

# INTEGRATED TECHNIQUES TO EVALUATE THE FEATURES OF SEDIMENTARY ROCKS OF ARCHAEOLOGICAL AREAS OF SICILY

**Maria Brai, Antonio Cimino, Giuseppe Raso, Tiziano Schillaci**

Dipartimento di Fisica e Tecnologie Relative, Università degli Studi di Palermo

**Stefano Bellia**

Dipartimento Chimica e Fisica della Terra ed Applicazioni  
Università degli Studi di Palermo

**Antonio Lo Casto**

Dipartimento di Biotecnologie Mediche e Medicina Legale, Università degli Studi di Palermo

**Paola Fantazzini**

Dipartimento di Fisica, Alma Mater Studiorum Università di Bologna

**Antonella Maccotta**

Dipartimento di Scienze e Tecnologie Chimiche e dei Biosistemi, Università di Siena

## 1. Introduction

This work is addressed to characterize the sedimentary rocks from Sicily used in cultural heritage, classifying them for mineralogical and chemical features as well as for porosity. Measurements on samples collected in Sicilian quarries will be compared with data obtained from micro-invasive techniques on monuments of archaeological interest.

In detail, the chosen techniques were X-Ray Diffractometry (XRD), X-Ray Fluorescence (XRF), Magnetic Resonance Relaxometry (MRR), Magnetic Resonance Imaging (MRI).

Furthermore, adsorption kinetics studies and internal microporosity surveys on samples, both through X-ray tomography, are performed.

Many of sedimentary rocks (common limestones, calcarenites, travertines, etc.) have been used for the building of archaeological-historical items of Sicily, from *Magna Graecia* to nowadays.

The final aim is the understanding of the deterioration processes and the eventual remedial actions to prevent the decay of the cultural heritage. In particular, our attention was focused on building materials used for some of the temples of Agrigento, Segesta and Selinunte. These temples are localized in Western Sicily (fig. 1).



Figure 1. A map of the archaeological areas of the survey.

The research will be broadened to other cultural heritages belonging to different historical periods, as roman, middle age, baroque and modern era. All the data will be inserted in a relational database to create a knowledge basis to define risk indexes for the monuments [1], including the relevant geological sites, so individuating restoration and/or preservation actions.

## 2. Historical outlines

The Valley of the Temples of Agrigento is one of the most important evidences of the Greek civilization in Sicily. It is located in the southern part of Agrigento town, on the ruins of the ancient Akragas.

According to the historical tradition, the city was founded in 582 B.C., by a group of settlers from Gela.

The building materials used for the temples come from different local quarries, among which *Villaseta* and *Casa San Filippo*. In detail, the *Villaseta* excavation exhibits at least two levels of rocks, different in the softness properties and in the clay content.

Segesta is an abandoned ancient town located in the province of Trapani. This large archaeological zone, with its magnificent Doric temple, is considered as one of the best-preserved Greek architectural sites. The temple of Segesta was built using travertine

rock. The samples of travertine have been drawn in the territory of Alcamo, a little town not far from Segesta where some quarries are still active. Beside its typical mechanical properties, the Alcamo travertine is very important also from a palaeontological point of view for the presence of several fossil remains, in particular a dwarf mammal (*Elephas falconeri* BUSK), and a giant tortoise.

Selinunte was founded in 651-650 B.C. and represented the western part of the Greek advance in Sicily. All the used materials are calcarenites and come from the Quarries of Cusa.

The quarries of Cusa are approximately 13 km far from Selinunte. They were used to extract the building materials of the town of Selinunte and of its temples. They were active from the 600 B.C. until the 409 B.C., when Selinunte was destroyed; since then the quarries remained intact and some cuts in cylindrical blocks are still visible (see more ahead). A large bank of calcarenite, parallel to the coast and almost 2 km long, forms the quarries. This bank is characterized from different veins of various hardness and mechanical resistance, and they were used for different applications in buildings. Through the historical-archaeological research it was possible to reconstruct the various operations for the quarrying and the transport of the blocks.

### **3. Geological sketch**

Samples and sites are referred to very different geological environments. Consequently, sedimentary settings have assigned peculiar mechanical features to rocks, certainly affecting the relevant hardness and workability characteristics. At this proposal, it should be very fascinating to dwell upon the ancient methods of cuttings and extraction of rocks from the quarries, the transport method towards the archaeological sites and, finally, upon the techniques of monument edification. Unfortunately, this is not the main purpose of the research to which this contribution belongs.

#### ***The Agrigento geological sites***

Quarries of “Villaseta” and “Casa San Filippo” localities, that have supplied the archaeological site of Agrigento, are not far from the all over the world famous “Valle dei Templi”. Both the arenaceous formation are called *Formazione di Agrigento* [2] and they are constituted by more or less rough calcarenites, lower Pleistocene aged, with crossed stratification and sand interbeddings. This lithology contains common microfossils and malacofaunas as *Arctica Islandica*. Temples area remains on the same arenaceous basement and, partially, on marly-clayey and more recent alluvial terraced formations (respec-

tively belonging to lower Pleistocene and Holocene ages). Marly-clayey deposits (*Formazione di Monte Narbone*), upper-middle Pliocene aged, occur below these formations, posing serious problems of stability for the Agrigento town and for the same archaeological area. The known landslide phenomena, due to the regression of the calcarenite front, represent an effective risk condition for the whole Agrigento region.

### ***The Alcamo geological site***

Travertine quarries are located north of the Alcamo village, relatively far from the Segesta archaeological area (about 10 km). The importance of this calcareous rock is testified, besides the notable mechanical properties, by the large occurrence in most of the territory on which the urban area of Alcamo is largely expanded. This very recent sedimentary rock (Holocene), chemically originated, generally presents minute laminations and numerous vacuoles, these last ones longed following the bedding trend [3]. Travertine commonly shows fossil forms as algal and vegetable rests, sometimes vertebrates. In particular, the Alcamo travertines may include eggs of terrestrial turtles.

