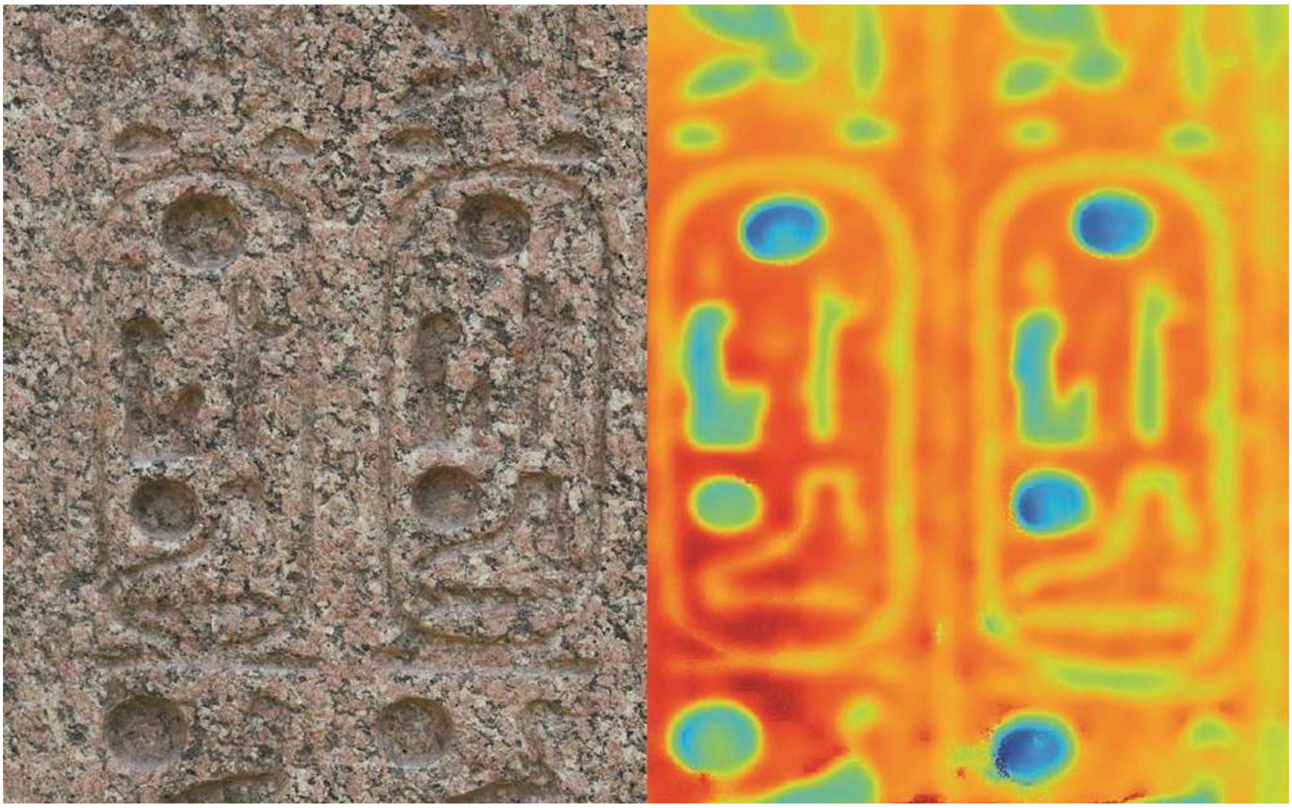
Sciences and Technologies applied to Cultural Heritage I (STACH 1)



Editors:

Marina Baldi and Giuseppina Capriotti Vittozzi

CONSIGLIO NAZIONALE DELLE RICERCHE

CENTRO ARCHEOLOGICO ITALIANO – ISTITUTO ITALIANO DI CULTURA

Italian - Egyptian Workshop on Sciences and Technologies applied to Cultural Heritage I (STACH 1)

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A cura di:
Marina Baldi e Giuseppina Capriotti Vittozzi

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Elaborazione del modello di elevazione digitale. *Fonte: CNR-MEM, Multidisciplinary Egyptological Mission*

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FOREWORD

This volume contains the proceedings of the Italian - Egyptian Workshop on Sciences and Technologies applied to Cultural Heritage I (STACH 1), held in Cairo (11-12 December 2016), and organized by The Italian Archaeological Centre of the Italian Cultural Institute in Cairo (CAI – IIC) in collaboration with the Italian National Research Council (CNR).

The workshop, organized in the framework of the activities of the CAI – IIC, represented the final event of the Italian-Egyptian Suez MultidisciplinaryLab (IESM Lab) of ISMA – CNR. It had also the function of training for young archaeologists and scientists of the Ministry of Antiquities of the Arab Republic of Egypt and for students from the Istituto Tecnico "Don Bosco" in Cairo.

The objective of the workshop was to open a wide and integrated view on sciences and technologies applied to Cultural Heritage, in particular to Egyptian Archaeology, and included several topics ranging from Archaeology, to Climate and Meteorology, Spectroscopy, Biology, Chemistry, Satellite Remote Sensing, Photogrammetry, Geophysical survey, IT/ICT.

In total 40 Scientists, 20 Italian, and 20 Egyptian, participated to the workshop, making it a unique experience and the basis to strengthen the collaborations between Italian and Egyptian research teams, continuing the road open by the Italian-Egyptian Workshop "Archaeology and Environment" (Aswan, November 2013) and the very important meeting of 100 Italian and Egyptian researchers hold in Turin (June 2015), strongly sustained by the former President of the National Research Council of Italy and the Egyptian Ministry of Scientific Research. The workshop was also the opportunity to display some features of the Italian archaeological work in Egypt following the path of the conference "Italian Research on Egyptology: from Ippolito Rosellini to current archeological projects" (Cairo, October 2014), organized by Paolo Sabbatini, Director of the Italian Cultural institute.

The program included the presentation of ongoing joint research project among Italian and Egyptian Institutions, as well as novel results recently achieved. This volume contains material from a selection of the Workshop lectures, ranging from archaeology, to environment, to observation technologies as satellite remote sensing, and analysis of materials with conservation techniques. In particular, the session on archaeology illustrated research results on the important area of the Suez Canal, focused by the Ministry of Antiquities through the Suez Project.

In this respect the volume represents a milestone of the Italian-Egyptian collaboration in a number of important research topics, and its publication aims to strengthen the cooperation and make the basis for future fruitful discussion among scientists from the two Countries in disciplines apparently diverse, but connected.

Marina Baldi Giuseppina Capriotti Vittozzi

FIRST OUTCOMES OF THE NRC-CNR BILATERAL PROJECT "JOINT INSTRUMENTAL INVESTIGATION OF MUSEUM COLLECTIONS AS A MEANS OF ENHANCING CULTURAL HERITAGE AND STRENGTHENING INTERDISCIPLINARY COLLABORATION"

F. Aatia(1), A. Angelini(2), G. Capriotti Vittozzi(3)(4), M. Ferretti(2), M. Ibrahim(1), A-A. Mahmoud(1), O. Osman(1), A. Refaat(1)

(1) National Research Centre, Spectroscopy Department, Dokki, Giza, Egypt.
(2) Consiglio Nazionale delle Ricerche, Istituto per le Tecnologie Applicate ai Beni Culturali (CNR-ITABC), Montelibretti (RM), Italy.
(3) Consiglio Nazionale delle Ricerche, Istituto di Studi sul Mediterraneo Antico (CNR-ISMA), Montelibretti (RM), Italy.
(4) Ministero degli Affari Esteri e della Cooperazione Internazionale, Ambasciata d'Italia - Il Cairo, Centro Archeologico, Cairo, Egypt.

Abstract
Since long, it has been proved that instrumental analysis of the constituent materials provides essential insight for a better understanding of cultural heritage artefacts. This involves having both natural and human sciences work together, and requires considerable communication and cooperation skills among scholars with different cultural backgrounds.
As an example of field collaboration among archaeologists, restorers, art historians and natural scientists, this paper presents the first outcomes - achieved in Egypt on Coptic icons and in Italy on archaeological metal artefacts - of the NRC-CNR bilateral project "Joint instrumental investigation of museum collections as a means of enhancing cultural heritage and strengthening interdisciplinary collaboration". The project has provided the framework to establish a common ground of cultural and scientific cooperation, which is expected to produce further results in 2017, second and last year of the project.

Introduction

Since long, instrumental investigation of ancient artefacts has been used for a deeper understanding of material cultures. For example, the first analyses of archaeological metals date back to the end of the XVIIIth century[1]. Nonetheless, only in relatively recent times, these researches have achieved the dignity of the autonomous discipline known as "Archaeometry". It aims at answering such questions as how, where and when artefacts were made, how were they used, what are their trading routes, and what are the archaeological implications of their presence in a given context.

Archaeology, however, is not the only discipline that may take advantage from instrumental investigation of ancient materials. Conservation and restoration as well require understanding ancient

[1] POLLARD *et al.* 2007.

artefacts, their deterioration, their interactions with the environment and the materials, and methods used for their conservation. As the methods and skills used by "Conservation Science" are basically the same as those of Archaeometry, the comprehensive term "Heritage Science"[2] is also used to refer to the application of natural sciences for the study and conservation of cultural heritage.

Independently on terminological distinctions, in all cases we are in the presence of multidisciplinary environment populated by art historians, archaeologists, conservators-restorers and natural scientists. It is a culturally contaminated environment, potentially capable of producing a huge amount of knowledge.

Unfortunately, it is in everyone's daily experience how difficult communication and cooperation can be. This is certainly due to different cognitive approaches and languages, but sometimes also due to mistrust and cultural autism. It is our opinion that such an unproductive vicious circle is mainly related to the fact that scholars often work apart from one another and lack confrontation.

The project discussed in this paper has been carried out in the framework of a bilateral agreement between the National Research Council of Italy and the National Research Centre of Egypt. Though within the boundaries fixed by limited funding and duration, it aims at fostering effective cooperation and confrontation among scholars from different disciplines by putting them at work together.

It provides an environment, *i.e.* a museum or a conservation laboratory, in which archaeologists, conservators-restorers and natural scientists share both the purpose of the work, *i.e.* the *in situ* investigation of a group of artefacts, and the physical space where it is carried out. Museums and conservation laboratories also provide a unique framework in which cultural heritage is promoted and cultural identity is strengthened by inviting the general public to attend small conferences and experiments, and use educational materials. Fieldwork was done in the Municipal Archaeological Museum in Milan and in the Conservation Laboratory of Palazzo Altemps in Rome.

This paper deals with the first year outcomes of the project and is concerned with the scientific results of the investigations. Subsequent dissemination and promotion activities will be discussed in a future paper.

Investigation techniques

The investigation techniques used for the experimental activities are X-ray Fluorescence, Molecular Modelling and Digital Photogrammetry.

X-ray Fluorescence is based on the possibility of producing electronic transitions in the inner shells of the atoms by irradiating the investigated material with electromagnetic radiation of suitable energy. Such transitions may result in the emission of X-rays whose energy is characteristic of the emitting

[2] www.erihs.fr/, 30 October 2017.

element, whereas the intensity of emission is related to its abundance in the sample. It is non-destructive and therefore particularly suitable for heritage materials[3].

Molecular Modelling is a computer-based simulation technique relying on the possibility of predicting the physical properties of materials and the interactions among molecules by solving the quantum mechanical equations governing their constituent electrons. The application of this technique based on molecular spectroscopy is of interest for the study of painting materials, in particular for understanding deterioration processes[4].

Digital Photogrammetry is a surveying technique based on the principles of multi-stereo vision[5], aimed at creating a high-resolution 3D numerical model of a given object. As data acquisition is simply performed by a digital camera, it can be an effective alternative to other more complex techniques, for instance laser scanner, in severe environmental conditions, such as archaeological excavations. The method used in the present research is based on the stereoscopic acquisition of 3 images. The space forward intersection allows to reach inaccessible points starting from 2 projections oriented on the same subject.

Experimental activities

Non-destructive X-ray Fluorescence analyses were performed by means of portable equipment in the Municipal Archaeological Museum in Milan and in the Conservation Laboratory of Palazzo Altemps in Rome.

The analyses carried out in Milan concerned a group of metal artefacts from ancient Egypt, belonging to the Ruffini collection (Fig.1). The purpose was to obtain information about the composition of the alloys and, where possible, about the manufacturing technique. All steps of the work were done in cooperation with a conservator-restorer who advised about the most significant areas of the artefacts and contributed to data interpretation.

The most interesting pieces are the statuettes identified with D and F in Fig.1. Statuette F is made of bronze, containing 88% copper, 11% tin and 1% lead. It is leaf-gilded; the thickness and the composition of the gilding are approximately 1 μm and 97% gold, 3% Ag, respectively. The eyes are made of a vitreous paste opacified with antimony. Also statuette D has the eyes made of a different material, in this case they are made of silver. Some of the artefacts (A, B, C and D) show unrealistically high amounts of tin and lead, which is supposedly due to their deeply corroded surfaces.

The analyses carried out in Rome concerned a group of proto-historical metal artefacts in course of restoration (Fig.2). In addition, a 3D survey of the object was carried out by Digital Photogrammetry for documentation purposes. Once again, the work was done in cooperation with a conservator-

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[3] Ferretti 2014.
[4] Karapanagiotis *et al.* 2009.
[5] Remondino – El-Hakim 2006.

restorer who discussed with the scientists about the most relevant aspects of the artefacts and the results of the measurements.

Fig.3 shows the results of X-ray Fluorescence analyses. It is immediately apparent that the artefacts can be distinguished according to the metallurgical know-hows. Objects E, F and G are made of almost pure copper, whereas the other are made of tin bronze. The second consideration is that at least one (object I) of the composite pieces H and I is made from sheets of different composition, possibly recycled from different pre-existing artefacts. The final remark is that the alloys of objects A, B, C and D, which pertain to a completely different context, show lower lead concentrations compared to the others. This aspect needs to be further investigated, however one of the possible explanations is that these pieces were subjected to repeated cycles of hammering and annealing more than the other pieces.

Digital Photogrammetric acquisitions were performed by a Canon 5D mark II digital reflex camera equipped with Canon 28mm/50mm optics. The camera was mounted on an aluminum bar placed at 0.5m from the surveyed object. The baseline of the three cameras was set at 0.1m. According to the Mencisoftware table, in this condition the accuracy of the points is 0.2mm[6]. The resulting high resolution 3D numerical model provided a quantitative representation of the objects, including important details of the execution technique (Fig.4). The RGB values provided by the camera sensor were used to map the model and highlight the details of the plate.

Molecular Modelling simulations were carried out to investigate the possible reasons for the fragility of painting layers in Coptic icons. In particular, we simulated the interactions between the metal oxides, such as Al_2O_3, Fe_2O_3 and ZnO, supposedly contained in the pigments, and the aspartic amino acid, supposedly contained in the binder (egg yolk), in adsorbed and complex states, with and without hydration. The model, built according to previous studies, was calculated with the GAUSSIAN09 program[7], installed on a workstation at the Spectroscopy Department, National Research Centre of Egypt, and optimized by the Density Functional Theory method[8].

Figs.5a-b show three metal oxides, namely Fe_2O_3, Al_2O_3 and ZnO, interacting with aspartic amino acid without and with hydration, respectively. The interaction takes place through hydrogen bonding of COOH and NH_2. The first carboxyl group is bridging onto Al_2O_3 while the second is bridging onto Fe_2O_3. ZnO is supposed to interact with aspartic acid through one hydrogen of NH_2 group. When hydration takes place, 7 water molecules form a weak interaction (Fig.5b). Technical details are given elsewhere[9]; here we want to remark that the structure remains reactive even after hydration with 7 water molecules and is potentially capable of causing severe deterioration in a painting layer.

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[6] ANGELINI *et al.* 2016.
[7] FRISCH *et al.* 2010.
[8] BECKE 1993, LEE *et al.* 1988, MIEHLICH *et al.* 1989.
[9] MAHMOUD *et al.* 2018.

Conclusions

A two-years research project, aimed at strengthening interdisciplinary collaboration among archaeologists, conservators-restorers and natural scientists, has been discussed with regard to the first-year achievements. These mainly concern the results of experiments carried out by natural scientists in close collaboration with conservators-restorers. Such collaboration allowed a deeper understanding of each other's point of view and language, and set the stage for future interdisciplinary work.

The investigations carried out in the Municipal Archaeological Museum in Milan and in the Conservation Laboratory of Palazzo Altemps in Rome concerned a group of bronze statuettes from ancient Egypt and a group of protohistoric bronze artefacts from excavations in Central Italy.

X-ray Fluorescence analyses highlighted the use of different materials, namely leaf gilding, vitreous paste and silver, to obtain chromatic effects in the artefacts from ancient Egypt. Compositional differences in the constituent parts of composite objects (the miniature double shields) from Central Italy show that they were made by recycling pre-existing bronze sheets from different objects. The latter group of artefacts was also graphically documented by digital photogrammetry.

Molecular Modelling simulations were used to describe the interaction between aspartic amino acid, contained in the binder of a painting layer, and aluminum, iron and zinc oxides, contained in the pigments. According to the calculations, the total dipole moment of the resulting coordination compound increases, thus increasing its capability to interact with the environment, in particular with water from environmental humidity. This interaction may cause severe deterioration of the painting.

Continuation of the project will include further experiments. The main concern, however, will be the dissemination of the results to the general public and specialists through small conferences, seminars and training activities.

Acknowledgements

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Fig.1 - Ancient Egyptian artefacts from the Municipal Archaeological Museum in Milan analysed by X-ray Fluorescence.

