rare to common, C: common, CA: common to abundant, A: abudant, X: not estimated abundance, d: dextral coiling, s: sinistral coiling.

5. GEOLOGICAL PROVENANCE OF BUILDING MATERIALS

In mortar samples, morphological characteristics of many clasts, especially their rounded shape, suggest that they have been greatly involved in aeolian process. Using this information it's possible to suggest a provenance of sands used to prepare mortar from deposits of aeolian accumulation, such as local dunes or beach. This suggestion is also supported by microfossil analysis which reveals the presence of some foraminiferal tests and other carbonate shells, all eroded and rounded as well. These organic rests first have been deposited on the beaches by waves, then moved to the backshore by wind, together with other clastic grains, forming dunal deposits.

The analysis performed on limestone samples, allowed us to refer limestone used in the roman monument to the Miocene Pietra Leccese formation. Three different lithic varieties have been recognized (Figure 6): 1) straw yellow compact biomicrite, 2) whitish-greenish slightly glauconitic biomicrite and 3) greenish biomicrite very rich in fossil shells (Piromafo). All varieties extensively outcrop in a broad geographical area in the backlands of San Cataldo (Bossio et al., 2006; Margiotta, 2006), from the modern city of Lecce to the surrounding area of the small town of Strudà.

Biostratigraphical and chronostratigraphical data pointed out that intensely glauconitic biomicrite (lithotype nr 3) belongs to the biozonal interval from MMi11 to MMi12. These data suggest the exclusion of the area nearest Lecce as geological source of the stone blocks, referred (Mazzei et al., 2009) to the *Paragloborotalia siakensis* Zone (MMi9 in the adopted zonal scheme) that is lower Tortonian in age. Otherwise, intensely glauconitic biomicrite referred to Tortonian/Messinian *Neogloboquadrina acostaensis* Zone (MMi11 Zone of the present paper) (Margiotta, 2006) crops out in the Acaja district along a narrow area extending north toward the Fossa and the Carrozzini farms. Some samples from a two meters thick section located in correspondence of the Acaja Castle have been collected (Figure 10). Here, Pietra Leccese formation is characterized by greenish limestone with glauconitic granules locally concentrated in dark green lenses. The sediment is bioturbated and marked by concentrations in fossil bivalve shells (mainly

Neopycnodonte, Flabellipecten, and *Amusium*), with subordinate phosphatic moulds, pteropods, brachiopods, mixed with small apatitic nodules. Biostratigraphic analysis of planktonic foraminifera revealed the presence of diagnostic taxa as *Globorotalia conomiozea* and sinistral *Neogloboquadrina acostaenis*. The foraminifera assemblage refers to Messinian biozone MMi13 and it is in full agreement with samples taken from blocks of the Roman pier.

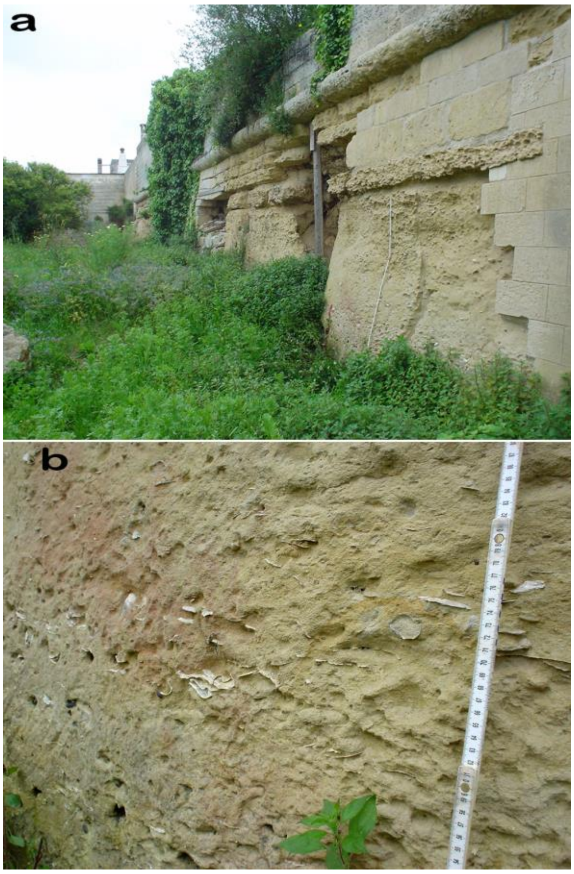

Figure 10 Panoramic view of the Acaja section (a) and detail of the Pietra Leccese outcrops showing a glauconitic and fossilifer level (b).

Small stone blocks used in the inner concrete are referred to Uggiano La Chiesa Fm., a Pliocene calcareous rock which largely outcrops in the surrounding of San Cataldo; this material was probably taken from the lands adjoining the pier, quarried from the rock surface.

CONCLUSIONS

Planktonic foraminifera assemblages provide a precise age determination to Miocene period and clearly attest the stone source as the upper part of the Pietra Leccese Fm., referred to the MMi11-MMi13 interval of the Tortonian-lower Messinian planktonic foraminiferal zonal scheme.

More particularly, results of comparative analyses on greenish lithological type (locally known as "Piromafo") reveal a provenience from the Strudà-Acaja area, where the upper part of Pietra Leccese Fm. shows the same geological age and identical features of lithic samples from San Cataldo. At Acaja, located some 10 kilometres from the archaeological coastal site, there is no evidence for ancient quarries, however the Roman route system allowed to cover that not considerable distance and easily transport big blocks, more than 2 meters length, for their employment in the monumental coastal building.

Regarding the concrete, it was quite evident right after macroscopic visual observation that limestone clasts derived from Pliocene Uggiano la Chiesa Fm., that crops out very close to the ancient harbour. Possibly limestone was dug up from the surface in a not defined area, nearby the pier.

Mortar used both in the filler layers of the outer walls and in the inner concrete shows the same characteristics. The granular component of mortar consists of quite mature sands which origin is due to aeolian accumulation, as possibly local dunes or beach. Both these subaerial depositional environment are present close to the ancient pier. This aspect, in addition to the lack of pumice scoria observed in the first macroscopic visual approach, clearly attest that pozzolanic volcanic fine sand from the Campi Flegrei area, extensively used by Roman engineers in seawater concretes (Oleson et al., 2004), was not used in San Cataldo structure.

This cement system remained stable for 2000 years, during partial to full immersion in seawater, as well. Further analytical investigations could possibly determine the diverse chemical processes that produced the cement microstructures, and why the harbour constructions have endured for two millennia. Vitruvius's treatise *De Ar-*

chitectura (1st c. B.P.) and other ancient texts describe the raw materials of the concretes, in particular pozzolanic sand, preparation of lime, and construction of submerged wooden forms. In San Cataldo pier, the use of weathered sea sand in mortar seems to be an efficient local alternative.

The results obtained gave the possibility of focusing on the potential of microfossils data integrated with archaeological information, including structural aspects of the manufacture and evidences from the surrounding territory.

The micropaleonthological technique discussed here, applied to the provenance of building materials from a pier of Roman age, may have wide utility in recognising the source of lithics used in roman buildings. Nevertheless, very few litho- and biostratigraphical analyses applied to ancient limestone structures in Apulia have been carried out so far. So, it is to be hoped that such an approach will be followed in other studies aimed at the reconstruction of both ancient human activities and landscapes.

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