The geological features of the Segesta archaeological site are fairly different from the quarry location. Outcrops of limestones, prevalently calcilutites with chert (*Scaglia*), occur in most of the mountainous area on which Greeks elevated the temple and the amphitheater.

### ***The Cusa geological site***

The Cusa quarries, 13 km west of Selinunte, are about 3 km far from the Mediterranean Sea. Here geological deposits, belonging to Holocene-Pleistocene age, occur, formed by calcarenite sediments [4]. The whole arenaceous outcrop is very conspicuous, covering a very large area with very different characteristics of hardness. Instead, the archaeological site rests on a terraced formation, locally named *Selinuntiano* (basal level of the Pleistocene), and largely diffused along a continuous coastal belt extended for many kilometers in South-West Sicily.

Locally, the Cusa arenites present the best mechanical properties of the neighborhoods: the ancient people selected accurately them for the edification of the biggest elements of the old town, as columns. For minor exigencies of buildings, Greeks used closer quarries (*Latomie*), where the rock presented worse mechanical properties. Calcarenite was extracted for 150 years, up to the successive, Carthaginian domination. As a matter of fact, Punic civilization neglected the quarries, leaving them in the same conditions as at the time of the sudden abandon by Greek people.

Selinunte is the most extended archaeological park of the whole Mediterranean region. Overcoming the same geological interest, this area has been intensely studied under the seismological point of view. Indeed, besides the tremendous earthquake that has shaken the Belice valley (1968), archaeo-seismological analyses have interpreted the collapse of the seven temples as the result of two strong telluric events.

#### 4. Materials and methods

Samples coming from the different quarries were collected (fig. 1). Table 1 reports sampling site and lithology as well as the archaeological areas in which the stones were used to built temples and other dwellings.

Figs. 2 and 3 show also the stones collected in the quarries of Agrigento. The samples named *Calcarenite 1* and *Calcarenite 2* have been collected respectively in the upper and lower parts of the “Villaseta” quarry (South-West of the actual Agrigento town). These outcrops correspond to different levels of rock, as indicated in the left picture of fig. 2. The *Calcarenite 3* sample has been collected in the “Casa San Filippo” quarry (eastern outskirts of town). The materials coming from these quarries were used to built, in the past, the Agrigento temples and recently for the restoration of columns.

Figs. 4 and 5 depict the quarries and the sampled stones relevant to Segesta and Selinunte archaeological areas.

Several measurements were performed over all the samples, using the methods and the below described techniques.

The mineralogical and geochemical characterization [5] was performed through X-Ray Diffractometry (XRD) and X-Ray Fluorescence (XRF) techniques.

*Table 1. Sampling sites and lithology.*

Sampling site	Lithology	Archaeological area
Villaseta (AG1)	Calcarenite 1	Agrigento
Villaseta (AG2)	Calcarenite 2	Agrigento
Agrigento (AG3)	Calcarenite 3	Agrigento
Alcamo (TP1)	Travertine 1	Segesta
Alcamo (TP2)	Travertine 2	Segesta
Cusa (TP3)	Calcarenite 4	Selinunte

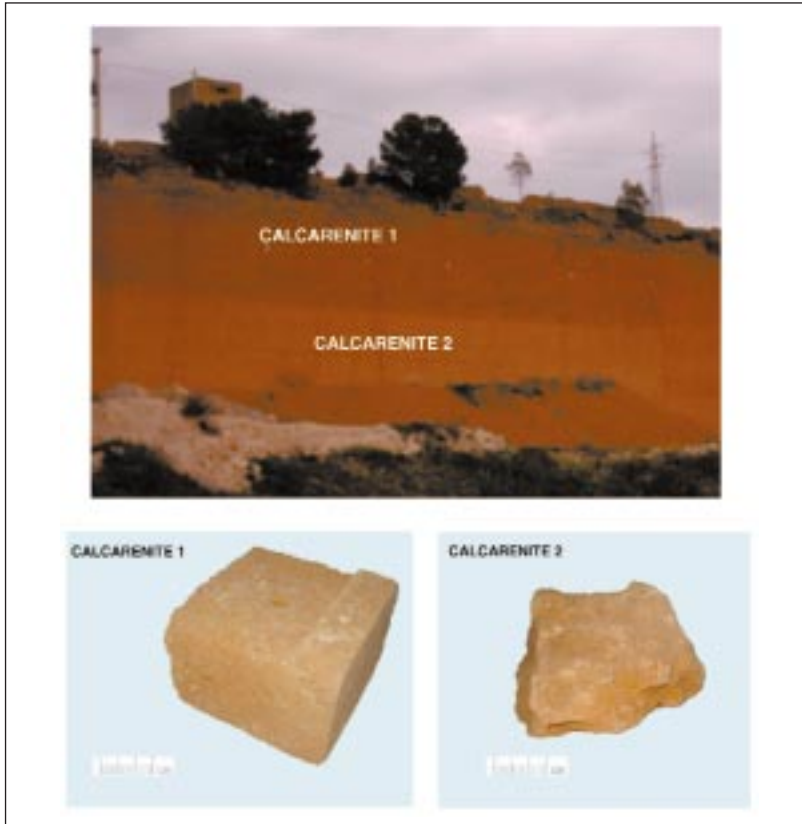


Figure 2. The "Villaseta" quarry. Below the samples collected respectively on the upper and lower parts of the quarry.

For the XRD and XRF analysis, all the samples were reduced in a powdery form consisting of fine grains of single crystalline material [6].

XRD measurements were carried out with a Philips XPERT diffractometer. A voltage of 40 KV and a current of 20 mA was applied at the X ray anode mated in Cooper material and the slit velocity was 2°/min.