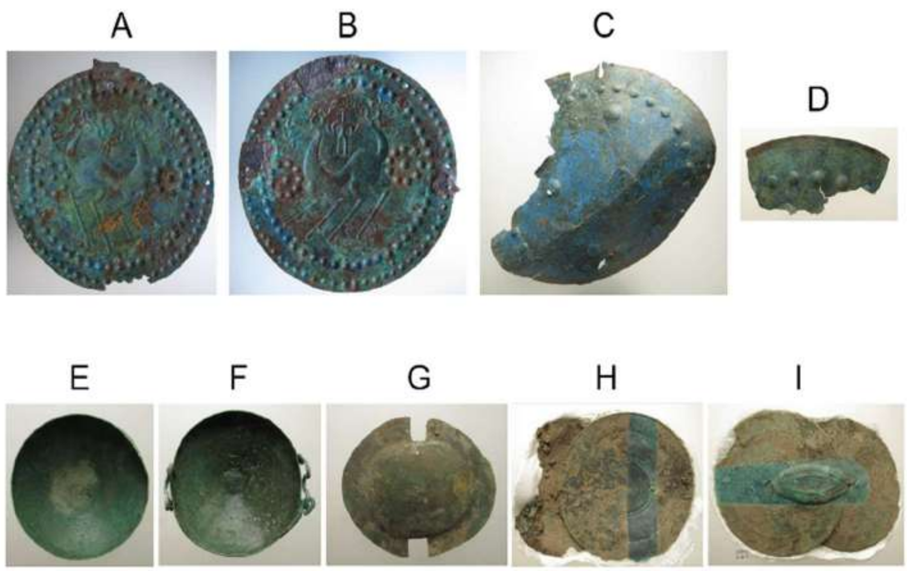

Fig.2 - Proto-historical artefacts from the Conservation Laboratory of Palazzo Altemps in Rome analysed by X-ray Fluorescence and documented by Digital Fotogrammetry.

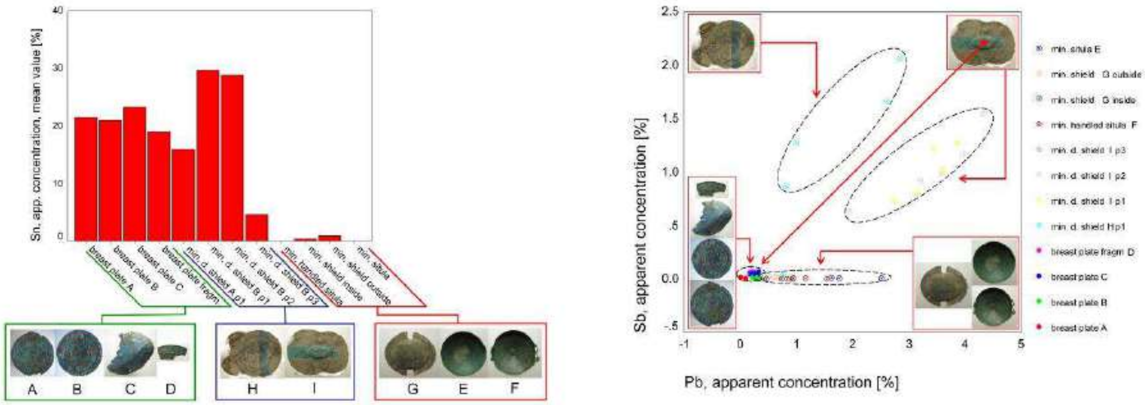

Fig.3 - Results of the X-ray Fluorescence analyses on the proto-historic artefacts. Left: distribution of the tin content. Right: scatterplot of lead vs. antimony content.

Fig.4 - Results of the Digital Fotogrammetry survey on the proto-historic artefacts: example of the 3D rendering of object A.

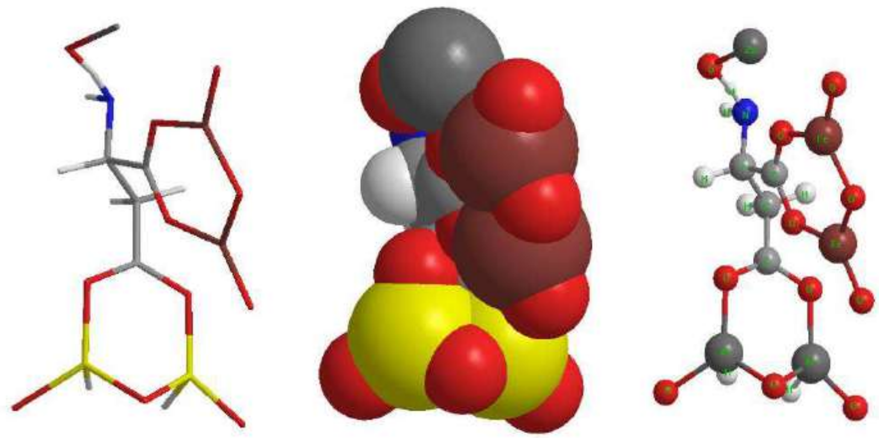

Fig.5a - Results of Molecular Modelling simulations: iron, aluminum and zinc oxides interacting with aspartic amino acid without water molecules.

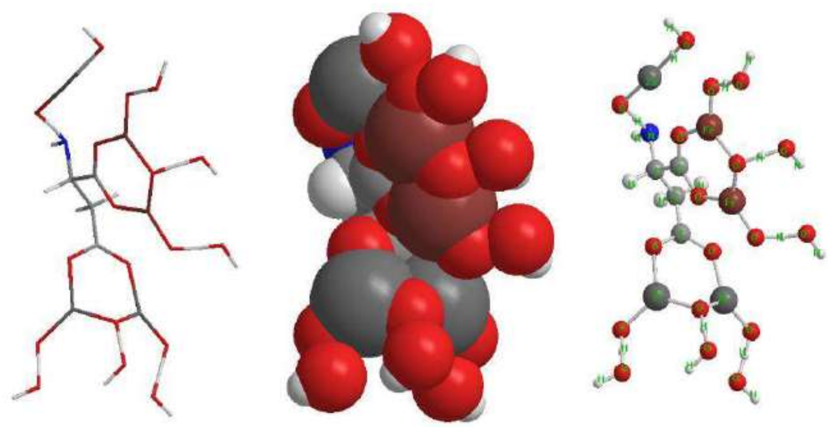

Fig.5b - Results of Molecular Modelling simulations: iron, aluminum and zinc oxides interacting with aspartic amino acid with water molecules.

STRATEGIES FOR PROTECTION OF METALLIC CULTURAL HERITAGE IN THE FRAME OF ITALY-EGYPT COOPERATION

E. Angelini (1), S. Grassini(1), M. Parvis(2), E. Di Francia(1), L. Iannucci(2), L. Lombardo(2), V. Gouda(3)

(1) Dipartimento di Scienza Applicata e Tecnologia, Politecnico di Torino, Italy

(2) Dipartimento di Elettronica e Telecomunicazioni, Politecnico di Torino, Italy

(3) National Research Center, Cairo, Egypt

Abstract

The project described is devoted to the development of tailored strategies for the safeguard and valorisation of the metallic artefacts stored in the basement of the Egyptian Museum of Cairo, Egypt. It is financially supported by the Egyptian Ministry of Scientific Research and the Italian Minister of Foreign Affairs in the frame of a long-lasting cooperation between Italy and Egypt in the field of Cultural Heritage, established through common European INCO-Med projects.

The artefacts displayed in museums, galleries, storage rooms, etc., are affected by environmental physical and chemical factors that may constitute a threat for their conservation. Continuous control and monitoring are needed to contrast the artefacts degradation, accelerated by adverse environmental conditions as pollution or poor conservation practices. Most of the artefacts stored in the basement of the Egyptian Museum have neither been catalogued, nor submitted to any chemical-physical analysis, and left for tenths of years in an uncontrolled storage environment. This huge collection of Egyptian antiquities, composed of more than 140.000 artefacts produced in 5000 years, includes objects belonging to the royal dynasties and to every-day life (statues, stele, coffins, stones, etc.); the metallic artefacts include more than 100.000 coins, bronze statues, iron and copper tools, funerary objects.

In order to plan tailored safeguard and valorisation strategies, it is mandatory to catalogue the artefacts with respect to their conservation state, production technology and degradation causes in order to suggest proper restoration and conservation materials and methods. To this aim a survey of the metallic artefacts is running in order to relate the corrosion products with the artefact chemical composition and the environmental parameters. A monitoring system suitable for assessing the environmental conditions in the basement and inside the exhibition showcases, has been developed. It is composed of sensing nodes for temperature (T) and relative humidity (RH), able to work in absence of wiring both for energy and for signal transmission and to transmit data without opening the showcases. Moreover, data receivers and concentrators have been designed and deployed in the basement to receive the T and RH values, and send them through a wired/wireless connection. The proposed system belongs to the smart and low-cost methodologies designed to facilitate widespread monitoring and to prevent damaging effects on the artefacts on display. The preliminary results are

a promising starting point for the development for conservation strategies, that evaluate the impact of the whole environment on the artefacts.

Introduction

Environmental monitoring is extremely important to ensure a safe and healthy life both to human beings and to Cultural Heritage artefacts. As a matter of facts, conservation of ancient metallic artefact displayed inside museums is a complex problem due to the large number of constraints mainly related to the artefacts fruition by wide public. The development of a simple procedure for monitoring the artefact conservation state promptly highlighting risky conditions without impacting on the normal museum operations is of interest in the Cultural Heritage field.

This paper describes the results obtained using a highly sensitive and innovative methodology for evaluating the safety level of the museum indoor areas, in particular of the basement of the Egyptian Museum of Cairo, with respect to the metallic artefacts.

The Egyptian Museum of Cairo is located in Tahrir Square, Cairo. Its basement occupies an area of 5000 m^2, divided into 40 storage rooms. The basement is currently used as a general storage area for the museum. It houses a vast collection of Egyptian antiquities, more than 140.000 artefacts, dating from as early as the Pre-dynastic Period (ca. 3500 B.C.) and as late as the Byzantine period (A.D. 641), and covering about 5000 years of Egyptian civilization. Since the inauguration of the museum in 1902, the basement has received objects in nailed wooden boxes; these objects were excavated from different sites in Egypt by Egyptian and foreign expeditions. Very often, the name of the site or the expedition and sometimes the date, were the only recorded information written in thick black ink on the boxes. Objects belonging to the royal dynasties and to every-day life as statues, stelae, coffins, vessels of pottery and stone, weapons, amulets, seals, scarabs, ushabti figurines, and so on, may be found. The metallic artefacts include more than 100.000 coins, bronze statues, iron and copper tools, funerary objects.

Most of the artefacts stored in the basement have neither been catalogued, nor submitted to any chemical-physical analysis, and left for tenths of years in an uncontrolled storage environment. A detailed survey is now running starting from the metallic artefacts in critical situations; the artefacts details are entered in the museum’s database, thus enabling the retrieval of information regarding any item both electronically and manually. Chemical-physical analyses are going on in order to identify the degradation mechanisms and establish best practices for the cultural heritage management, taking advantage of the long-lasting experience of the Italian-Egyptian research group involved[10].

Metallic materials are rather sensitive to atmospheric corrosion phenomena, which are the result of various synergic effects due to condensation phenomena, as a function of temperature (T) and relative humidity (RH) fluctuations during night-and-day cycle, and to chemical reactions between the

[10] INGO 2006; MEZZI 2014; PAPADOPOULOU 2014; PAPADOPOULOU 2016.

metallic surface and the atmospheric pollutants.

The aggressiveness of the indoor atmosphere may be evaluated on the basis of the corrosion rate of metallic reference specimens, of the same alloy chemical composition and microstructure of the real artefacts. The evaluation may be done by monitoring the surface conditions of the metallic specimens as a function of a long-time exposure to the indoor atmosphere and to microclimate parameters.

In order to acquire meaningful information on the environment of the basement of the Egyptian Museum, a monitoring campaign, is going on with two actions:

- Recording temperature and relative humidity values by means of a flexible and reliable monitoring system based on a smart sensors network, both in the basement and inside some showcases, in order to highlight any difference between microclimate and atmosphere conditions in the different areas.
- Exposure of Ag and Cu-based reference specimens, either as-received or, for Cu-based samples, coated with a Cu nanostructured thin film in order to increase their reactivity. The specimens are exposed both in the basement and inside some showcases, in order to observe the surface degradation phenomena and analyse them as a function of time.

The monitoring system

Different system architectures have been proposed in literature for environmental monitoring in indoor environments[11], mainly for specific applications, as telecommunications and energy power distributions. Most of them are not suitable for environments as museums, where power supply and Internet connection are not always available. To deal with these situations a two-fold application, whose architecture is schematized in the following block-diagram has been developed (Fig.1).

Several nodes, designed to measure the quantities of interest are installed in the different sites to be monitored. Fig. 2 shows a node, based on a CC2510 device, a compact System On Chip by Texas Instruments that employs a 32bit ARM NRF51822, a chip by Nordic Semiconductor, providing a BT-LE wireless capability. The chip contains an ADC, that can be used for similar measurements and digital pins suitable for controlling the other components in the node. Moreover, the chip exhibits a low energy consumption and can be selectively put in sleep mode to further increase the battery life.

These small dimension nodes, easily installed and hidden in the monitored area (Fig. 3), are designed to be powered by a small battery and to send the data through a wireless connection. Connection distances of more than ten meters have been easily achieved still providing a node life of a few years without changing the battery.

The nodes have a local memory, consequently the measurements are permanently stored for quality assurance and in the case they cannot be delivered to the receiver. If the monitored site is equipped

[11] SCHMALZEL 2005; CARULLO 2007; GEDIK 2005.

with electric power, powered receivers that can continuously receive data from the nodes in real time may be installed. The receivers can cover a radius of ten meters, so every device can cover a space equivalent to a room and, due to the small dimensions, can be installed without impairing visitor fruition.

The receiver can store locally all the data and can be connected to the Internet via cabling or via a WiFi connection. In both cases the measurements recorded by the nodes can be immediately delivered through the Internet to a distributed storage where users can remotely access them. If the Internet connection drops and/or the power supply goes off for a limited period of time, the receiver can collect the T and RH data relying on a backup battery and deliver them when the connection is re-established. If the monitored site has no power supply, as the museum basements or not accessible sites, it is possible to rely on the nodes' memory downloading their measurements only from time to time by means of a USB receiver connected to a portable PC. This configuration allows to follow the evolution of the environmental parameters even though not in real time.

The recorded data may be observed by users, by means of a smart-phone or on a PC. However the development of applications for smartphones can be a long and boring operation, for this reasons the authors decided to take advantage of the μ-Panel environment[12], which allows a quick and easy deployment of a measuring system. In this case data can be either viewed on a web browser or a simple program can be implemented to download and manage the measurements. The μ-Panel environment enables another interesting feature, related to the possibility of a direct connection to the powered receiver: users can directly monitor the local nodes to see what happens in the monitored rooms, even in the case of a missing Internet connection. This can be performed in un-powered sites too, if the sensing nodes implement the BT-LE protocol.

Smart phones can take advantage of the μ-Panel architecture in which a free App, downloadable on both iOS and Android based devices, permits both real-time monitoring and control of the receivers. This result can be achieved through a Virtual App, which consists of graphical panels described by the receiver and automatically transferred and displayed on the smart phone's screen when the communication between receiver and mobile device is established. The communication can be established through Internet via a Cloud storage system or through a direct connection, when the user is located close to the nodes in the monitored room. The μ-Panel architecture can be employed with micro-controllers with limited memory and available power resources, as the Arduino-based receivers or the low power BT-LE systems. As a matter of facts the μ-Panel system is based on a graphical and functional description of the Virtual App coded with a language HCTML (Hyper Compact Text Markup Language), which originates from the HTML but can be easily compressed (1:20), in terms of required memory. Fig. 4 shows three screen-shots of graphical panels implementing the Virtual-App sent by a receiver through an HCTML string of 500 bytes. On the screen on the left a box appears for each sensor of the network with the indication of the last measurements performed.

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[12] [3] μPANEL 2016; CORBELLINI 2016.

If the user taps on the temperature or humidity values, in the screen a diagram appears with the evolution of the parameter during time. Each receiver can be easily reprogrammed with a different HCTML for generating others panels or diagrams in dependence on the sensors to be managed in the room. Personal computer based clients can access the measurement database simply through a Web browser and a valid account on the Cloud. Specific web-pages allow the clients to display the data using different criteria, for example displaying all the data generated by a sensor over a given time interval.

Twelve nodes have been installed in the basement of the Egyptian Museum for the monitoring campaign (Fig. 5). The basement is provided of power supply, meanwhile no Internet connectivity is present, consequently the on-line version of the monitoring system cannot be used and all data have to be periodically downloaded by using the USB receiver.

Fig. 6 shows an example of T and RH values recorded by two nodes located in two different areas in the basement, during the first year of the environmental monitoring campaign. Node n.115 is located on the wall near a sarcophagus, in the area 39C, meanwhile node n.117 is located in another corridor in area 39B inside a showcase containing pottery. The yearly temperature diagram shows that the temperature ranges from a minimum of 21°C during winter, to a maximum above 29 °C during summer. The behaviour of the two nodes is similar, however the node located close to the wall, has a higher temperature change during the day, mainly during the summer when a high daily excursion is expected. The relative humidity values range from about 40% to 68%. The humidity in both the areas increases of up to 20% during the day, and is higher when the temperature is lower. From the experimental findings, the monitored area can be considered safe for metallic artefacts, except when the humidity exceeds 65%.

Exposure of reference samples

In order to evaluate the effect of the environmental conditions, a set of reference specimens, of pure silver (99.96 wt%) and pure copper (99.96 wt%) was employed. The specimens were polished with abrasive papers (from 240 to 3000 grit) and diamond pastes up to 0.1 μm, then cleaned with ethyl alcohol and dried with acetone, thus obtaining a mirror-like surface. Some copper specimens were coated with a 100 nm Cu nanostructured film, whose deposition was performed by plasma sputtering using a capacitively-coupled parallel plate reactor with an asymmetric electrode configuration.

The specimen surface was characterised from the chemical and morphological point of view by means of a field emission scanning electron microscope (FEG –SEM Supra 40, Zeiss, Germany), equipped with a Quanta energy dispersive X-ray spectrometer, in order to observe the growth of the corrosion products at microscopic level.