XRF measurements were performed using a X-ray fluorescence instrument Philips PW 1400. The voltage range was 30-50 KV and the current is 30-50 mA. The X-ray anode is chromium-made for the light elements and wolfram-made for the heavy ones.

MRI measurements were executed at 30°C by means of ARTOSCAN (Esaote Italy), a tomograph consisting of a 0.2-T permanent magnet (15 mT/m maximum gradient inten-

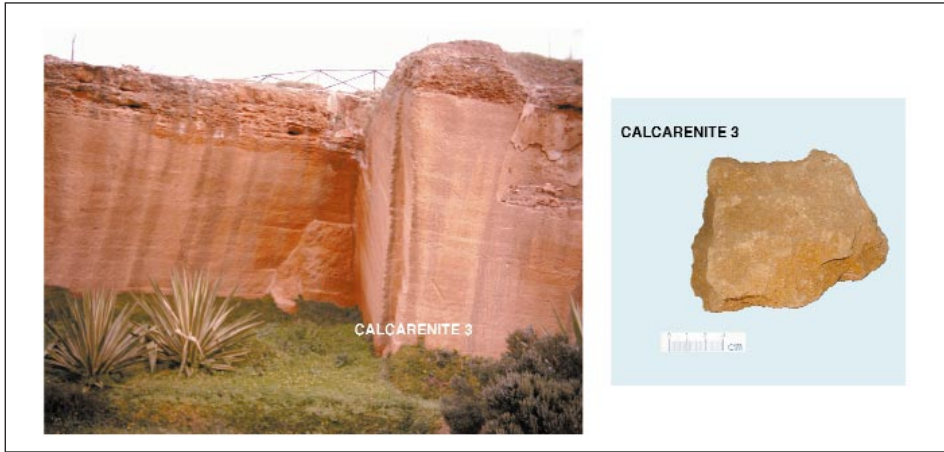


Figure 3. The “Casa San Filippo” quarry, on the left. The relevant sample is also shown.

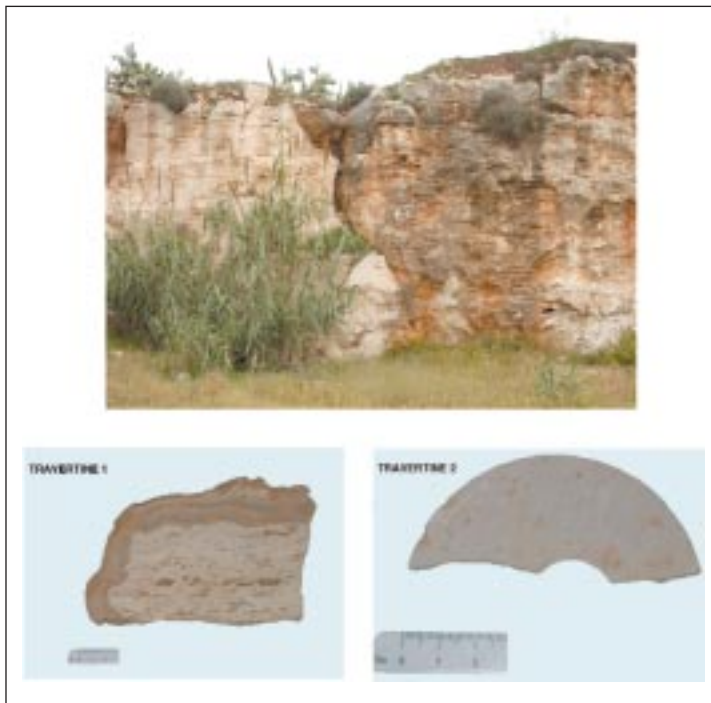


Figure 4. The “Alcamo” quarry. Below the two different samples. The sample marked as Travertine 2 was collected performing a core drilling.



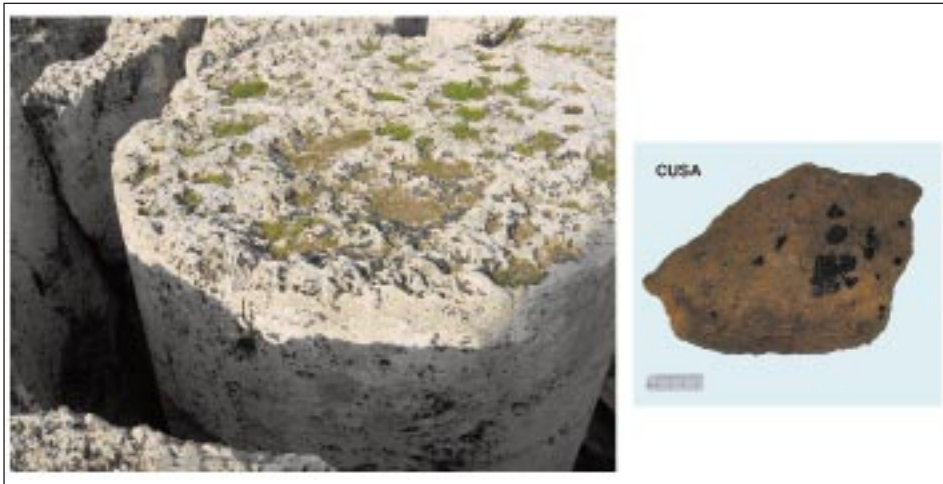


Figure 5. The “Cusa” quarry on the left will the relevant sample.

sity) corresponding to 8 MHz for  $^1\text{H}$ . Many adjacent sections (5 mm thickness) were acquired at the same time by multislice Spin Echo (SE) sequence with echo time  $T_E = 10$  ms and repetition time  $T_R = 900$  ms. The voxel size was  $0.5 \times 0.5 \times 5$  mm<sup>3</sup>.

NMR Relaxometry measurements were performed at the Larmor frequency of 20 MHz by means of a relaxometer based on a Jeol variable-field electromagnet equipped with Spinmaster, a NMR data station by Stelar (Mede, Pavia, Italy). Transverse relaxation decays were acquired by the Carr-Purcell-Meiboom-Gill (CPMG) pulse sequence. Longitudinal relaxation curves were acquired by Inversion Recovery sequences. Experimental curves were analyzed on the assumption of continuous distributions of relaxation times by means of UPEN, a uniform penalty inversion algorithm for multiexponential decay data [7].

For NMR Imaging (MRI) [8] samples of the same rocks were used. In particular, for the Agrigento samples, cylinders of 10 cm in diameter and 10 cm in height were extracted by core-drilling.

The samples used for imaging were wrapped in plastic film in all cases in order to prevent water evaporation during measurements. In particular, the *Travertine 1* sample was kept into the water during the measurement because of the large and numerous cavities.

For NMR relaxometry [8] small cylindrical plugs (7 mm in diameter and 7 mm in height) were cored from all the original samples. For both MRI and relaxation analyses, the samples were completely dried and then saturated under vacuum with distilled water.



The liquid excess was wiped off the small plugs with filter paper and put into the NMR tube for the relaxation measurements.

The interpretation of relaxation data in terms of “pore-size” distributions was done by a specific methodology described in the literature [9].

As an alternative method to investigate the structural porosity of rocks and to give further pieces of information on the absorption kinetics, Authors propose also the application of the X-ray Computerized Tomography (CT).

The CT imaging were performed by means of a Philips apparatus belonging to the Brilliance series. The voltage at the anode was setted to 140 kV value, and the current to 600 mAs. The continuous acquisition imaging was performed with the slice widths of 0.67 mm. The collimation of the radiative source was 40 mm x 0.625 mm.

The samples were cut in blocks 50x50x30 mm<sup>3</sup> of size.

Samples were settled in a plexiglas container, with an interposed filter papers wet with distilled water. The images were acquired in sequential times after contact with water.

## 5. Results and discussion

Table 2 presents the XRD data. The mineralogical characterization shows for all the samples a prevalence of calcite. Quartz and traces of clay are also present. Quartz exhibits variability in the different samples [10].

Table 3 reports the XRF values for each sample. The elemental analysis confirms the calcium abundance and, in agreement with the mineralogical data illustrated in table 2, the low levels of Si and Al. Among the other elements, iron is the most abundant. The light elements cannot be measured [10].

The phosphorous presence can be explained with the presence of fossils in the biocalcareneite.

*Table 2. XRD data.*

Sample	quartz	calcite	clay
AG1	++	+++	traces
AG2	++	+++	traces
AG3	+	+++	absent
TP1	absent	++++	traces
TP2	absent	++++	absent
TP3	+	++++	traces

Table 3. Content of elements expressed in % of oxides and corrected for L.O.I.

Sample	SiO <sub>2</sub>	TiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	P <sub>2</sub> O <sub>5</sub>	Fe <sub>2</sub> O <sub>3</sub>	MgO	MnO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O
AG 1	12.86	0.12	2.51	0.33	8.30	1.56	0.14	73.63	0.27	0.29
AG 2	24.72	0.16	3.13	0.33	8.74	1.57	0.12	60.52	0.13	0.58
AG 3	22.32	0.07	1.77	0.41	8.49	1.20	0.14	65.17	0.09	0.34
TP 1	1.22	0.03	0.78	2.32	0.27	0.13	0.13	95.08	0.00	0.04
TP 2	2.06	0.03	0.59	0.07	0.23	0.11	0.15	96.68	0.00	0.09
TP 3	6.84	0.04	0.75	0.23	1.79	1.35	0.16	88.69	0.05	0.11

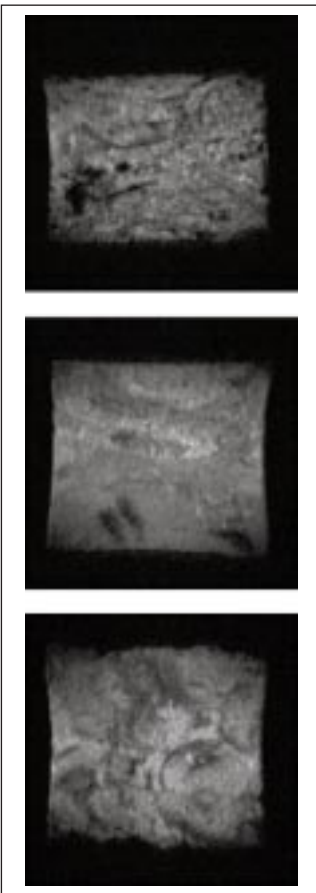


Figure 6. Inner MRI section of sample a) Calcarenite 1, b) Calcarenite 2, c) Calcarenite 3.

MRI was utilized to study the local structure in internal regions of the stones saturated by water. NMR Relaxometry gave information on the pore space structure at smaller scale than MRI [10,11]. In the figures relative to results obtained by NMR Relaxometry, the ordinate is  $(dS)/(d \ln T_1)$ , where S is percent of total signal (proportional to the number of <sup>1</sup>H nuclei), in such a way that areas under the curves are normalized to unit area.

The MRI images of the three samples from Agrigento are reported in fig. 6.

The relaxation measurements obtained on two plugs cored from each sample are reported in fig. 7.

The  $T_2$  distributions are similar to the  $T_1$  distributions, simply shifted to shorter times. The shape of the distributions reflects an heterogeneous pore space, covering three decades for  $T_1$  and four decades for  $T_2$ . Even if it is not right to think of sharp boundaries, it appears that two fractions of water may spend their NMR lifetimes confined in not well connected pore spaces, the one with higher and the other with smaller S/V ratio. In order to better compare the three samples, all the  $T_1$  distributions and the  $T_2$  distributions are collected in Figs. 8a and 8b, respectively.