Fig. 7 shows the optical images of silver samples aged for 8 months and 12 months in the basement of the Egyptian Museum of Cairo in the locations of nodes N. 115 and N. 117.

Slight tarnishing appears on all the surfaces, independently of the locations and the FESEM images highlight the presence of corrosion products constituted by chlorides and sulphides (Fig. 8).

Concluding remarks

From the experimental findings, it is clear the role of monitoring of the environmental conditions to ensure the long time conservation of metallic artefacts.

The environmental conditions in the basement of the Egyptian Museum of Cairo may be considered safe for the metallic artefacts for most of the time, except for the periods of the year in which the relative humidity reach values higher than 65%. A slight tarnishing is observed on the Ag reference samples exposed in the basement after one year exposure. The monitoring campaign is still running as well as the characterisation of the stored artefacts.

Acknowledgements

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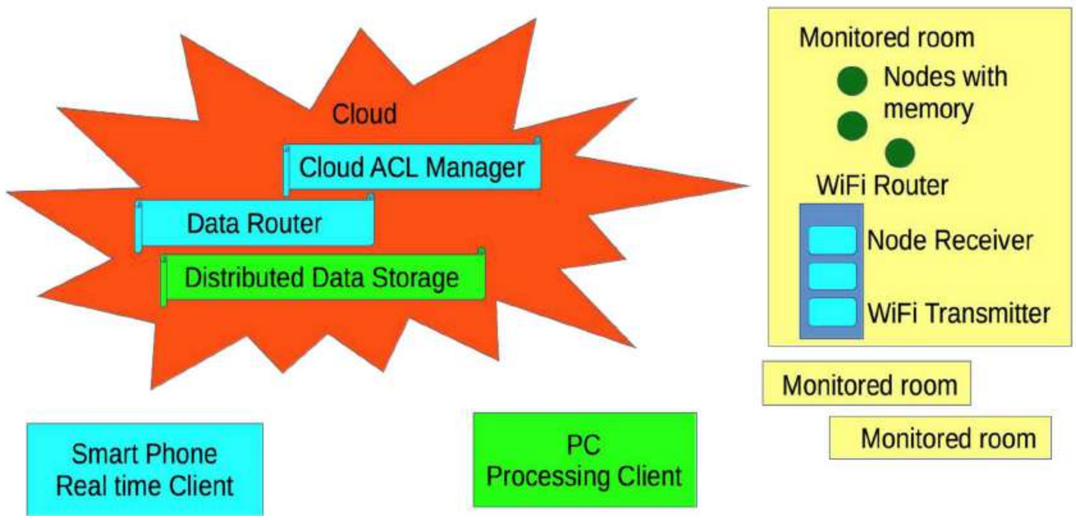

Fig. 1 - Block-diagram of a possible monitoring architecture

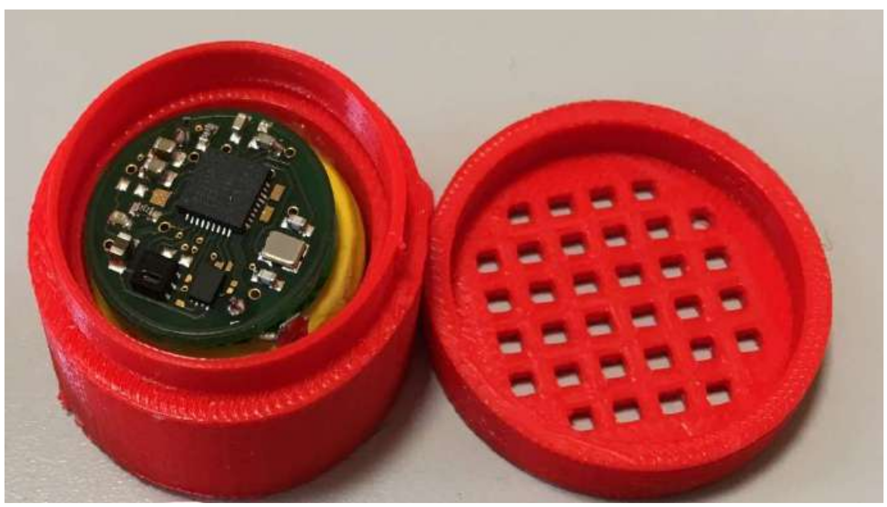

Fig. 2 – Small node designed to measure temperature and relative humidity.

Figure 3 - Insertion of a small node in a show-case of the Egyptian Museum of Cairo for continuous monitoring of temperature and relative humidity

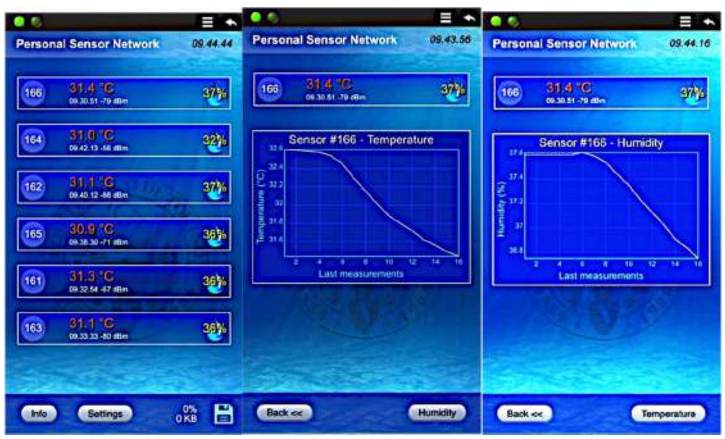

Fig.4 - The smart phone receiver: the app for continuous monitoring on a smart phone

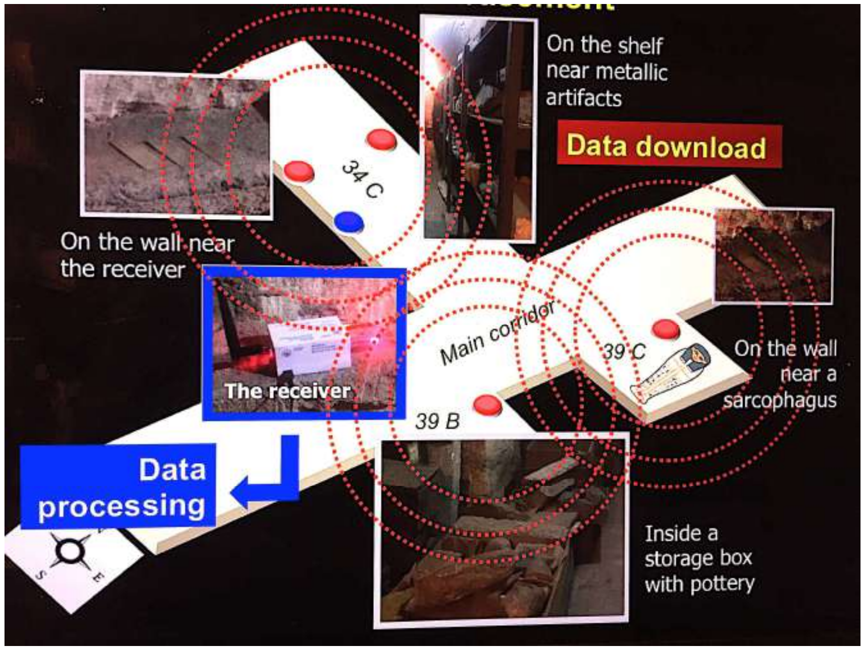

Figure 5 – Positions in the basement of the Egyptian Museum of Cairo of some nodes for the monitoring of temperature and humidity.

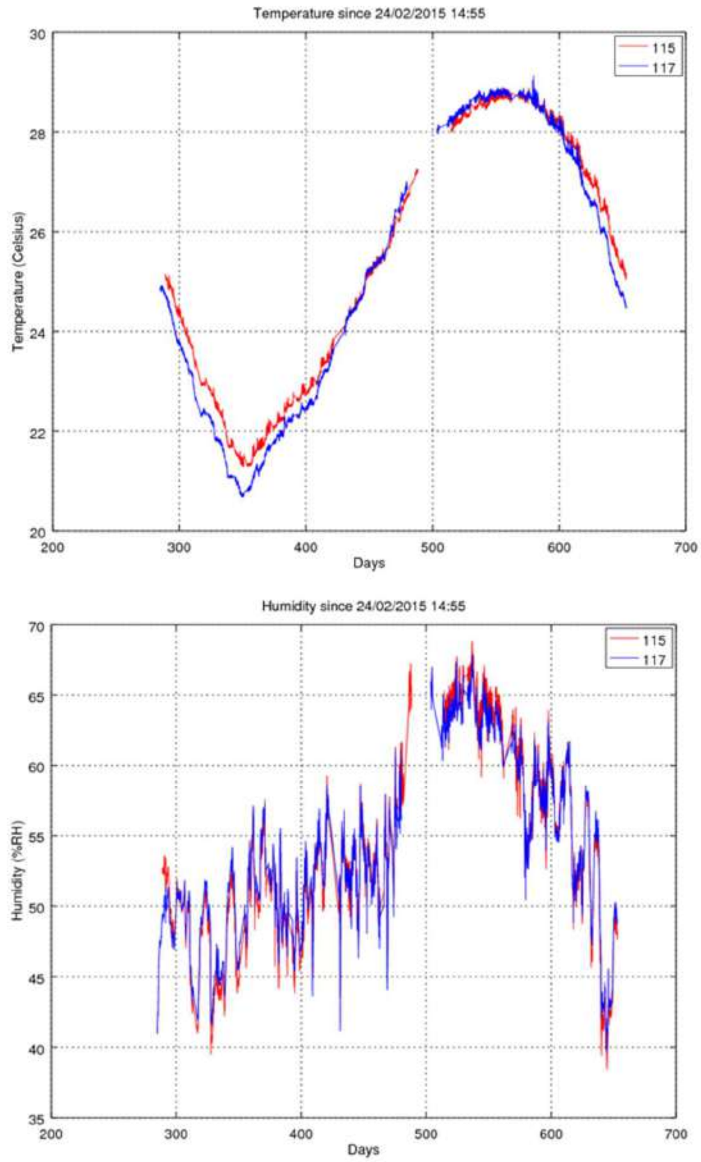

Fig. 6 – Example of temperature and relative humidity recorded by two nodes located in the basement of the Egyptian Museum of Cairo, respectively n.115 located in the area 39C and n.117 located in the area 39 B.

Fig. 7 - Reference Silver samples located in the basement of the Egyptian Museum of Cairo, respectively in the area 39C and in the area 39 B.

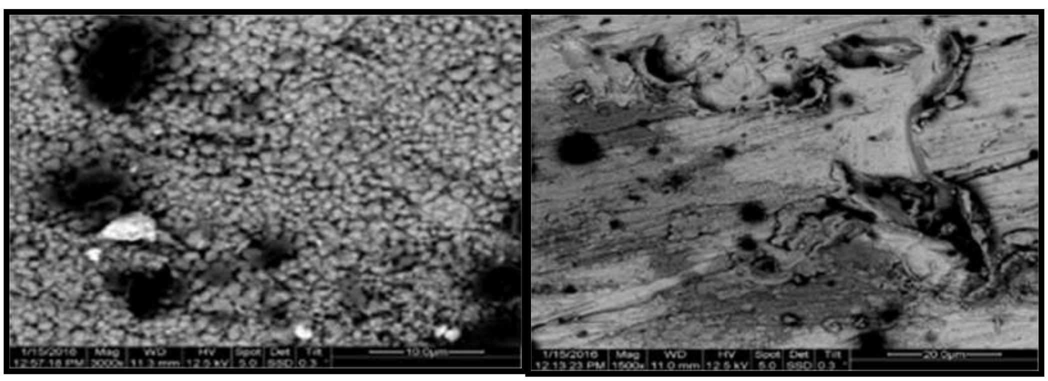

Fig. 8 – FESEM images of the reference Silver samples located in the basement of the Egyptian Museum of Cairo, respectively in area 39C (left) and in area 39 B (right).

CLIMATE CHANGE, WATER AVAILABILITY, AND CULTURAL HERITAGE IN EGYPT.

Marina Baldi

Consiglio Nazionale delle Ricerche, Istituto di Biometeorologia (CNR-IBIMET), Roma, Italy.

Email: m.baldi@ibimet.cnr.it

Abstract

Changes in weather and climate and in their extremes have significant impacts on several sectors, including ecosystems, agriculture, human health, energy, tourism, cultural heritage; and today are among the most serious challenges for society. In the case of Egypt, a study of the changes in the climate and in particular in the precipitation intensity and frequency is important for two main reasons: not only climate change affects the water availability and the access to clean water, with direct consequences on agriculture, human health and safety, but also it represents a major treat for ancient archaeological sites and monuments.

The results presented refer to a climatological analysis carried on in two different areas of the Country: Sinai Peninsula and the archaeological site of Qubbet el-Hawa in Aswan. Both areas are affected by climate change, where intense storms, rare, but fierce, not only are a risk on human health and safety in the two areas, but they affect the water availability in Sinai and the monument site in Aswan.

Introduction

Changes in weather and climate and in their extremes have significant impacts on several sectors, including ecosystems, agriculture, human health, energy, tourism, cultural heritage, and are among the most serious challenges for society[13].

For Egypt, a study of the changes in the climate and in particular in the precipitation intensity and frequency is important for two reasons: not only climate change affects the water availability and the access to clean water, with direct consequences on agriculture, human health and safety, but also it represents one of the major treats for ancient archaeological sites and monuments.

Concerning water, future rainfall amount in specific areas, like in Sinai, affects the surface water availability in the numerous watersheds of the Peninsula. In this respect, only after a detailed study of present climate and of climate projections, specific long-term flow simulation can be conducted on significant watersheds in order to obtain the flash flood water volumes at the outlets of the effective watershed(s). This information will help policy makers and local governments to define strategies and measures for water harvesting and/or protection works in the Region.

[13] MACH 2014.

Concerning cultural heritage, physical and chemical weathering represents a major treat for ancient archaeological sites, and require a detailed knowledge of present and future trend of deterioration factors of environmental origin in order to identify the more suitable and effective conservation and management strategies of the sites. Heavy rainfall, pressure, persistent winds, extremely high (low) temperatures, as well as sand storms, air pollution, and, along the Nile, humidity evaporated from the surface of the river, certainly represent a hazard for fragile monuments and for unique archaeological areas. Mechanical or physical weathering involves the erosion of rocks and soils through direct contact with atmospheric elements, such as heat, water, pressure and it is accentuated in extreme conditions, like, for example, in very dry environments, and the damages produced by natural phenomena on buildings, monuments and, at larger extent, on archaeological sites can be severe and permanent. Irreparable in most of the cases. In this framework climate extremes like thunderstorms with heavy downpour and flash floods represent a major treat for these highly vulnerable areas, and, in order to identify and implement appropriate conservation measures, a detailed study of the climate of the region, and of its past and future evolution, including extreme events, at different scales, from regional to local is necessary.

In the next decades, the projected continual and gradual warming of Egypt, an arid/hyper-arid Country, will increase the frequency and duration of heat waves and severe drought[14], and enhance the strength of flash floods[15].

The torrential rainfall and flash floods, although occurring very seldom, are expected to become more frequent and destructive, especially in desert and arid landscapes. In recent past heavy thunderstorms and rain swept major cities in Egypt in several occasions: forgotten wadis have been converted into fierce streams, urban areas flooded, power cut off, traffic halted, with subsequent large economic losses and death toll.

A better knowledge of climate and its extremes, therefore, is fundamental in order to assess the impacts. In this paper a description of actual climate and its changes in the Country and of possible future scenarios is presented focusing, as much as possible, on heavy rainfall episodes in two areas of the Country: Sinai Peninsula for the implications on water, and Aswan for the impacts on the archaeological site of Qubbet el-Hawa.

Discussion

Changes in the mean and extreme climate in Sinai Peninsula and in Upper Egypt

Results are presented from a climatological analysis focused on two different regions of Egypt: Sinai Peninsula, and Aswan in Upper Egypt. The two regions, different from several point of view (geography, geomorphology, climate, urbanization), are affected, although with different frequency and duration, by torrential rainfall episodes with catastrophic consequences on population first, and on two other sectors: water availability in Sinai, and impact on monuments and archaeological sites in Upper Egypt.

[14] LELIEVELD 2016.
[15] BUCCHIGNANI 2018; OZTURK 2018.

The whole territory of the Sinai Peninsula is characterized by an elevated number of watersheds, which drains into the Mediterranean Sea, Gulf of Aqaba and Gulf of Suez. The dry streams in these watersheds become fierce due to the effects of heavy rainfall episodes causing flash floods. Still the area has a great potential for agriculture and industrial development, but, in general, it suffers from water shortage. Although rainfall is scarce, flash floods, characterized by heavy, sudden and short duration events, cause loss of lives and damage to infrastructures in the region. However, these flash floods represent a precious non-conventional fresh water resource for Sinai. A certain water volume can fulfill a non-negligible amount of water demand or recharge shallow groundwater aquifers. The main goal of the study is to increase the present knowledge on current climate variability and future climate change scenarios in the Peninsula, in order to obtain, in a further development of the research, information on the forthcoming water availability in the region.

The Nile river is the major feature of Upper Egypt territory, stretching from South to North. It represents the main and only source of fresh water. Life along the river is connected to its discharge (which, in turn, depends on climate at the sources, outside the boundaries of Egypt, in the Ethiopian plain, and is regulated by the dams upstream), while the rest of the region is arid and covered by the desert. Frequent extreme heat waves occurring in the region have a devastating impact on the harvests of smallholder farmers[16] with dramatic consequences on their incomes, and these rare heavy rainfall episodes have a devastating impact on lives and properties.