The shape of the distributions does not show remarkable differences among samples. It is worth of note that relaxation measurements were obtained from drained plugs, after they had spontaneously lost water from the large pores connected to the outside. The distributions therefore describe only the water contained in the pores after the drainage, only weakly coupled with each other. So, the distributions in Figs. 8a and 8b show a very similar pore structure in the three samples at the length scale smaller than the sample

scale.

In fig. 9 a MRI section, representative of all the slices acquired on the Travertine 1 sample, is reported. In this case, in order to prevent the sample from emptying through the

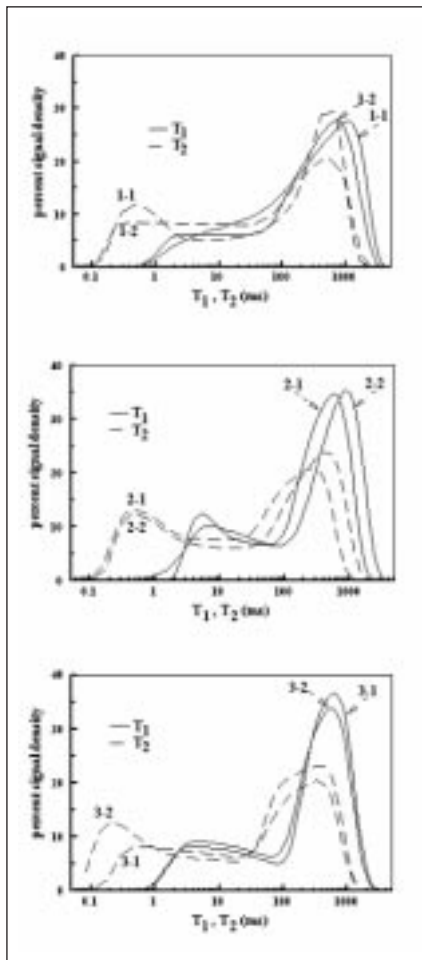


Figure 7. T1 and T2 distributions, for each pair of two plugs cored from the Agrigento samples. Solid lines are for T1, dashed for T2.

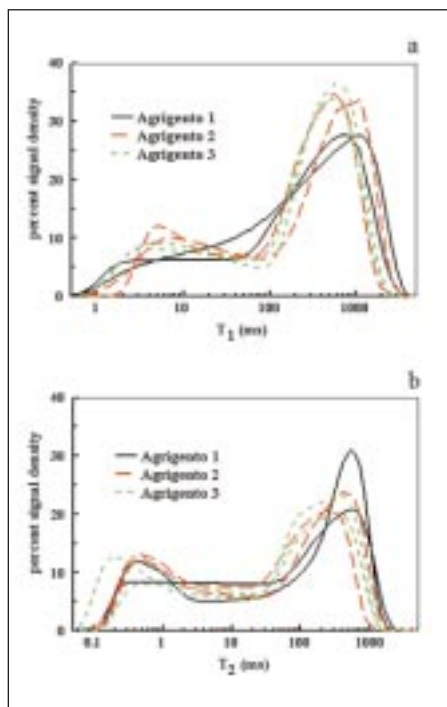


Figure 8. a) Relaxation time distribution functions of T1 for all the plugs (two plugs for each sample); b) Relaxation time distribution functions of T2 for all the plugs (two plugs for each sample).

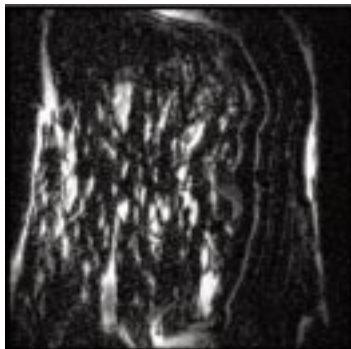


Figure 9. Inner MRI section of Travertine 1 sample.

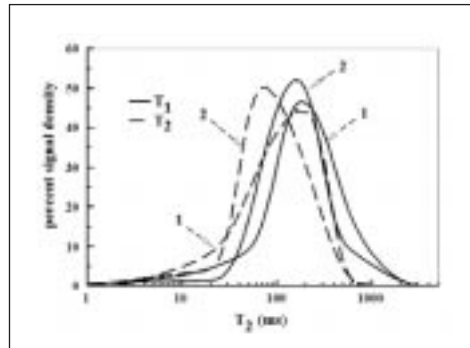


Figure 10. Relaxation time distribution functions of  $T_1$  and  $T_2$  (Travertine 1 sample).

large cavities, it was put into a plastic bag containing water. This sample presents two parts (see fig. 4): the former (A) has an alabaster appearance and originates from chemical precipitation of calcium carbonate only, the latter (B) is the travertine and originates from chemical precipitation of calcium carbonate with organic components (algal) that cause the making of vacuoles. Data in table 2 and 3 are referred to B part. In the image pixels corresponding to cavities with water appear bright. Water is also present between layers of the region with alabaster appearance.

NMR Relaxation measurements, reported in fig. 10, were performed on two plugs cored from Travertine 2, a more compact travertine sample (see again fig. 4), coming from a region deeper than Travertine 1. The distributions show a single peak, centered at about 200 ms for  $T_1$ , standing on a wide pedestal: about 80-90% of the signal is due to water in a single class of diffusion cells not well connected, or in slow exchange at the NMR relaxation time scale with the remaining fraction of water confined in higher or lower S/V pore spaces. The shapes of the distribution functions of  $T_1$  and  $T_2$  suggest a broad distribution of pore sizes. There are tails towards short and long times, likely showing small amounts of water in smaller and larger pores not well connected at the NMR time scale with the major broad peak.

In fig. 11 a MRI section, representative of all the slices acquired on Calcarenite 4 sample, is reported.

The sample appears very homogeneous both between slices and inside the same slice. The pore space structure of the samples can be investigated with a larger resolution power by means of the spatially-not resolved relaxation measurements.

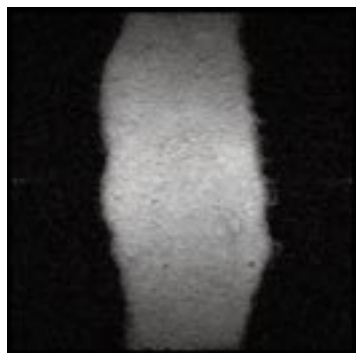


Figure 11. Inner section of Calacarenite 4 sample.

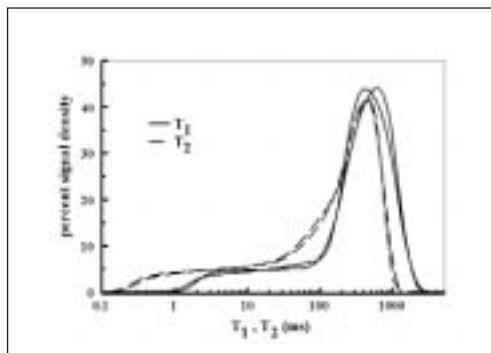


Figure 12. Relaxation time distribution functions of  $T_1$  and  $T_2$ .

In fig. 12  $T_1$  and  $T_2$  distributions of two small plugs cored from the sample are reported. Both  $T_1$  and  $T_2$  distributions for the two Calacarenite 4 plugs are wider than for Travertine 2 plugs. The samples appear to have a quite homogeneous structure, with a single class of low S/V pore spaces plus a low and wide tail that reveals the presence of high S/V pore spaces not well connected with the lower S/V pores.

The internal structure of some samples was also investigate with the CT imaging.

	SAMPLES	SAMPLE DRY	SAMPLE WET
AG 1			
AG3			
TP3			

Figure 13. Photos and CT images of three calcarenite samples.

The fig. 13 shows a photo of the calcarenite samples marked as AG1, AG3 and TP3. In the same figure the internal views of the same slice, acquired at different time, are also presented, second column shows the internal view of the dry samples, and third column the images of wet samples, acquired after  $t = 15$  min in water adsorption. The images of the wet samples are more intense.

The system of units represents a transformation from the original linear attenuation coefficient measurements into one where water assumes a value of zero and air has a value of  $-1000$ , while, for example, bones rich of calcium has H unit of  $+1000$ . If  $\mu_w$ ,  $\mu_{air}$ , and  $\mu$  are the linear attenuation coefficients of water, air and a substance of interest, the CT number of the substance of interest is:

$$H = 1000 \frac{\mu - \mu_w}{\mu_w - \mu_{air}}$$

It follows that a measurement of the Hounsfield value of the same portion of different slices, acquired in different times, can give information about a evaluation of adsorption kinetics in rocks. Moreover, considered samples of known porosity, from the Hounsfield value measured, it is possible to evaluate the pore size dimension of the material of interest. Our future working investigation is to compare CT resolution with MRI. The possibility to investigate the internal structure of porous materials will be also strengthened by the three dimensional views of the items (see fig. 14).

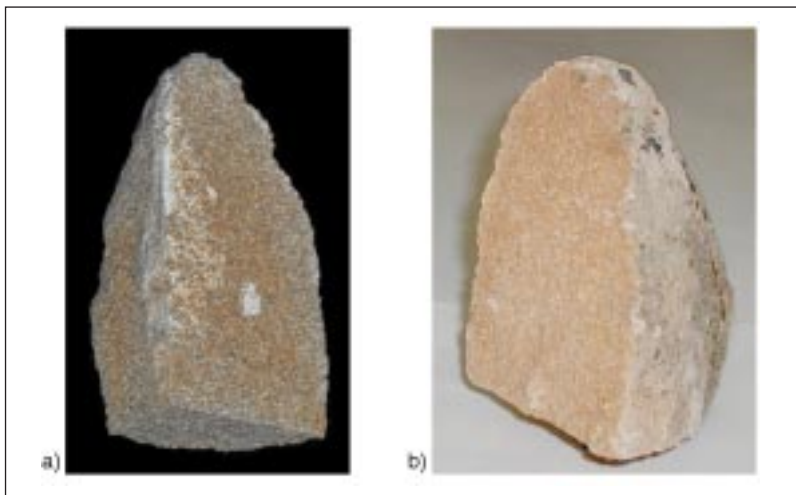


Figure 14. a) CT 3D reconstruction; b) Picture of the stone.

These preliminary surveys confirm the considerable heterogeneity of sedimentary rocks for porosity and for ability to trap water, also in the case of very similar mineralogical and chemical features [10]. The data obtained from different techniques can give a complete insight in order to select not invasive protective treatments. The preliminary results of the present paper will form the basis for the creation of a relational database on Sicilian sedimentary rocks of interest to study the health state of cultural heritages for eventual prevention and therapy.

### Acknowledgments

The authors wish to thank M. Mirabello (*Dipartimento di Fisica e Tecnologie Relative, Università degli Studi di Palermo*), C. Garavaglia (*Dipartimento di Fisica, Alma Mater Studiorum Università di Bologna*), F. Sorrentino (*Dipartimento di Biotecnologie Mediche e Medicina Legale, Università degli Studi di Palermo*) for technical assistance; P. Meli, Parco Archeologico di Agrigento, and the F.Ili Scirè quarries of Villaseta, Agrigento, for assistance in sampling.