At national scale, the climatological analysis over the past decades compared to the baseline period (1981-2000) shows that air temperature at 850 hPa increased of about 1°C in the Sinai and more than 1°C in Upper Egypt (Figure 1). Regarding precipitation, the pattern is not homogeneous and results do not show strong signals of changes (not shown). Climatologically, the only region with appreciable rainfall is the northern coast of Egypt, with 100-200mm/year, while within the Delta, the precipitation is only 40-60 mm/year, and precipitation in the south and desert is (almost) non-existent. The more detailed analysis based on surface meteorological data and performed over the period 1979 to 2015 over Sinai shows a clear tendency towards decreasing total rainfall and increasing average temperatures (Figure 2), while data scarcity does not permit a similar analysis in Upper Egypt.

The trends observed in recent decades in Sinai and Upper Egypt show not only measurable changes in the climate with drier and hottest conditions relative to the baseline period, but also more intense storms. In the past severe thunderstorms and torrential rainfall have been already documented in scientific papers[17] and travelers tale[18]. Today their frequency is increased; and severe and long dry periods are suddenly interrupted by torrential rainfall difficult to forecast because of their large variability in space and time. If this tendency continues, the impacts can become more severe.

In Upper Egypt a major flood disaster occurred in early November 1994 in Luxor, and torrential rains caused serious flooding also in Durunka (about 100 miles downriver from Luxor) where the flood caused a bridge to collapse on two fuel storage tanks which then exploded. The fiery flood that resulted killed over 500 persons in the city of 20,000. More recent Episodes (2009, 2010, 2011, 2014)

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[16] Lelieveld 2016.
[17] Sutton 1947; Sutton 1950.
[18] Lattil 1802; Lepsius 1853; Belzoni 1821.

occurred in the Country, and flooded the urban areas of Cairo, Luxor, Aswan, causing a power cut off, a complete halt of traffic, and large economic losses and death toll.

Table 1. The 7-10 March 2014 storm: total rainfall (mm) observed in Upper Egypt, Red Sea and Sinai

	Station	Precipitation (mm)
Upper Egypt	Aswan	29
	Luxor	29
	Asyat	9
Red Sea	Hurgada	21
Sinai	Sharm El-Sheikh	27
	Dahab	28
	Saint Catherine	29
	El Tor	17
	Nuwaibaa	8
	Nekhel	5

The 2014 event lasted over Egypt for few days: 7-10 March, and affected Upper Egypt, Red Sea and Sinai with a maximum daily rainfall 30mm measured at Dahab station, then, on the 10th the system moved rapidly towards East, as clearly captured by TRMM satellite images (Figure 3). Table 1 reports the total amount of precipitation occurred in the Upper Egypt, Red Sea and Sinai Peninsula during the storm.

During a more recent episode, occurred in 2016, heavy rains and flooding affected the Upper Egypt and the Red Sea coast, affecting more than 6,500 families at the governorates of South Sinai, Red Sea, Sohag, Qena, and Assuit. The torrential rains started late on Wednesday 26 October 2016, accompanied by exceptionally strong winds.

Usually Upper Egypt and Red Sea mountainous regions, impoverished areas with poor infrastructure, receive torrential downpours annually in late October and early November. In 2016, due to bad weather, the heavy rainfall and floods hit several governorates of Egypt (South Sinai, Red Sea, Sohag, Qena, and Assuit). In addition to deaths and injuries, houses have been swept away, main roads were closed and telephone and power lines were cut especially in Red Sea Governorate: according to official estimates as of 29 October 2016, 26 people have been killed and 72 injured. The Integrated Multi-satellitE Retrievals - IMERG for GPM indicates (Figure 4) that during the episode some places received over 24 mm of rain (light brown), and others over 32 mm (orange).

Some discussion about the mechanisms leading to thunderstorms with heavy rainfall episodes, and on their trajectory can be found in recent studies[19] and has been illustrated by the Author in previous papers[20], and is not discussed here.

In order to assess if any change in the frequency of the phenomenon occurred in recent decades I Sinai, a list of heavy rain episodes occurred both in South and North of the Peninsula for the period (1990-2015) is presented (Table 2). The list is based on data collected at meteorological stations installed in the Sinai Peninsula, and it shows clearly that the number of very short but intense events since year 2000 is quite remarkable.

Table 2. Catalogue of flash flood in South and North Sinai (1990-2015).

Flash Floods Records in Sinai					
South Sinai				North Sinai	
Ras Sedr	**Ras Sedr (Elmelha)**	**Saint Katherin**	**Newabaa**	**Godirat**	**Maghara**
02/03/1997	07/12/2000	22/03/1991	17/01/2010	22/03/1991	27/10/2005
07/02/1999	04/12/2001	17/10/1993	27/01/2013	05/01/2001	21/10/2007
07/12/2000	06/01/2003	20/10/1993	09/03/2014	29/01/2004	18/01/2010
10/01/2002	14/12/2003	01/01/1994	08/05/2014	17/04/2006	09/01/2013
16/12/2003	22/01/2004	18/01/2010	12/09/2015	10/12/2009	09/05/2014
14/01/2004	05/02/2004	08/01/2013	26/10/2015	17/01/2010	29/10/2015
04/02/2004	04/04/2011	25/01/2013		09/03/2014	
18/01/2010	31/12/2013	27/01/2013		09/05/2014	
25/02/2010	09/03/2014	09/03/2014		25/10/2015	
09/01/2013		08/05/2014		29/10/2015	
01/02/2013		12/09/2015			
09/03/2014		25/10/2015			
07/05/2014					

[19] DE VRIES 2013; KRICHAK 2012; OBASI 1997.
[20] BALDI 2015; BALDI 2016.

Results from climate projections over the Middle East-North Africa (MENA) region show, over Egypt, a significant warming (Figure 5) at the end of the 21st century, along with a general reduction in precipitation (Figure 6) in accordance with other Authors[21], but a specific study of the future climate at high resolution for the two regions is not yet concluded, and it will be discussed in a next paper.

Climate and cultural heritage – A case study

The study regarding the impacts of meteorological factors on archaeological sites conducted in Upper Egypt is part of the Bilateral Project *TECH - Technologies for the Egyptian Cultural Heritage*, funded by the National Research Council of Italy and the Academy of Scientific Research and Technology of Egypt (ASRT). The main goal of the project was to test a non-invasive methodology for documenting Egyptian monuments and epigraphy. The overall project provided a detailed documentation of the tomb of Harkuf, one of the tombs of the Nobles, carved in the sandstone, and located in the archaeological site of Qubbet el-Hawa on the west bank of Nile at Aswan, using photogrammetry, with the support of spectroscopy, geology and climatology, in order to obtain data on the actual state of conservation, to verify the decay and the environmental stresses. A specifically designed experiment conducted in 2013, permitted to define the microclimate of the area, and to determine the possible risks of deterioration of the inscriptions carved on the façade of the tomb[22].

The climatological study discussed in the previous paragraphs offered a general picture of the climate changes and variability in Upper Egypt, while *TECH* project permitted to focus on the local scale climate and its possible impacts on monuments, through the analysis of micrometeorological data. The area is characterized by hot and dry weather conditions, typical of a desert climate: night time relative humidity can be more than 30% during the winter months, which rise rapidly during heavy rainfall episodes; the total rainfall amount per year is about 1 mm, and heavy precipitation is a very rare event occurring once every 1 or 2 years, often resulting in flash flood.

The effects of the environmental and meteorological elements are evident in the lower part of the façade if compared to the upper part. For centuries, and until the work done by Schiaparelli[23], the lower part has been covered by sand deposited on the façade, therefore remained well sheltered by external factors, while the upper part was always subject to the environmental stress. This resulted in a better status of conservation of the lower part in comparison with the upper, which is still clearly visible. For this study case, an experiment, designed using portable meteorological instruments, has been carried out in order to collect meteorological data: air temperature, its diurnal excursion, and wind, and, to some extent, relative humidity, around the tomb (Figure 7), and results from the micrometeorological study can be important in order to identify the conservation measures to preserve the site.

The experiment confirmed that the microclimate around the Harkhuf Tomb reflects the climate of the larger Aswan area, described by the meteorological data collected in the nearby airport. In addition,

[21] Bucchignani 2018.
[22] Angelini 2016.
[23] Schiaparelli 1892.

the analysis of meteorological data collected at the site between 8:00 am and 4:00 pm local time (Figure 8) shows clearly a differential heating of the façade, with the right part reaching temperatures warmer (few degree C) than the left and for a longer period, being under the direct sunrays until early afternoon.

If relative humidity outside the tomb does not represent a big concern during the day, however it is important in the interior where it can reach larger values and maintain a risky level during night-time which can favor the formation of mold. In fact, during the day evaporation from the surface of the Nile river is considerable and can increase the air humidity in the lower layer of the atmosphere, the boundary layer. The humid air, penetrating into the tomb, remains trapped, condensates and deposit on the internal walls and ceiling increasing the risk of mold formation.

All these environmental factors certainly play a key role in the deterioration of the monument and in particular of its façade so magnificently engraved, making its preservation and conservation an absolute necessity. In this respect the assessments of local environmental risk factors and the knowledge of their evolution in a changing climate can help to understand the risk for monuments and archaeological sites, while, in parallel, the documentation using photogrammetry represents a great tool for conservation, and can be successfully applied to other open air sites.

Conclusion

The climatological analysis presented shows some unequivocal climate change signals in Upper Egypt and in the Sinai Peninsula, which reflects what is observed, at larger extent, over the Middle East-North Africa region. In particular, temperature has increased over the last decades, while precipitation has decreased, and extreme events like heat waves, severe drought, heavy rainfall increased in number and intensity. Future projections show, at a first glance, continuous warming which in turn can be responsible of more frequent thunderstorms.

The presented results represent a step forward for the evaluation of the impacts of current and future climate on desert landforms, on water resources, and on cultural heritage, however, future studies will be necessary to better understand how the current climate conditions will evolve in the future at local scale and if extreme events like heavy rainfall will change their intensity and frequency due to climate change. A better knowledge of the present and future climate change in the Country will permit to understand more in deep the impacts of natural hazards on i) water availability and access to clean water; ii) on buildings, infrastructures, archaeological sites, monuments.

The climatological analysis presented for the Sinai can certainly help to identify tools and methodologies to be adopted by central/local governments for water harvesting and protection works in order to protect population, while the Aswan case study, instead, shows how the larger scale climate analysis, if accompanied by focused climatological study at local/micro scale, can help to assess the role of environmental factors in the deterioration of archaeological sites and monuments, therefore facilitating the identification of the necessary conservation measures to be adopted in archaeological sites.

Acknowledgements

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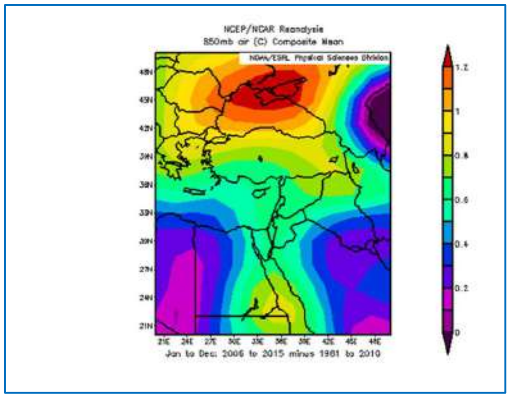
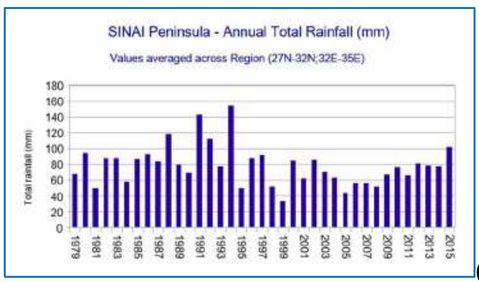


Figure 1. Composite mean air Temperature at 850hPa: anomaly over the period 2006 2015 relative to the base period 1981-2010. *(Source: NCEP-NCAR reanalysis)*

(a) 

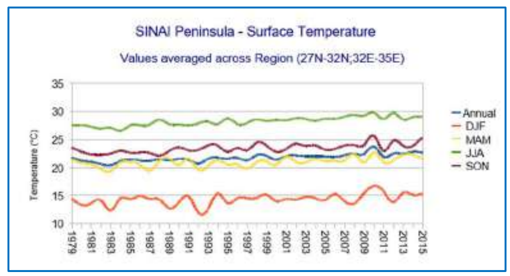
(b) 

Figure 2. (a) Annual Total Precipitation over the Sinai Peninsula. (b) Mean Annual and Seasonal Air Temperature at surface (2m) over the Sinai Peninsula. *(Source: ERA-Interim reanalysis)*

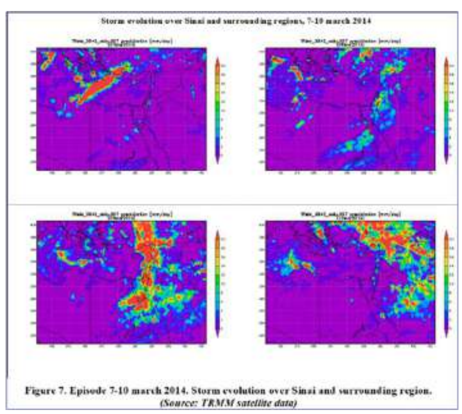


Figure 3. The 7-10 March 2014 storm: evolution of the phenomenon over Sinai and surrounding region. *(Source: TRMM satellite data)*

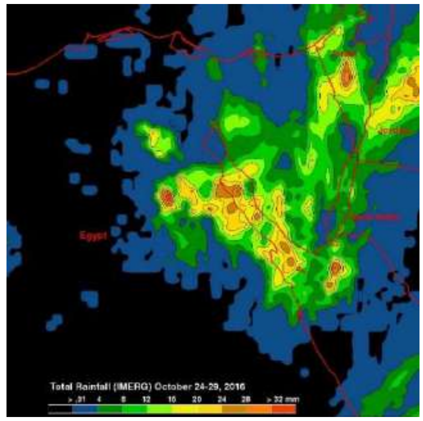


Figure 4. Precipitation pattern during the 24-29 October 2016 storm. *(Source: Integrated Multi-satellitE Retrievals - IMERG for GPM)*

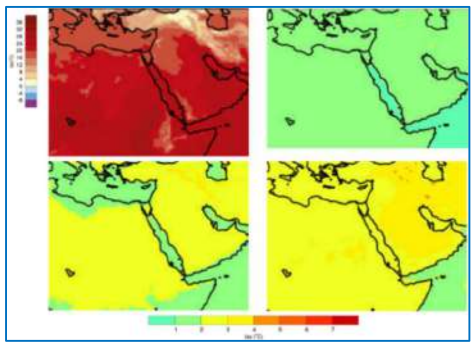


Figure 5. Temperature - Results from an ensemble of nine GCM, for RCP4.5 scenario. Ensemble mean (mm/day) for the control period (1971-2000) (upper left - color scale on the upper left). Change in Ensemble mean (% - color scale at the bottom), for 2011-2040 (upper right), 2041-2070 (bottom left) and 2071-2100 (bottom right) compared with 1971-2000. (Source: www.smhi.se)

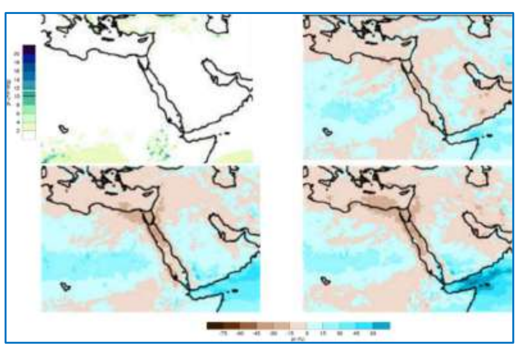


Figure 6. As in figure 5, but for Precipitation

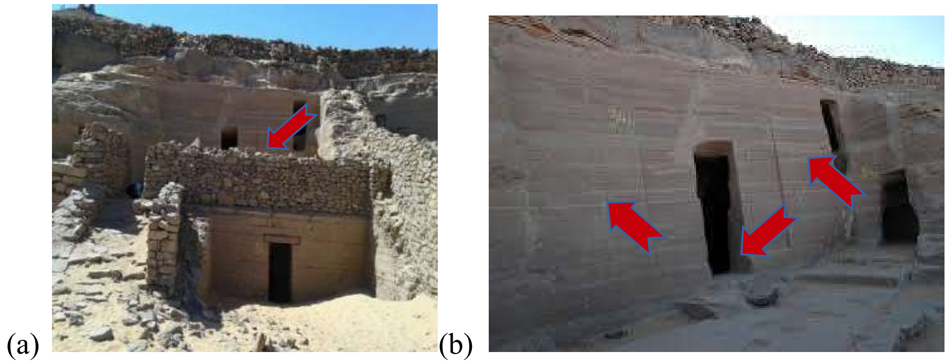


Figure 7. Façade of the tomb of Harkuf in Aswan. (a): the right arrow shows the sheltering wall where meteorological instruments have been located. (b): the red arrows show the points for the differential heating of the façade.

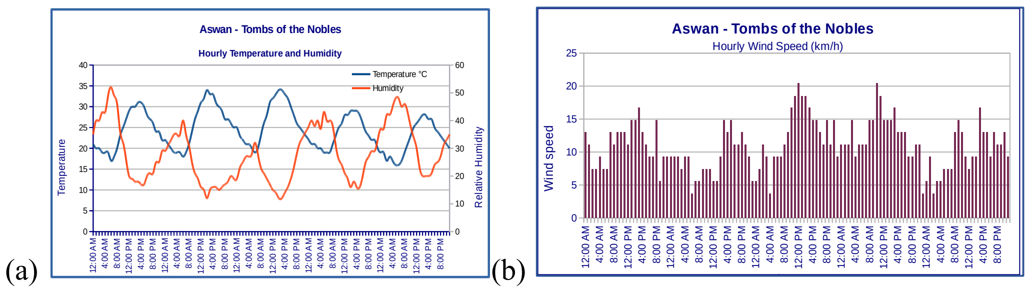


Figure 8. Diurnal variation of temperature and relative humidity (a), and of wind speed (b) outside the Tomb of Harkuf.