### References

- [1] CIMINO A., ABBATE R., MANNINO G. 1990, *Prime indagini geofisiche per la tutela di un'area archeologica del Palermitano*. Ambiente, Salute, Territorio, 4, 1, 20-25.
- [2] SERVIZIO GEOLOGICO D'ITALIA 1972, *Carta geologica d'Italia a scala 1:50.000, Foglio 636 "Agrigento"*, Grafica Editoriale Cartografica, Roma.
- [3] UNIVERSITÀ DI PALERMO, DIPARTIMENTO DI GEOLOGIA E GEODESIA 1995, *Carta geologica a scala 1:50.000, Foglio 606 I.G.M. "Alcamo"*, Stabilimento L. Salomone, Roma.
- [4] SERVIZIO GEOLOGICO D'ITALIA 1976, *Carta geologica d'Italia a scala 1:500.000, Foglio 5 "Sicilia"*, Stabilimento L. Salomone, Roma.
- [5] RIZZO S., BRAI M., BASILE S., BELLIA S., HAUSER S. 2002, *Gamma Activity and Geochemical Features of Building Materials: Estimation of Gamma Dose Rate and Radon Level Indoors in Sicily*, Appl. Rad. Isot., 55, 259-265.
- [6] BARTOLOTTA A., BELLIA S., BRAI M., CASIERI C., DE LUCA F., FANTAZZINI P., MACCOTTA A., MORREALE F., RASO G., SCHILLACI T. 2004, *Caratterizzazione di materiali lapidei*, in Regione Siciliana (ed.), *Il teatro greco-romano di Taormina. Progetto pilota. Analisi, studi ed indagini, prima fase*, Palermo, 109-112.
- [7] BORGIA G.C., BROWN R.J.S., FANTAZZINI P. 1998, *Uniform-Penalty Inversion of Multiexponential Decay Data*, J. Magn. Reson., 132, 65-77.
- [8] BORGIA G.C., BORTOLOTTI V., CAMAITI M., CERRI F., FANTAZZINI P., FRATTINI F., PIACENTINI F. 2002, *Caratterizzazione strutturale di materiali porosi: un nuovo approccio mediante tecniche NMR*, in Patron Editore Bologna (ed.), ATTI del



- Secondo Congresso Nazionale dell'Assoc. Italiana di Archeometria, (Bologna, 29 gennaio - 1 febbraio), 135-150.
- [9] BORGIA G.C., BROWN R.J.S., FANTAZZINI P. 2000, *Uniform-Penalty Inversion of Multiexponential Decay Data II: Data Spacing, T2 Data, Systematic Data Errors, and Diagnostics*, J. Magn. Reson., 147, 273-285.
- [10] SCHILLACI T., BELLIA S., BRAI M., CAMAITI M., DI STEFANO C., FANTAZZINI P., MACCOTTA A. 2005, *Integrated techniques to study sedimentary rocks from Sicily used in cultural heritages*, in (ed), "Non-destructive testing and microanalysis for the diagnostic and conservation of the cultural and environmental heritage" Proceedings of the 8<sup>th</sup> International Conference (Lecce, 15-19 May 2005), digital support (article number 147).
- [11] BRAI M., CAMAITI M., CASIERI C., DE LUCA F., FANTAZZINI P., MACCOTTA A., MORREALE F., TRENZI C. 2005, *From laboratory to in-situ Nuclear Magnetic Resonance diagnostics: an application to building materials of the Greek-Roman theatre of Taormina*, in (ed.), "Non-destructive testing and microanalysis for the diagnostic and conservation of the cultural and environmental heritage" Proceedings of the 8<sup>th</sup> International Conference (Lecce, 15-19 May 2005), digital support (article number 140).

### Riassunto

In Sicilia sono presenti numerose unità geologiche, le quali forniscono al paesaggio una relativa complessità. L'origine è prevalentemente di tipo sedimentario. È ben noto che le rocce sedimentarie rispetto ai depositi metamorfici e vulcanici, possono presentarsi maggiormente tenere e, quindi, con una discreta facilità ad essere modellate.

Questa lavorabilità, caratteristica e vantaggio delle rocce sedimentarie, è tuttavia un inconveniente rispetto alla loro utilizzazione per il patrimonio culturale, poiché questi materiali evidenziano spesso un'elevata porosità, con distribuzione e dimensione dei pori che portano al loro deterioramento per assorbimento d'acqua.

In questa nota, si propone una classificazione di più rocce sedimentarie adoperate nei manufatti del patrimonio storico-culturale della Sicilia, dalla *Magna Graecia* ai giorni nostri.

La classificazione riguarda le caratteristiche mineralogiche, la composizione chimica e la porosità. Nel dettaglio, saranno presi in considerazione e caratterizzati, usando tecniche integrate (XRD, XRF, NMR e CT), campioni raccolti in cave appartenenti ai siti archeologici di Agrigento, Segesta e Selinunte.

I dati sui campioni ottenuti in laboratorio saranno confrontati con i corrispondenti valori misurati *in situ* sui monumenti di interesse storico-culturale ricadenti nelle citate località archeologiche.

### Summary

Sicily includes a great variety of lithologies, giving a high complexity to the geologic landscape. Their prevalent lithology is sedimentary. It is well known that rocks of sedimentary origin, compared with metamorphic and volcanic deposits, can be relatively soft and hence fairly easy to model. Nevertheless, this workability advantage is a drawback for Cultural Heritage applications. In fact, these materials show a high porosity, with pore-size distributions that lead to deterioration through absorption of water.

In this paper, several sedimentary rocks used in historical Cultural Heritage items of Sicily, from *Magna Graecia* to nowadays, are classified for mineralogical features, chemical composition, and for porosity. Particularly, some samples collected in quarries relevant to the archaeological sites of

Agrigento, Segesta and Selinunte will be considered and characterized using integrated techniques (XRD, XRF, NMR and CT).

Data on samples obtained in laboratory will be compared with the relevant values measured *in situ* on monuments of historical-cultural interest of the quoted archaeological places.

## Résumé

En Sicile sont présentes de nombreuses unités géologiques, lesquelles fournissent au paysage une relative complexité. L'origine est essentiellement de type sédimentaire. C'est bien connu que les roches sédimentaires, par rapport aux dépôts métamorphiques et volcaniques, peuvent se présenter plus tendres et, donc, avec une discrète facilité à être modelées.

Cette usinabilité, caractéristique et avantage des roches sédimentaires, est toutefois un inconvénient par rapport à leur utilisation pour le patrimoine culturel, étant donné que ces matériaux mettent en évidence souvent une porosité élevée, avec distribution et dimension des pores qui portent à leur détérioration par absorption d'eau.

Dans cette note, on propose une classification de plusieurs roches sédimentaires employées dans les ouvrages du patrimoine historico-culturel de la Sicile, de la Grande Grèce à nos jours.

La classification concerne les caractéristiques minéralogiques, la composition chimique et la porosité.

Dans le détail, seront pris en considération et caractérisés, en employant des techniques intégrées (XRD, XRF, NMR et CT), des échantillons recueillis dans des carrières appartenant aux sites archéologiques de Agrigente, Ségeste et Sélinonte.

Les données sur les échantillons obtenus en laboratoire seront confrontées avec les valeurs correspondantes mesurées *in situ* sur les monuments d'intérêt historico-culturel retombant dans les localités archéologiques citées.

## Zusammenfassung

In Sizilien sind viele geologische Einheiten, die die Landschaft ziemlich komplex machen. Die Herkunft dieser Einheiten ist hauptsächlich sedimentär. Es ist weit bekannt, dass die sedimentären Steine im Vergleich mit den metamorphen und vulkanischen Ablagerungen weicher sein können und deswegen können sie relativ einfach geformt werden.

Dennoch ist die Tatsache, dass diese Steine einfach zu formen sind, nicht nur ein vorteilhafter Merkmal der sedimentären Steine, sondern auch einen Nachteil, was ihre Verwendung für das Kulturgut angeht, weil diese Materialien oft sehr porös sind, und die Verteilung und die Größe verursachen ihr Verderben wegen der Absorption von Wasser.

Hier ist eine Klassifizierung von verschiedenen sedimentären Steinen, die in den Artefakten des Geschichts- und Kulturgutes von Sizilien, von der Magna Graecia bis zur unseren Zeit benutzt wurden.

Die Klassifizierung betrifft die mineralogischen Merkmale, die chemische Zusammensetzung und die Porosität. Insbesondere werden einige Muster betrachtet und charakterisiert, die aus Gruben in den archäologischen Ausgrabungsstätten von Agrigento, Segesta und Salinunte gewonnen wurden, es werden dabei integrierte Techniken angewandt (XRD, XRF, NMR und CT).

Die Daten über die Muster im Labor werden mit den entsprechenden Werten verglichen, die vor Ort aus historisch und kulturell interessanten Denkmälern in den obengenannten Ausgrabungsstätten gemessen wurden.

## Resumen

Sicilia presenta numerosas unidades geológicas, que dan al paisaje una relativa complejidad. El origen es predominantemente de tipo sedimentario. Es bien sabido que las rocas sedimentarias, con respecto a los depósitos metamórficos y volcánicos, suelen presentarse blandas y ofrecen, con ello, una cierta facilidad para ser modeladas.

Esta modelabilidad, característica y ventaja de las rocas sedimentarias, es sin embargo un inconveniente en lo que se refiere a su uso para el patrimonio cultural, ya que, en cuanto materiales, a menudo muestran una elevada porosidad, con poros que, por su tamaño y distribución causan el deterioro por absorción de agua.

En esta nota se propone una clasificación de diversos tipos de rocas sedimentarias utilizadas en las obras del patrimonio histórico-cultural de Sicilia, de la Magna Graecia a nuestros días.

La clasificación atiende a las características mineralógicas, la composición química y la porosidad. En particular, se tomarán en consideración y se caracterizarán, mediante técnicas integradas (XRD, XRF, NMR y CT), muestras recogidas en canteras pertenecientes a los sitios arqueológicos de Agrigento, Segesta y Selinunte.

Los datos en las muestras obtenidas en laboratorio se compararán con los valores correspondientes medidos in situ en los monumentos de interés histórico-cultural pertenecientes a las citadas localidades arqueológicas.

### **Резюме**

На Сицилии находятся многочисленные геологические элементы, придающие пейзажу этой местности соответствующее многообразие. Происхождение этих элементов, по большей части, - осадочное. Хорошо известно, что осадочные горные породы, по сравнению с метаморфическими и вулканическими отложениями, могут быть более ломкими, и потому, достаточно легко обрабатываемыми. Эта хорошая обрабатываемость, представляющая собой особенность и преимущество осадочных пород, тем не менее, является дефектом при их использовании в культурном наследии, т.к. эти материалы часто имеют повышенную пористость; расположение и размер пор приводят к разрушению материала, т.к. он впитывает воду. В этой заметке предлагается классификация многих осадочных пород, использованных в постройках культурно-исторического наследия Сицилии, со времен Великой Греции до наших дней. В классификации рассматриваются такие параметры, как минералогические свойства, химический состав и пористость. Подробно будут рассмотрены и охарактеризованы, при совокупном использовании техник (XRD, XRF, NMR и CT), образцы, взятые из карьеров археологических раскопок Агридженто, Сегесты и Селинунте. Полученные в лаборатории данные будут сопоставлены с соответствующими значениями, установленными при исследовании памятников, представляющих культурно-историческую ценность и располагающихся в выше названных археологических зонах.