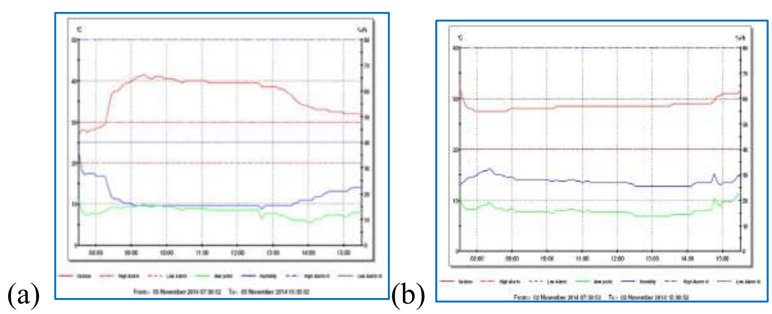


Figure 9. Example of diurnal variation of temperature (continuous red line) dew point (continuous green), Reative Humidity (continuous blue) inside (a) and outside (b) the Tomb of Harkuf.

Fluorescence In Situ Hybridization Technique: A Tool Useful For Detecting Cultural Heritage Biodeteriogens

Martina Cardoni[1,2], Anna Barra Caracciolo[2], Paola Grenni[2]

[1] Dipartimento di Scienze Ecologiche e Biologiche, Università della Tuscia, Viterbo

[2] Consiglio Nazionale delle Ricerche, Istituto di Ricerca sulle Acque (CNR-IRSA), Roma

Corresponding author: *cardoni@irsa.cnr.it*

Abstract

Microorganisms such as Bacteria and Archaea can damage monuments and stone artworks through various mechanisms, including biofilm formation, chemical reaction with the substrate and production of pigments. The biogenic release of inorganic and/or organic corrosive acids is probably the best known and most commonly investigated biogeochemical damage mechanism concerning inorganic materials. For example, aerobic microorganisms producing respiratory carbon dioxide, which becomes carbonic acid, contribute to dissolving stone and forming soluble salts. Moreover, the production of organic acids, such as lactic, oxalic and acetic, has been associated with the dissolution of calcite in calcareous stones. For these reasons, the phylogenetic classification of microorganisms colonizing cultural heritage substrates is very important, in order to detect the taxa involved in biodeterioration and apply the appropriate countermeasures. Fluorescence in situ hybridization (FISH) technique is a rapid and highly valuable culture-independent molecular method for detecting and identifying individual microbial cells in environmental samples using rRNA-targeted oligonucleotide probes. When used for detecting and identifying Cultural Heritage biodeteriogens, the FISH method can be performed in two ways: on powdered samples from the surface studied or more recently on adhesive tape strips applied on the surface and immediately removed. In contrast to other identification approaches, the FISH method largely maintains the characteristics of the targeted microorganisms and makes it possible to have a mirror image of the whole microbial community of a sample.

Introduction

Historic monuments and artworks are exposed to different physical, chemical and biological deterioration factors; this can represent a significant loss of our cultural heritage due to mechanical and aesthetic alterations and damage. Biodeterioration can be defined as any undesired change of the properties of a material caused by biological activity of living organisms such as Bacteria, Archaea, Fungi, Algae, Lichens, Protozoa and small animals, for example mites (Fig. 1). In this context, this chapter is focalized on prokaryote organisms, in particular Bacteria and Archaea (such as alkaliphiles, halophiles, epiliths and endoliths)[24] [25] [26] and their biodeterioration effects on stone monuments. These organisms produce pigments and other substances through their metabolism and perform a mechanical action through biomass colonization[27], resulting in an irreversible and irreparable loss of physical strength, aesthetic appearance and historical value and data[28]. Although in general the mineral composition, nature of the stone substrate and the surrounding environmental conditions are the major determinants of the type and extent of microbial colonization, a presence of microorganisms on monumental stones and artworks does not imply that the biodeterioration is associated with their growth. In fact, the ability of microbes to colonize stone surfaces depends on numerous other factors such as nutrient availability, pH, salinity, surface texture, moisture content, porosity, permeability and climatic and micro-environmental conditions[29]. The mineralogical nature of stone together with its surface properties and environmental conditions synergistically controls its bioreceptivity (the ability of stone to be colonized by microorganisms), while the intensity of colonization is influenced by the surrounding environment conditions (including pollutant concentration and micro-climatic conditions) and by anthropogenic eutrophication of the atmosphere.

Quantification and identification of microbial communities colonizing monuments are an essential first step for understanding the biodeterioration process; the second is highlighting the functional properties of these microorganisms and their role in the biological mechanisms. The final step is to use the information obtained to implement control strategies and develop appropriate protection measures.

Most of the information available on microorganisms that colonize cultural assets comes from the use of classical microbiology methods; however, these methods, based on microorganism cultivation, detect only a small part of the many existing microbial taxa. Moreover, sometimes they form biofilms in which the identification of single species is very difficult. For example, cyanobacteria are found in association with other species, such as fungi, algae, and heterotrophic eubacteria (including Actinomycetes) in the biofilm; consequently, their isolation is laborious, requiring extreme care and successive replication of colonies, cells, and filaments[30].

Most of the Bacteria identified by molecular techniques are not cultivable and their role in the mechanisms of stone surface biodeterioration is not well understood. Even less is known about the role of Archaea in this process, but recent research has investigated this group; for example, the archeal species *Halobacillus trueperi* has been shown to participate in the *in vitro* mineralization of carbonates[31] and this may be the first indication of previously uncultured microorganisms in

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[24] SAIZ-JIMENEZ 2000.
[25] ORTEGA-CALVO 1993.
[26] PIÑAR 2009.
[27] MIHAJLOVSKI 2014.
[28] TIKAM 2012.
[29] WARSCHEID 2000.
[30] CRISPIM 2005.
[31] RIVADENEYRA 2004.

monument deterioration. Recent studies have used culture-independent techniques to solve the problem of detecting microorganisms in natural samples.

Our knowledge of microbial diversity is far from complete; molecular methods, such as fluorescence in situ hybridization, allow the identification and enumeration of microorganisms in environmental samples and give us the possibility to characterize microorganisms never isolated before and never considered to play a role in biodeterioration of cultural heritage.

Biodeterioration phenomena

The detrimental effects of microorganisms on monuments can be aesthetic, biogeochemical and/or biogeophysical. Microorganism can contribute directly to the deterioration of artworks by using them as a substrate or indirectly by causing physical stress or providing compounds for secondary chemical reactions[32]. May[33] estimated that the association of microorganisms with the mineral substrate might reach more than 3 cm deep into the stone, but microorganism mechanisms of penetration are not fully understood[34].

Pigments released from, or contained in autotrophic microorganisms such as *Cyanobacteria*, may cause the aesthetic problem of monument discoloration (Fig. 2). However, this process is not only aesthetic: in fact, the discoloured areas may absorb more sunlight and the latter increases physical stress by the expansion and contraction caused by temperature changes[35].

On the surface of a stone, microorganisms, especially prokaryotes, can be organized in the form of biofilms by producing exopolymeric substances (EPS), forming a matrix; biofilm formation has many advantages for the microbial colonizers, such as increased accessibility to nutrients and protection against stress (UV radiations, drying). The EPS matrix serves as an intermediary for the adhesion of microorganisms to the surface and plays a key role in the phenomenon of biodeterioration[36]. The EPS of the matrix can produce mechanical stress on the stone, modifying the distribution of the pores on the surface, and these alterations can modify water circulation within the material and its sensitivity to temperature variations[37,38]. Moreover, the presence of biofilm on stones accelerates the accumulation of pollutants, which can serve as nutrients for microorganisms, increasing the biological activity on the substrate[39].

Filamentous organisms, such as some *Cyanobacteria*, can penetrate into the stone causing various damage[40] owing to the different substances produced. For example, some inorganic acids, mainly

[32] SAND 1996.
[33] MAY 2003.

[34] SALVADORI 2000.
[35] SAND 2002.
[36] MIHAJLOVSKI 2014.
[37] WARSCHEID 1996.
[38] GUIAMET 2013.
[39] NUHOGLU 2006.
[40] HIRSCH 1995.

nitric and sulphuric, which can dissolve acid-susceptible materials, promote the production of substances more soluble in water; organic acids such as oxalic, citric and gluconic, react with stones, solubilizing them via salt formation and complexation[41,42].

Fluorescence *In Situ* Hybridization

Fluorescence *In Situ* Hybridization (FISH) technique has various applications in environmental microbiology: for example analysing complex communities, including biofilm structure, and detecting dominant populations in the microbial community[43]. The phylogenetic identification is mainly based on the sequencing of the gene codifying for the bacterial 16S rRNA; FISH consists of the *in situ* characterization (without cultivation and DNA extraction) of microorganisms using fluorescent labelled 16S rRNA-targeted oligonucleotide probes. Molecular probes consist of 15-30 nucleotides, labelled with a fluorochrome. Once a molecular probe is introduced into a cell, it can hybridize exclusively with a specific complementary 16S rRNA sequence and the hybridization can be visualized under an epifluorescence microscope. FISH is very useful in environmental studies for identifying microorganisms at different phylogenetic levels (from domain to species).

In the field of cultural heritage conservation, fluorescence *in situ* hybridization can be directly applied to samples collected from a monument by a sterile scalpel and subsequently powdered in a sterile mortar or on adhesive tape strips (Fig. 3). Urzì and Leo[44] proposed the use of adhesive tape strips as a non-destructive sampling method for the study of monument surface colonizing. These strips can be gently applied on the stone surface and immediately placed on sterile glass slides for microscope analysis and stored at 4°C. Both the powdered samples and small pieces of adhesive strips are fixed with paraformaldehyde solution (4% paraformaldehyde in PBS, pH 7.2). After fixation, the samples are dehydrated by successive passages in different percentages of ethanol (50, 80, 100%) and then treated with the hybridization mixture, containing 2µL of a specific labelled probe in the hybridization buffer as described by Urzì and Albertano[45], and incubated at 46°C for at least 3 hours. After hybridization, samples are placed in a washing solution (NaCl, Tris-HCl, SDs and EDTA), for 30 minutes at 48°C and rinsed with distilled water[46].

The use of several specific probes at different phylogenetic levels can provide valuable information on the structure of colonizing microflora. The FISH method has also been successfully tested on fungi isolated from monuments[47]. FISH also makes it possible to observe the morphology, cell size and distribution of microorganisms in their natural habitat. Moreover, if a specific and new microorganism involved in the biodeterioration processes is identified by DNA extraction methods, it is possible to design a new appropriate probe for its direct identification. However, some limitations of this method should be considered, for example the interference of phototrophic organisms, due to

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[41] SCHEERER 2009.
[42] SAND 2002.
[43] CONO - URZÌ 2003.
[44] URZÌ - LEO 2011.
[45] URZÌ - ALBERTANO 2001.
[46] CONO - URZÌ 2003.
[47] STERFLINGER - HAIN 1999.

the presence of autofluorescence chlorophyll, which diminish the fluorescence of fluorochrome binding to the molecular probes. Inorganic material surrounding the bacteria can also be fluorescent and sometimes cause signal interference. Moreover, an underestimation of the diversity of species observed can also occur owing to the low rRNA content of some cells[48]. Finally, in some cases, the bacterial cell wall structure can hamper probe penetration. In any case, most of these problems can be overcome with specific sample processing and protocols.

Final considerations

Although it is well established that microorganisms can cause serious damage to cultural heritage objects, knowledge of the precise mechanisms of biodeterioration is still fragmentary. The use of molecular identification methods provides us with a broader understanding of the diversity of organisms growing on monuments and could expand our knowledge of new types of microbial metabolism occurring in these habits. Understanding the interactions between microorganisms and their environment is crucial for determining whether they are damaging art objects and choosing the best method for conservation and/or restoration. In order to assess the contribution of microorganisms to the deterioration of cultural heritage objects and take the appropriate countermeasures, interdisciplinary approaches between conservators and scientists, such as microbiologists, biologists, geologists and chemists, are needed.

Acknowledgment

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Fig. 1 – Algae colonization on a sculpture (Courances castle park) (A) and on a pillar (Les Salles-Lavauguyon church) (B)[49].

Fig. 2 – Discoloration phenomena on Palàcio Nacional da Pena (Portugal) colonized by Trentepohlia, Cyanobacteria[50].

[49] MIHAJLOVSKI 2014.
[50] MACEDO 2009.

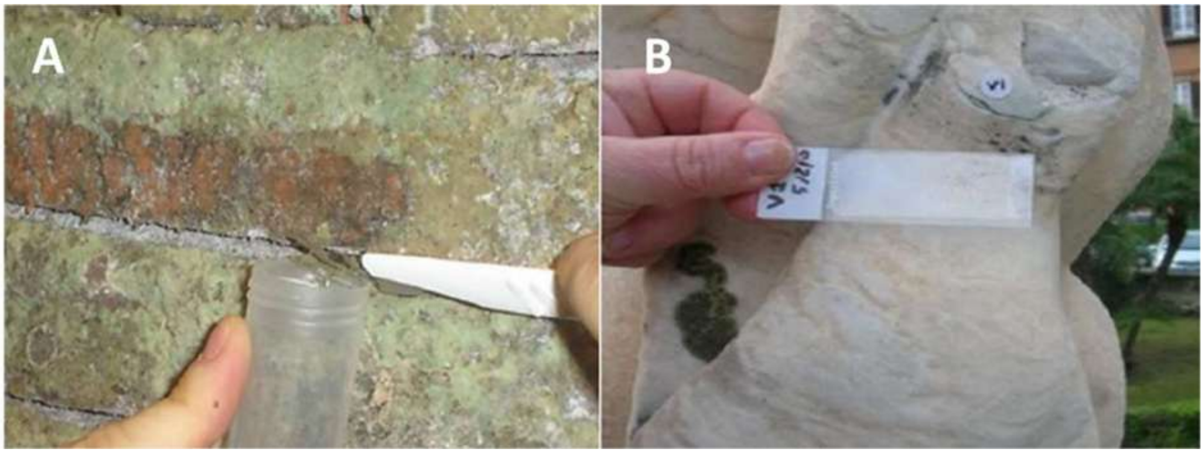

Fig. 3 – Collecting of sample on monument surface by a sterile scalpel (A) and by adhesive tape strip (B).

Digital Model, Acquisition And Processing: The New Technologies For Architectural Survey

Marco Carpiceci

SAPIENZA Università di Roma

The new procedure of the architectural survey sets the "numerical model" or "model made by points" as central structure. This structure is able to describe precisely the architectural object in its own morphology. From the numerical model we can process the "mesh model" or "surface model", which produces a careful description of the skin of the architecture; this last model can be subsequently textured by color images. This must be considered just the beginning of the Architectural Survey process, indeed it needs several elaborations that can lead to an infinite number of possibilities of use, such as restoration, conservation and communication.

The current history shows how three factors of strong structural impact have determined the evolution in the architectural survey. These are laser scanning, computer graphics and digital photography (Fig.1).

The total station of the 80s already allowed the old theodolite to become the main instrument of the polar survey; though with the new millennium we witnessed the birth of the instrument that has brought new life to the architectural survey: the laser-scanner. With this instrument it has been possible to collect all the points, and not only the most significant ones selected by the operator. It was also possible to select a dense matrix of points homogeneously distributed in the spherical space around the instrument, rather than a discretization based on a relatively limited choice. But though the cloud is dense of points, it is not able to provide information on the geometry of the object, nor of its physical nature.

Apart from the position of the measured point, the laser scanner is able to give information on the RGB value and the apparent brightness. There is, however, a huge gap between the two measurements. On one hand the color value is recorded by a photographic sensor that traces the entire scanning space while, on the other hand, the brightness depends mainly on the surface's aspect and on the laser beam emitted from the instrument. So, while the color detection needs external light, the brightness itself can be measured even in darkness, because the scanner uses its own beam to measure what is known as reflectance.

The software that manages the clouds of points provide the sequence from the numerical model to the "mesh model", surfaces composed by flat minimum elements defined by points (mesh). The surfaces are then enriched by color and contrast. In this way the generation of an analog representation, a virtual object that reproduces the real object as a clone, is complete.

The numerical model can be produced by using two techniques based on two different and opposite principles: the "polar" survey and the "epipolar" survey. Thanks to the laser technology, the polar survey has currently reached its maximum development, as a matter of fact any survey is based on its use. But more and more we can observe a new technology that uses the dynamic and fruitful partnership between digital photography and stereophotogrammetry: the photomodelling or image-based system, based on the geometrical model, well-known as the epipolar geometry.

Except for particular types of lasers that use triangulation systems, the laser scan has a polar structure, and it must be used considering this fundamental characteristic so as to allow to cover all the points of the architectural object with the minimum number of scans. Regardless of the accuracy of the instrument, the nature of the surface influences the measures very much. Sharp and clear edges negatively influence the survey, especially when they are taken sideways, as well as shiny and reflective surfaces and very dark ones.

Problems caused by lighting can be reduced by scanning in total darkness; this procedure allows the registration of both Cartesian coordinates and brightness value. The result is a defined black and white surface without contrast problems introduced by lighting (Fig.2). The photographic acquisition, taken separately and with properly and uniformly lighting, produces then a number of images applicable on the scans afterwards. This way it is possible to get a 3D model with applied light and shadow depending on the desired effect and not from the conditions of the exact moment of the survey.

The stereophotogrammetric model of the image-based system is processed by computer in order to facilitate the automatic recognition of homologous points on the images; these points allow to calculate the exact position in space and to produce as result a meshed and mapped cloud of points. The automatic model that allows the operation is defined through the epipolar geometry, it defines the scanning rules for the couples of images in order to produce the numerical model. Similarly to the stereophotogrammetry basic concepts (Fig.3), the internal orientation, common to all images, defines the position of the projection center of each image while the relative orientation reconstructs the mutual position of each pair of contiguous images. Each pair of homologous points reconstructs the position of the relative point in space. The geometric system used to automatically search and find the homologous points is known as "epipolar". There is an epipolar line passing through each point of an image which has its homologous line passing through the other image of the couple, and the homologous point on this second image is found automatically. It is clear then that in order to achieve a good result every point of the object must be seen by at least two or three different points from which take the pictures. This aspect is important when we plan the survey. Homogeneous surfaces are impossible to reconstruct by photomodeling so we always need a minimum of variation on the surface pattern, otherwise we will have no morphological reconstruction. Last but not least, it is important to underline that images for photomodeling must be taken without any automatism such as focusing, exposure and image stabilization, so that all parameters remain constant for all the shots, allowing a more accurate result for the automatic operations.

One of the latest technologies, still under development, is represented by aircraft models or UAV (Unmanned Aerial Vehicle), commonly called drones.

Thanks to this technology it is possible to make a survey of objects otherwise difficult to reach (uncomfortable paths, for example) such as the roofs or for instance the upper part of a tower (Fig.4). Drones can be very useful also for archaeological excavations, characterized by walls of limited vertical development whose shape and extension would require a high number of scans. Three are the technological areas that involve drones: radio-controlled aerial vehicles, digital photography and the photomodeling. Sophisticated algorithms combined with increasing calculation and visualization skills are making the photomodelling technique more and more accurate and reliable. Along with this, digital photography has now achieved results and computing potential incomparable with the past, bringing quality and operability on cameras lighter and lighter, smaller and smaller. The improvement in radio control and remote control technologies even from tablets and smartphones have made drones navigation easier and easier. Currently the interest is mainly focused on light drones with a weight range around 1.4 kg and under 250g. For instance UAVs of 1kg need to fly in protected areas while lighter UAVs can be used more easily in critical areas despite the performance and flight range limitations.

As mentioned above, the preservation and the transmission of the architectural appearance is an issue that involves not only the shape of the architectural object, but also the color of its surfaces. When a colored shape is collected with the goal of preserving and restoring, the acquisition method must follow strict criteria. This is even more valid when the painted surfaces constitute a peculiar characteristic of the architectural object itself, such as painted facades of buildings or frescoed walls or mosaics.

The chromatic survey, produced in digital format, is intended to remain unchanged in time, offering always the same visual impression. Though this kind of documentation too presents technological and physical problems.

While the acquisition of the shape is absolute, recording the position of each point of the surfaces, the detection of the color does not record the real color of the surface but only its appearance during the acquisition step with camera. For these reasons mainly the photography must satisfy two basic requirements for color acquisition, light correspondence and chromatic correspondence.

Concerning the light, it might seem a banality, but if you take pictures of the same facade of a building in different times of the day (and of the year), you'll immediately notice how its appearance is mutable depending on its light variations.

Even if each facade has been painted with the same color, the results will be different because the photograph collects not only the color but also the brightness.

The Architectural Survey should collect the real color, not changed by any light source, available only avoiding any shade or contrast variation, something that currently seems to be impossible. The first problem of light correspondence is caused by surface variability according to the lighting incidence. Flat and small sized surfaces can be evenly illuminated while for the other surfaces approximate conditions can be found.

In the survey of the main front of a building, the only way to provide the most uniform illumination possible is by acquiring the images in complete shade. Cloudy days are normally used to have as less shadows as possible. The problem of color saturation, that becomes well evident in the shade, is easy to bypass with post-production correction of local brightness and contrast (Fig.5). In the inside, the problem is leaved to the total management of the light sources. The procedure normally known and used for the reproduction of the paintings consists in arranging illuminators and diffusers in order to cover homogenously the surfaces to then proceed to the shooting. Another problem of the light correspondence is given by the lack of roughness of the surface, which normally facilitates an homogeneous illumination. Glossy surfaces are instead affected by the reflection phenomenon, thus representing a real obstacle to their color survey. When this phenomenon is generated by glass surfaces, the acquisition can be performed with polarizing filters applied to the cameras. Sometimes these filters are also applied on the illuminating light sources.

Each measuring operation involves an approximation process. This happens because the acquisition transforms some elements of the object (such as the shape) in a series of numerical data, and color (and so the chromatic correspondence) is not exempted from this rule, indeed, it is one of the silent victims.
Cameras typically use a CMOS sensor (Complementary Metal-Oxide Semiconductor), composed by a flat rectangular matrix of photoreceptors able to convert light intensity into electrical energy. Each photodiode records a single chromatic band, but the final result is an image in which each pixel has three RGB values. So the final color is not totally measured but partly interpreted. The corrective software processing, together with high image resolution, makes the matrix interpretation not excessively different from the direct perception of the object.
The CIE 1931 diagram describes all the colors perceived by the human eye. Any three colors on the diagram identify a triangular "color space" that contains the color range (gamut) that the three colors can reproduce. A similar trichromatic structure, in which the colors in the corners are the "primary colors" able to generate all the others, is the basis of almost all color recording and visualization devices.

The additional color reproduction system is based on the RGB triad (Red Green Blue), since these three colors are the necessary and sufficient condition to reproduce a gamut able to almost entirely satisfy our eye.

You can usually set two color spaces in cameras: sRGB and Adobe RGB. The first one (sRGB) matches most of the devices (monitors and televisions) that are used to display and which offer 35% of the totality of color space visible by the human eye. With the Adobe RGB we can cover 50% of the total color space. There is no device capable of recording color space over this percentage.

Despite the great potential and the methodological change, new technologies have not produced a radical transformation of the results, above all for that part of the architectural survey that continues to be identified by drawing (Fig.6). Though a fracture has been created between drawing and digital model, this last one having as main virtue the simulation of the reality by reproducing the outward appearance.

The cloud of points (even if colored) is just a set of coordinates that describe the surface of the object. The visualization of the 3d model satisfies the viewer's eye that browses through the simulated space, giving the sensation to possess the real object. In truth the numerical model represents only a large amount of data still to be processed.

We're just at the beginning. Currently it is important to work on the data with judgment for a deep knowledge, process it and modify it according to a specific goal before any conservation and restoration project. The cloud of points represents only a crystallization of the shape and the appearance of the architectural object. It must be processed in order to be read, studied and measured. Despite the numerical model has formal recognizable features, it must be transformed into a geometrical model to be understood and passed on. At the same time a digitalized architecture, in order to be understood and explained, needs to be converted into a graphic representation as well as into a specific 3D model able to translate dimensional data into useful information for the knowledge of the space (Fig.7).

The Architectural Survey has had a huge technological upgrade due to the development of the last technologies, that's a fact. It is also true, however, that one must beware the charm and the emotion of the " it looks real" that these technologies easily offer, and rather address the results to those representations that favor quality, data readability and transmission of organized and measurable knowledge.
Since the beginning of computer science history, the ultimate goal was to get from a computer the same graphics quality and accuracy achieved by manual drawing.

Today the representation has been enhanced by new media formats, but it is necessary to back them up with many drawings and images (2D) which are ever more necessary to understand, as well as describe and communicate, Architecture.

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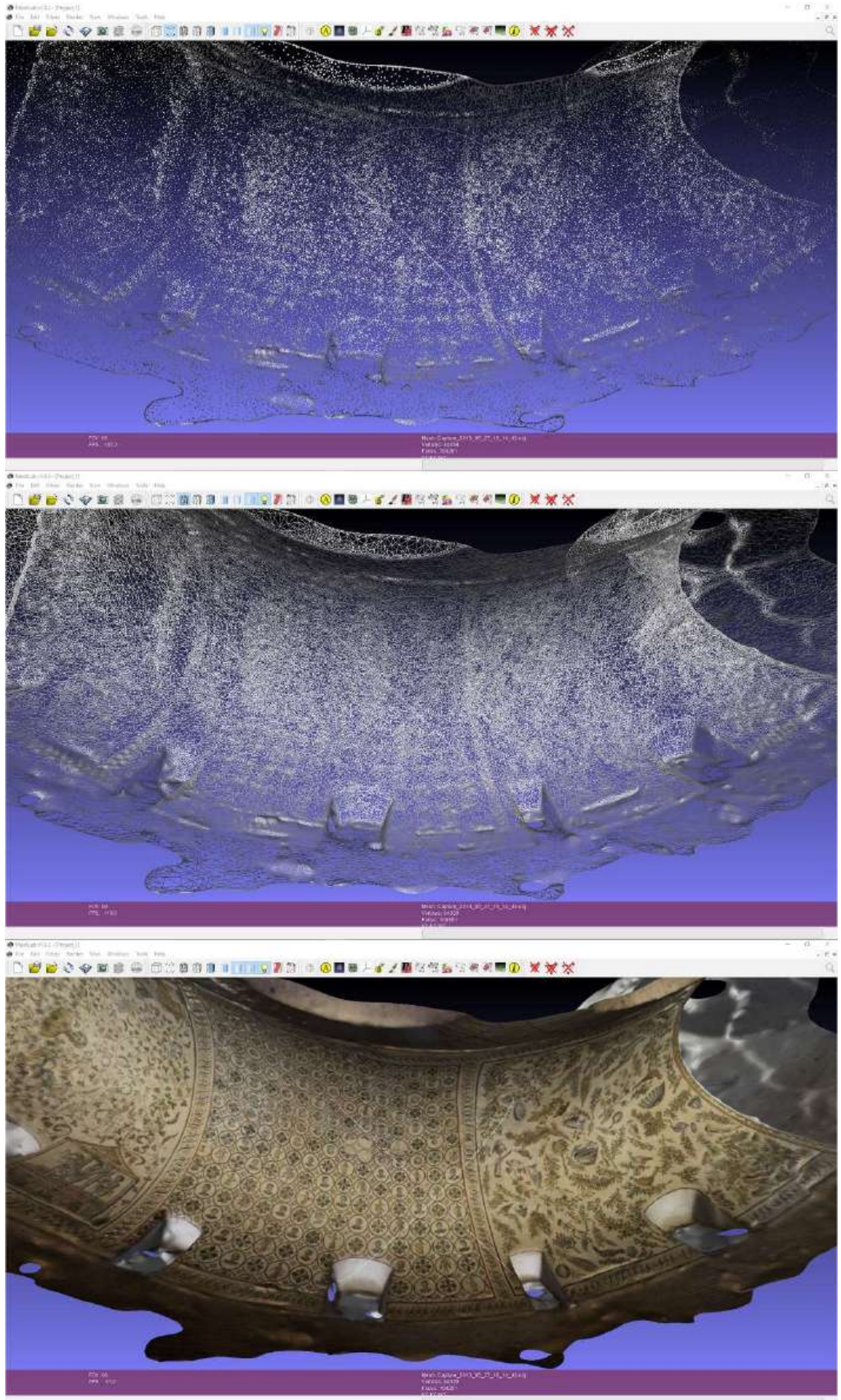

Fig. 1 - Roma (Italia), S.Costanza, annular vault; numerical model (up), mesh model (mid) and textured model (down) (by Marco Carpiceci)

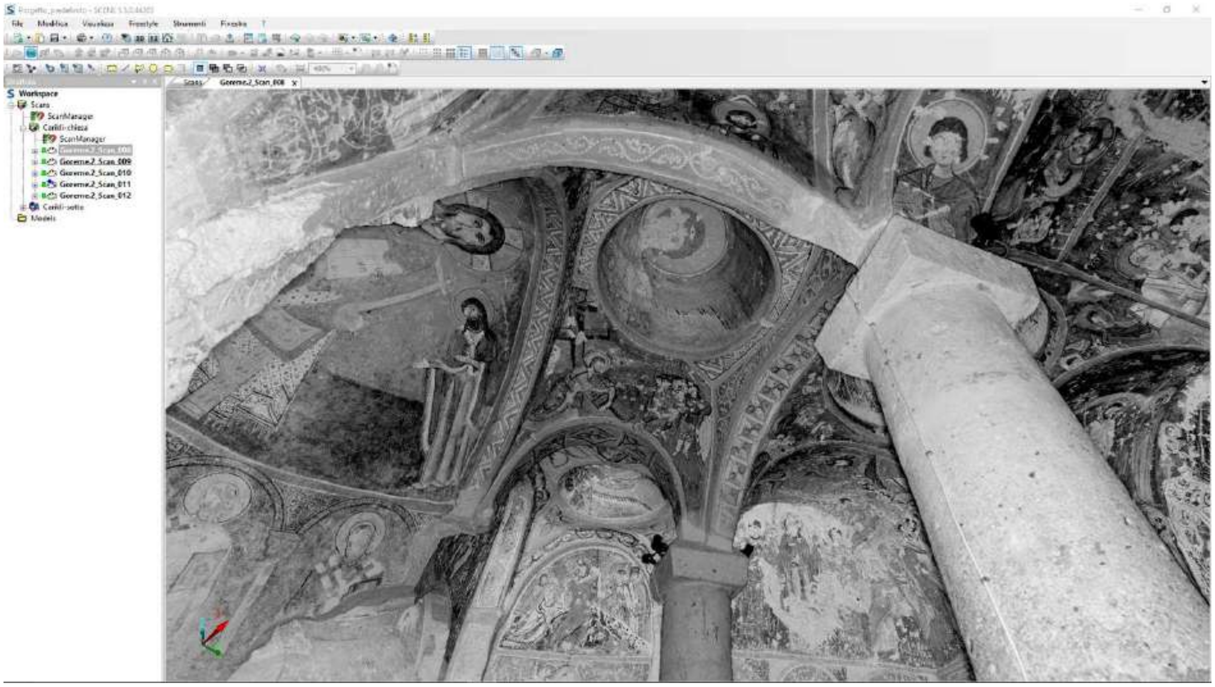

Fig. 2 - *Göreme (Türkiye), Açık Hava Müzesi, Carikli Kilise, reflectance scanning (by Marco Carpiceci)*

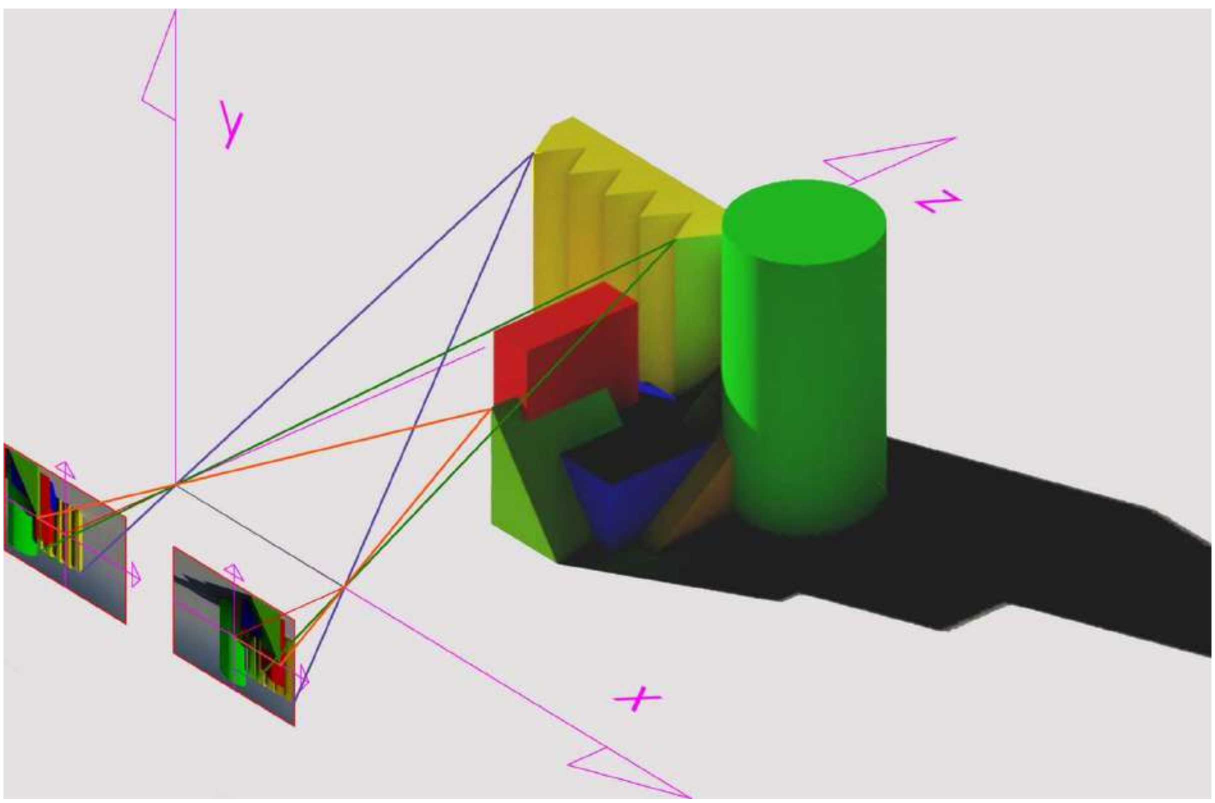

Fig. 3 - The stereophotogrammetric model (by Marco Carpiceci)

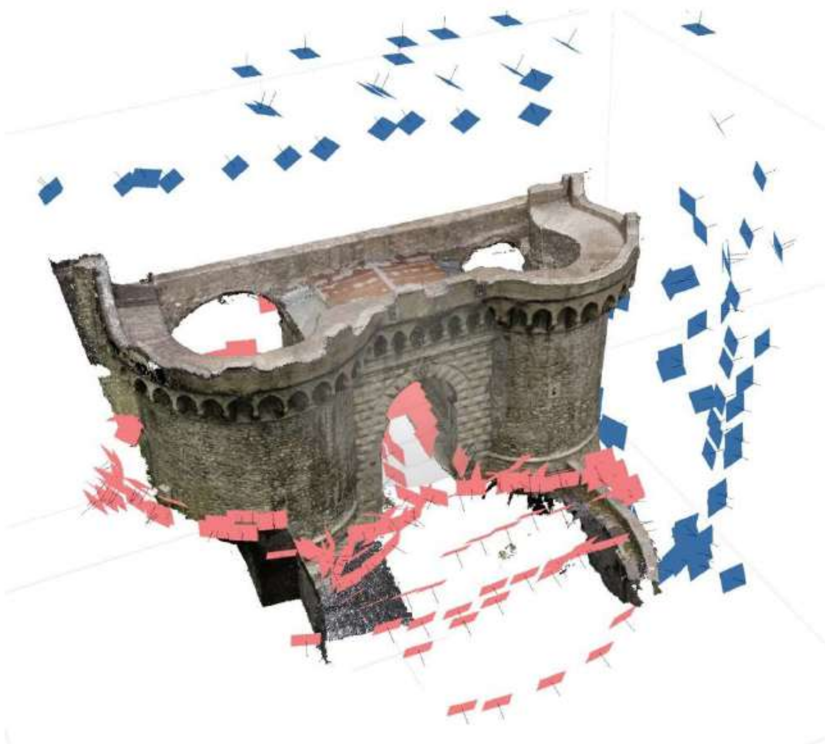

Fig. 4 - Narni (Italia), Porta Ternana; dense cloud and shots positioning (by Marco Angelosanti)

Fig. 5 - Firenze (Italia), Santa Maria Novella, facade; cloudy day without shadows (by Marco Carpiceci)

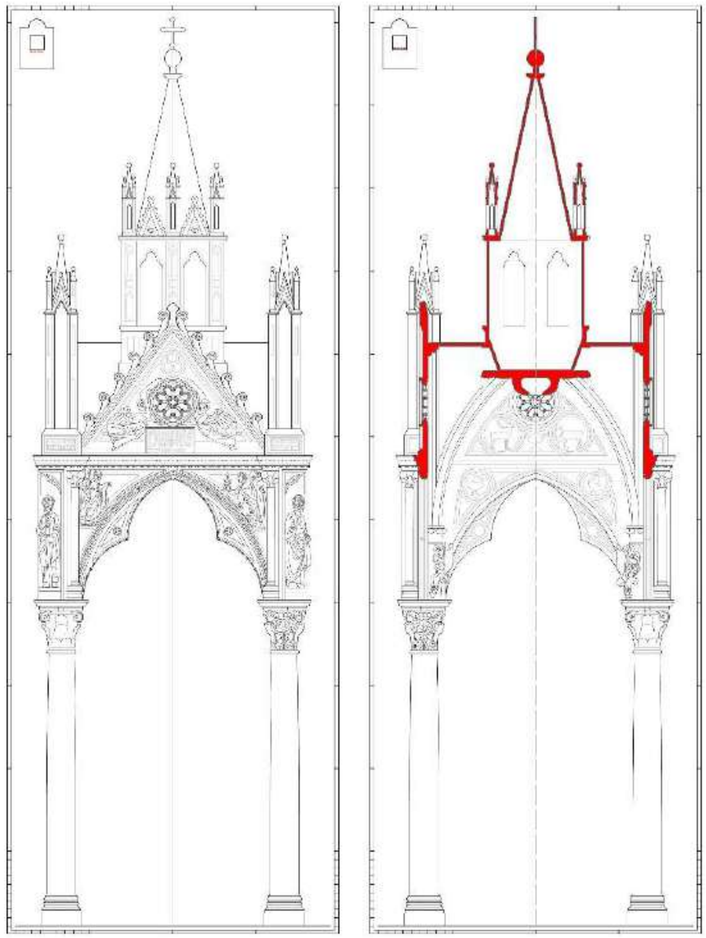

Fig. 6 - Roma, San Paolo fuori le mura, ciborio; West facade and relative section (by Marco Carpiceci)

Fig. 7 - Göreme (Türkiye), Açık Hava Müzesi, Karanlik Kilise; Colored contour lines at different levels (by Marco Carpiceci)

Geophysics For Archaeology: Methodologies And Case Histories

Marilena Cozzolino

Dipartimento Scienze Umanistiche, Sociali e della Formazione

Università del Molise, Campobasso, Italy

Abstract

Terrestrial remote sensing is an important tool to locate, map and acquire information through indirect means from sites of our cultural heritage. The non-invasive geophysical methods that can give information useful for the reconnaissance of buried structures into the soil and analyse monuments, historical buildings and urban centres are numerous. Beyond the implemented method used in the survey, the procedure of geophysical analysis is based on the concept of "anomaly". The measurement of a given physical field (electric, magnetic or electromagnetic) generates always the same value in a homogeneous and isotropic soil. On the contrary, in proximity of a buried body with different physical features respect to the surrounding material, the measured value tends to differ from the unperturbed value: the observed physical field indicates an anomaly that is a variation respect to the reference value relative to the homogeneous condition. Therefore, considering these variations, it is possible to hypothesize the nature and the geometry of the hidden bodies.

The principal problem during the survey planning is the definition of the physical parameter to measure and analyse for the optimal characterization of the buried structures inserted in a definite context. Taking into account the probable type, dimensions and depth of the submerged bodies, the logistics of the investigated area and the geological and physiographical characterization of the soil different methods can be implemented. This contribution gives information about the potential of geophysical prospections through the discussion of case histories in Molise Region that involve the application of non-invasive diagnostic detection systems, in the field of applied geophysics, specifically in the field of preventive diagnostics, urban centres, archaeological parks and historical monuments.

Key words: Ground-based geophysical methods, buried archaeological structures, Cultural Heritage of Molise Region.

Introduction

In recent years, significant technological advances have produced benefits in the field of geophysical prospecting applied to archaeological research. Modern, portable and easy-to-use devices allow the management and automatic control of data acquisition operations and are equipped with electronic memories for storing recorded values. With simple operations, the detected data is directly transferred to the computer for automatic processing and graphic display in the form of charts or graphs of the collected information, displaying the various burial structural features and allowing reaching the archaeological interpretation.

The planning of a geophysical survey should be prepared, in agreement with the archaeologist, by hypothesizing the type, size and depth of the finds in the subsoil. All this, compatible with the logistics of the survey area and considering the nature of the terrain on which to operate, allows to plan the most suitable surveys for the study of a particular area.

Data acquisition generally takes place on lines where instrumentation readings can be performed continuously or at regular intervals. If the target that detection has to discover under the surface is linear and stretched, such as a foundation, a wall or a channel, the best profile is obtained perpendicularly, as far as it can be estimated. Sometimes several parallel profiles are needed to see how much the body extends into the ground or changes its size. If the target is irregular, the best strategy is to acquire data in a grid in which profiles are acquired with a regular step[51].

Often, the raw readings provided by the instrument cannot be used directly because of the so-called environmental noise due to undesirable variations in the magnitudes that are being measured. Such disturbances may be due to various causes: intrinsic soil (inhomogeneity), topographic (irregular topography can generate unacceptably effects), anthropic (electric lines, piping or other objects buried). A common way to improve the signal is the acquisition of a large number of data in order to analyse the deviation of each individual measure from the average value. When environmental disturbances are minimized, measures must be treated by a reverse procedure, a process that allows to trace back to the physical model and hence to the geological or archaeological model.

Numerous non-invasive geophysical methods can provide useful information for the recognition and discrimination of underground structures in phases preceding the direct archaeological excavations[52]. Generally, they are classified into two main categories: passive methods and active methods. In the first ones, the intrinsic properties of the soils are directly measured as in the magnetic method, the gravitational method and the Self-Potential (SP) method; in the second ones, the terrains are energized with artificial fields and the resulting disturbances are measured. This category includes seismic, electromagnetic, electrical and Ground Penetrating Radar method (GPR).

Passive methods

Among the passive methods, the magnetic method is the one that has had a wider application in archaeology[53]. It is because the underground rocks have magnetizations that differ from the surrounding ones and thus produce anomalies in the magnetic field on the surface. The magnetization is due to induction by magnetizing forces associated with Earth's field and in part remnant magnetization[54]. The first is based on the difference between the magnetic properties of the abnormal source, as the archaeological structure, and those of the soil in which the structure is embedded[55]; the second phenomenon is influenced by the characteristic of materials to assume a permanent

[51] MUSSETT - KHAN 2003.
[52] CLARK 1989.
[53] SCOLLAR *et al.* 1990; BECKER 1995; COLE *et al.* 1993; NEUBAUER *et al.* 1998; PIRO *et al.* 1998.
[54] PARASNIS 1997.
[55] WEYMOUTH 1986.

magnetization after being subjected to very high temperatures[56]. It allows the identification of certain archaeological structures, such as furnaces, thermal systems and brick walls, in which the material has been subjected to very high temperatures.

The gravimetric method has been used by geophysics for archaeological studies since 1965[57]. It consists in measuring the relative variations of the Earth's gravitational field. Minor variations in gravity are due to changes in the density of underground materials or in the presence of underground constructions. If there are dense and compact rocks in the subsoil, gravity is greater than areas where smaller densities are present, such as sand, clay or untied material. As the value of the gravitational field measured in a given instant, at a certain point, can be influenced by a large number of factors, an accurate data correction is needed to determine the archaeological anomalies.

The Self-Potential (SP) method measures the potential difference of a natural field that occurs spontaneously between two points in the ground due to the underground circulation of aqueous electrolytic solutions in porous media. The equipment of the SP method is very simple and consists of a pair of low noise unpolarizable electrodes inserted into the ground connected to a digital voltmeter[58]. The procedures of data acquisition are essentially two: in the first, the two electrodes, whose distance is fixed, move simultaneously along the profile and, in each position, the difference of potential is detected; in the second, an electrode is fixed in a point while the other moves along the line to be probed. Given the simplicity of the devices, data acquisition operations take place in a fast way.

Active methods

Active geophysical methods are more widely used in archaeological explorations.

The Induced Polarization (IP) method detects voltage time decays or resistivity frequency spectra using unpolarizable electrodes. An IP source is connected to the oxide-reducing processes along the interface between metallic grains and interstitial fluids (electrode polarization). Another substantial source of IP refers to ionic accumulations in moving electrolytes because of variations in mobility along the pathway[59].

The Electrical Resistivity Tomography (ERT) has been used by many geophysics for archaeological investigations since the 1960s[60]. The electrical resistivity parameter, on which the method is based, has such a large variability to allow the great majority of the structures and bodies of archaeological and architectural interest to be readily distinguished, in principle, from the hosting material. In general, the rock resistivity depends on many factors, as water content in fissures and fractures, porosity, degree of saturation and nature of pore electrolytes. In dry state, most rocks are non-

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[56] SCOLLAR 1990.
[57] LININGTON 1966; KOLENDO *et al.* 1973; FAJKLEWICZ *et al.* 1982.
[58] CORWIN 1984; CORWIN - HOOVER, 1979.
[59] CAMMARANO *et al.* 1997.
[60] AITKEN 1974; PATELLA 1978; BERNABINI *et al.* 1985; ORLANDO *et al.* 1987; LA PENNA *et al.* 1992; CAMMARANO *et al.* 1997.

conducting, i.e. they have extremely high resistivities, which decrease rapidly with existence of fluids, usually containing various ions to form the electrolytic solution.

In archaeological prospecting, the presence of a high resistivity anomaly is usually an indicator of some resistive structure, such as the presence of accumulated tiles, a stone wall, building foundation or a cavity respect to the less resistive hosting soil. Instead, the presence of a moist ditch filling in a resistive rock background is characterized by a low conductive anomaly. In the study of historical buildings, where for capillary ascent of humidity and ingression of more or less aggressive waters, internal alteration nucleuses, typically characterized by very low resistivities, become the sources of degradation and even dis-aggregation of structure[61].

The resistivity is measured by means of a device composed of a pair of energizing electrodes that sends the current into the ground and a pair of potentiometric electrodes that measures the potential difference generated by the current input. Nowadays, sophisticated low-cost multi-electrode instruments are available, which store a considerable sequence of data in a detailed way.

The seismic method involves introducing a pulse of sound into the earth and measuring the time of return of the pulse reflected by discontinuities in mass density and elastic properties of the soil. It have been used in archaeology with relatively little success[62] because of the difficulty of discriminating extremely small times differences related to the interference of the seismic signal caused by the buried archaeological structure. In practice, the possibility of recovering archaeological structures, especially if they are disintegrated and dissipated, is very low and, in any case, it is not comparable to the application of magnetic and electrical systems.

The Ground Penetrating Radar (GPR) is one of the methods that has received broader consensus among archaeologists[63]. The use of GPR for the study of archaeological contexts is possible because human activities inevitably alter the natural cycle of soil formation, produce physical and chemical changes within the soil and led to the accumulation of cultural remains. Such alterations can be detected by transmitting an induced electromagnetic field into the ground that is then viewed through a contour map of the subsoil. Certain anomalies shown in such maps reflect changes of basic properties of the electromagnetic field, in its conductivity, electric permittivity and magnetic permeability; those parameters that are interrelated and therefore correspond to alterations caused by accumulations of objects and/or are products of the interfaces between different soil types. The factors that affect system performance are above all the electromagnetic properties of the medium propagation that determine the depth of investigation, which therefore varies from point to point. However, as medium mitigation is a function of frequency radiated, the use of low-frequency antennas can generally extend the depth of penetration of GPR signals but can also generate the loss of resolution. During data acquisition, two parameters are measured: the time in which the electromagnetic wave fulfils the path transmitter antenna-discontinuity-receiver antenna (two way time) and the amplitude of the wave. The two way time depends on the velocity with which the wave spread into the materials and gives information about the depth of reflectors. The amplitude represents the amount of energy that returns to the surface and depends on the energy of the transmitted wave,

[61] CAMMARANO *et al.* 1997.
[62] AITKEN 1974; CARABELLI 1967; CARSON 1962.
[63] CONYERS - GOODMAN 1997.

on how much of it is dissipated along the path and on the contrast in the electromagnetic properties of the materials that determine the reflection surface.

Electromagnetic (EM) methods are based on the measure of electromagnetic fields connected with alternate induced currents into the subsoil by a primary magnetic field. In different methods, the induced field is produced by the passage of the current through a transmitter coil or a metallic antenna[64]. The primary magnetic field spreads above and below the ground and therefore through probable target bodies. The induced currents generate a secondary electromagnetic field that usually differs in intensity, phase and direction from the primary field and allows detecting probable hidden targets. A receiving coil receives the secondary field. The signal depends on multiple factors such as the type of material (higher is its conductibility, stronger is the current), the form and the depth of the hidden target and the position of the transmitter and the receiving coil.

Selection of the best geophysical method for archaeological purposes

The evaluation of the survey methodology to be used is a very important factor that can seriously undermine the success of research for archaeological purposes. This choice depends on many factors: geological, economic, logistic and purely geophysical factors. It is principally managed by the purpose of exploration and by the contrasts of geophysical properties in the elements present in the subsoil that may highlight, with more or less marked anomalies, the supposed structure. The issues on which geophysics are addressed may concern the search for objects such as tombs, foundations of buildings, furnaces, canals, trenches, etc. or the resolution of problems related to the restoration of buildings of historical interest such as cases where it is necessary to assess the extent of fractures or water infiltrations in the walls. Depending on the type of problem, the environment in which working and the type of instrumentation to be used, the methodology that can lead to better results is selected.

A uniform soil, composed by fine materials and with moderate magnetic susceptibility, represents a good condition for the realization of a magnetic prospection while sandy soils, surface irregularities, volcanic blocks or a shallow irregular rock bottom can be less advantageous. Moreover, the extreme sensitivity of the magnetic method to iron and its derivatives results in a number of problems. They allows identifying shallow archaeological objects, but the interpretation is more difficult when they are close to anthropic structures, influencing the field they produce[65]. These unfavourable conditions can be considered as stationary noise that can be treated with common filtering techniques. This type of prospecting has very rapid implementation times, but it is not compensated by the excellent resolution of the structures. For this reason, the magnetic method is useful especially in the study of large areas for an overall overview of the archaeological site.

The gravimetric method can be useful for locating deep targets such as cavities, caves, galleries or areas of strong mineralization, but it is less effective in detecting small and shallow archaeological objects[66]. It is frequently applied only to get a large-scale mapping of sites.

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[64] TELFORD *et al.* 1976.
[65] PIRO 2001.
[66] LININGTON 1966.

The SP method has been widely used in archaeology[67] considering not only the simplicity and low cost of the equipment but also the discrete results that can be obtained from such an analysis. The anomalies observed at archaeological sites are mainly due to diffusion phenomena as the compact structures represent elements of significant discontinuity in the subsoil that affect the circulation of water in the soil by acting as drainage structures (tombs, terrains disturbed in historical times by anthropic activity) or obstructing normal water circulation (buried foundations, wall remains). This is detected by an abnormality in the surface electrical field[68].

The use of the IP method in the field of archaeology has achieved moderate successes. It may be useful to obtain indications for the recognition and geometric definition of anthropogenic metal bodies as well as to better evaluate any changes in the physical properties of buried bodies following interaction with water.

The GPR method provides high-resolution sections but it has limited penetration that, in the case of high conductivity rocks such as clay, is reduced drastically to a few decimetres. It appears to be particularly unsuitable if applied on disconnected ground but it is very useful in studying historic buildings (fracture detection) or when working on paved surfaces: in these cases, it is the less invasive methodology.

The EM method is susceptible to the presence of moisture present in the soil that can hinder the detection of objects at high depths and provides resistivity sections with a low resolution. Given the speed with which the survey is conducted, the method is mainly used to have extensive area information that is being analysed.

The ERT method, although having shorter acquisition times than other methods, is effective because it provides easily interpretable results, it is very versatile to variations in soil conditions and it is ideal for the detection of very deep structures.

During the planning of a research, all the aspects that have just been discussed must be taken into account. The ideal condition would be to integrate different methodologies, if environmental conditions allow it, so that comparisons could be made and geophysical anomalies could be better identified.

Examples of geophysical prospections in the Molise Region (Italy)

The Molise Region is located in southern Italy. It has a rich archaeological and architectonical heritage that testifies the complex history of its territory from the prehistory until present[69].

The most ancient proof of the human presence in Molise is attested by the Upper Paleolithic settlement of Isernia La Pineta, dated back about 700.000 years BP[70]. The site represents a unique example in the history of the human frequentation in Europe for the presence of a great number of

[67] WYNN - SHERWOOD 1984; CAMMARANO 1996.
[68] CAMMARANO *et al.* 1997.
[69] DE BENEDITTIS 1979.
[70] COLTORTI *et al.* 1982; ESU 1983.

paleontological finds associated to lithic artifacts and for the complexity of the site. More recent prehistoric evidences are indicated at Rio Verde (Pescopennataro, IS), Piana S. Mauro (Carovilli, IS), Fonte Curello (Carovilli, IS), Grotta Reali (Rocchetta a Volturno, IS), Morricone del Pesco (Civitanova del Sannio, IS), Monte S. Croce (Cerro al Volturno, IS) and in the Biferno Valley[71].

Between the IV and the I century BC the panorama of the territory is characterized by the presence on the major mountains of about thirty Samnites fortifications, built with the technique of *opera poligonalis* and in communication between them through transhumance routes, the so called *tratturi*[72]. The remains of Pietrabbondante[73], the small temples of Vastogirardi[74] and S. Giovanni in Galdo[75], the fortifications of Terravecchia di Sepino[76] and Monte Vairano[77] are example of the Samnites culture.

The city of *Saepinum* is the symbol of the history of Roman civilization: in the VI century BC it was a commercial Samnitic *forum* and a service centre, then it became a Roman city of taxation and in recent times, it was transformed into a medieval and modern rural village[78].

The monastery of San Vincenzo al Volturno[79] and the necropolis of Campochiaro[80] attest the early medieval phase.

The cathedrals of Trivento, Guardialfiera, Termoli and Larino and the castles of Civitacampomarano, Roccamandolfi, Cerro al Volturno, Termoli, Venafro, Gambatesa and Campobasso are also noteworthy testifying the middle Ages through their stories and their transformations, representing important pages of the history.

The overview of the historical and cultural reality of Molise provides guidance to understand how much hidden heritage there is still in this area, to explore and exploit, but on the other hand, how much known heritage exist to protect and monitor preventing the destruction and the loss. In this context, the use of non-destructive geophysical methods becomes a valuable tool of cognitive investigation immediately in the bud of any archaeological verification projects, restoration and architectural restoration, safeguard through preventive archaeology operations, exploration of large areas within archaeological parks and redevelopment of city centres. From 2000 until present, a fruitful collaboration between the University of Molise (Supervisor Prof. Paolo Mauriello) and the Regional Directorate of Cultural Heritage of Molise has led to undertake significant actions of intervention for the knowledge and the preservation of the ancient landscape.

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[71] BARKER 1975; GRIMALDI 2005; MINELLI - PERETTO 2006.
[72] AA. VV. 1980.
[73] CAPINI - DE BENEDITTIS 2000.
[74] MOREL 1984.
[75] STEK 2010.
[76] MATTEINI CHIARI *et al.* 1984.
[77] DE BENEDITTIS 1974, 1988.
[78] GAGGIOTTI - MATTEINI CHIARI 1979; DE BENEDITTIS 1981.
[79] MARAZZI - DELOGU 1996.
[80] CEGLIA 1988.

The project involved a reconnaissance activity oriented to a definition of a geo-referenced archaeological map, a critical analysis of the archaeological literature and a multi-scale and multi-methodological analysis through non-invasive diagnostics. The focus of the research has been placed on both the most important archaeological sites than on the recent findings following the surveys carried out in the frame of important public works (pipelines) or during the preliminary survey for photovoltaic and wind systems (in application of the regulations relative to preventive archaeology according to the articles 95-96, d.Lgs 163/2006). All data were stored in a Geographic Information System that allowed drawing up a new archaeological map that gives an updated view of the rich archaeological heritage of Molise.

117 sites have been investigated in the territory of Molise Region (Fig. 1).

Taking into account the features of the sites and the problem to solve, the method of prospection has been chosen for each site in order to obtain the better result:

- ERT was implemented in 76 surveys. Even if the time of data acquisition is higher than in other methods, it is very advantageous because it gives easily interpretable results, is very versatile and is ideal for the individuation of deep structures.
- The EM prospections were realized in 28 sites in order to have, in a very fast way, extensive information at a wide scale of the analysed territory.
- The GPR surveys were realized in 13 cases. It was unsuited to being applied on uneven soils but it was very useful for the study of historical building and for the analysis of paved surfaces.

Geophysical prospections were realized with the following purposes:

- Acquiring information about structures still buried into the soil of 60 well-known archaeological sites.

  ERT surveys were carried out, for example, at Fonte Romita, Capracotta (IS) (site No. 21 in Fig. 1). It is the place where in 1848 an important Osco inscription (the so-called Tavola of Agnone) was discovered, currently preserved at the British Museum. The tomographic map relative to 1 m in depth has been linked to the structures (shown with blue), currently buried, found in the excavations in 1980[81] (Fig. 2). Clear resistive alignments are evident with a trend and orientation similar to that of the already known constructions. The series of environments almost certainly belongs to a Sannitic farm.

  The ERT was also applied at the site of Grotta Reali at Rocchetta a Volturno (IS) (site No. 89 in Fig. 1), one of the most important prehistoric contexts in the region where numerous fossils and artifacts related to Neanderthals were found[82]. The investigation, realized with the aim of understanding the succession of the Musterian site located on the walls of a travertine bench, allowed to outline the geometry of an occluded portion of the prehistoric cavity and to represent three-dimensionally a high resistivity vertical body (identified by excavations and corresponding to a travertine column)[83] (Fig. 3).

[81] RAININI 1996.
[82] MINELLI - PERETTO 2006.
[83] COMPARE *et al.* 2009.

Another example is site No. 53. It is located in Piazza Celestino V in Isernia where excavations brought to light a section of the walls of the Roman colony[84]. The purpose was to verify the existence of other archaeological structures still buried beneath the pavement of the modern square. Fig. 4 shows the resulting slice expressed in the time window from 9 to 24 ns (two way time). On the east side of the trench excavation, the presence of small straight anomalies has led to hypothesize the continuation of some medieval walls leaning on the blocks in polygonal technique. In the northern part of the wall, high amplitude spots seem to attest the presence of the continuation of the wall circuit within the subsoil. On the west side of the slice, two segments forming an angle of 90° are observable and could correspond to the corner of a buried structure[85].

Fig. 5 and Fig. 6 show the results of the geoelectric surveys carried out at the Roman villas of S. Maria Vecchia[86] (site No. 62 in Fig. 1) and Valle Porcina (Colli a Volturno) (site No. 27 in Fig. 1). The results show clear evidences of buried structures.

- Identifying the three-dimensional features of buried structures whose presence is supposed to high concentrations of finding detected by pedestrian surveys in 26 sites.

  An example is the site No. 77 located in the south eastern part of the Portocannone (CB) (Fig. 7), where the archaeological surveys (conducted by Prof. C. Ebanista, University of Molise) highlighted the presence of abundant archaeological material such as to hypothesize the presence of a complex structure. ERT was carried out in order to clarify the geometry and extension of the presumed archaeological constructions buried on a surface of 100x40 m. From the study of the resistivity map, it was possible to detect several anomalies with respect to the median values measured in the survey area. The main element, indicated by a magenta-colour arrow, is represented by a probable archaeological structure of rectangular shape whose major side develops in NE-SO direction. Within it, it is even possible to perceive a division in smaller elements. Interestingly, there are also straight-line heterogeneities, marked with blue arrows, located northwest of the investigated area and linked to the previous anomaly: they are perpendicular to each other and appear to be confined by delimiting a likely outer courtyard.

- Verifying the presence of archaeological evidences in 23 areas in the frame of actions of preventive archaeology for public or private works (building restorations and installation of pipelines, photovoltaic and wind systems).

  An articulated study was carried out near the Industrial Area in the Pozzilli plain (IS). The area has a high archaeological potential as evidenced by the many findings that have occurred during the construction works of industrial buildings and the creation of roads. In particular, traces of the Augustus aqueduct[87] and an archaic necropolis dating back to the VI and V centuries BC[88] were found. EM and ERT surveys have been carried out on a large area covered by private works. An example is shown in Fig. 8 (site No. 78 in Fig. 1): in correspondence of

[84] TERZANI 2005.
[85] AMATO *et al.* 2016.
[86] PAGANO *et al.* 2005.
[87] SCAROINA 2004.
[88] CAPINI 1989.

an abnormal light-colour trace visible on the satellite image of Google Earth of October 15, 2005, geophysical surveys have identified a rectangular structure with East-West orientation. The archaeological digging, conducted by the Superintendence of Archaeology of Molise, has verified the existence of a small Roman building precisely in the point signed by the geophysical anomaly.

Another example is the prospection carried out in the territory of S. Giacomo degli Schiavoni (site No. 98 in Fig. 1). In this case, the results of EMI surveys clearly show some very high resistive anomalies probably attributable to buried archaeological structures (Fig. 9).

- Providing a proper representation of the conservation status of 8 historical buildings (churches and castles) for the display of potential structural anomalies, the location and extent of hidden structures inside the walls and the individuation of wet points into the walls. As example, GPR surveys were carried out on the façade of the Cathedral of Termoli (Site 112 in Fig. 1) with the aim to ascertain, if there were, structural damage, likely due to a masonry expansion on the portion beneath the rose window. Fig. 10 shows the slice in the time window from 5-10 ns (two way time). The results obtained put in evidence that the areas marked by darker shades, which tend to red, indicate greater amplitudes of reflections relative to materials characterized by pores or voids produced by erosion, such as the oldest sandstone blocks. Areas characterized by lighter shades with less amplitude of reflections, can be traced back to more integer limestone blocks, which, on the contrary, have no obvious signs of degradation. Thus, it can be assumed that the masonry expansion is due to a reaction of the structure in response to the pressure exerted by the limestone blocks on sandstone, more fragile and lighter and therefore not to damage due to external causes.

The shown cases represent excellent results of geophysical surveys. However, it is not always so. In some cases, the surveys revealed no abnormalities attributable to archaeological structures or intercepted natural rocks into the soil. Even negative results such as these are, however, an important cognitive element because it allows concentrating excavation works only in areas where fruitful results can be really reached.

All data were finally implemented in a Geographic Information System (GIS) that allowed an updated view of the rich archaeological heritage of Molise through the production of a computerized map of submerged and "invisible" heritage. This product, constantly updating, perfectly integrates with the existing information systems relating to "visible" archaeological sites and represents an operational tool for institutions for the definition of guidelines for knowledge, study, protection and promoting the Molise Cultural Heritage.

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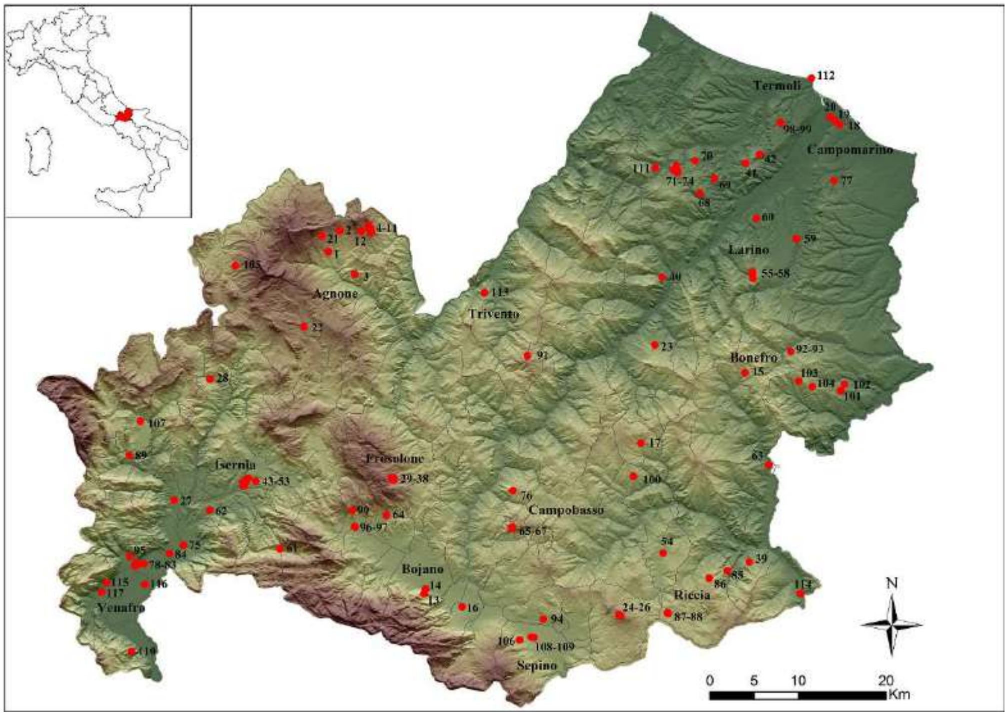

Fig. 1 - Molise Region: localization of the 117 surveyed areas.

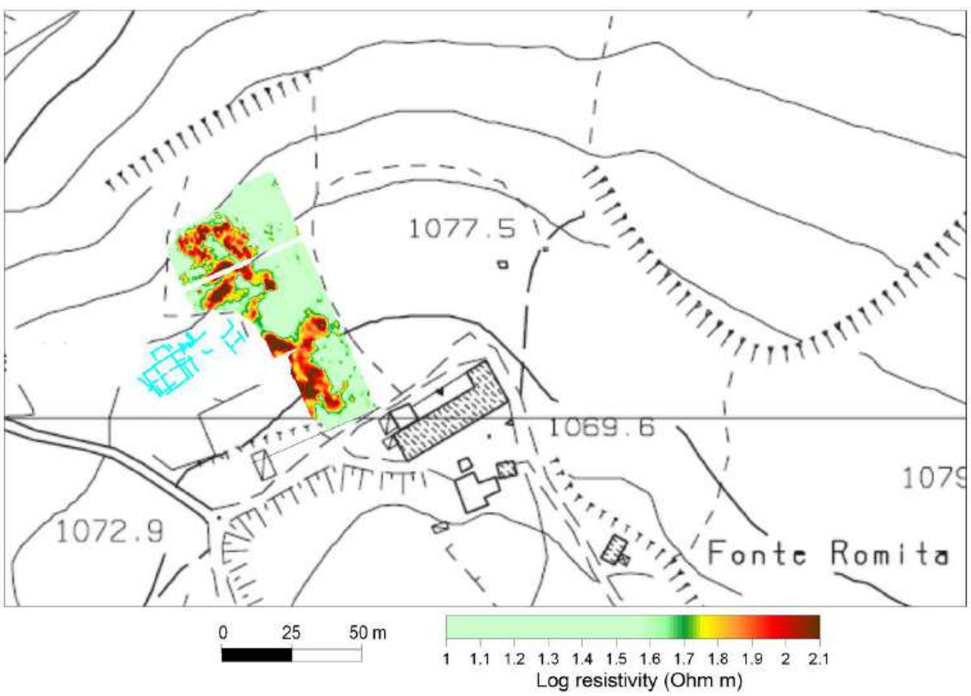

Fig. 2 - Fonte Romita (Capracotta): electrical resistivity tomography relative to 1 m in depth.

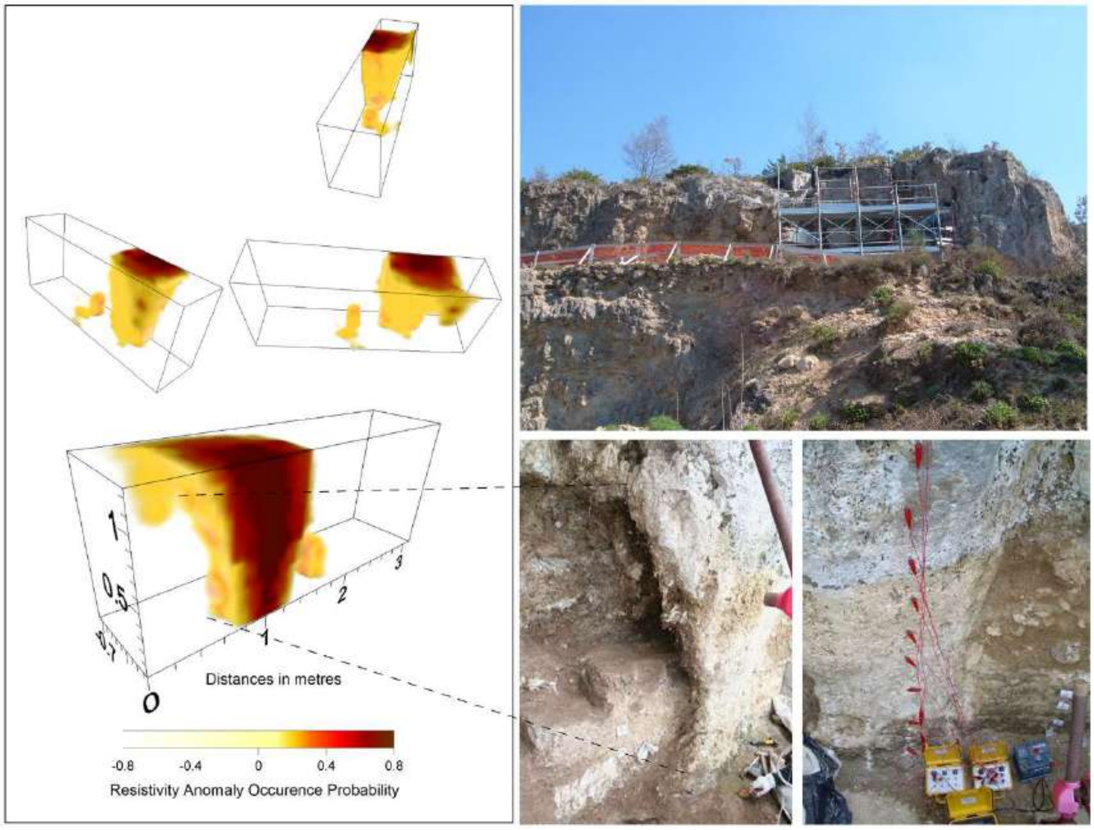

Fig. 3 - Grotta Reali (Rocchetta a Volturno): electrical resistivity tomography.

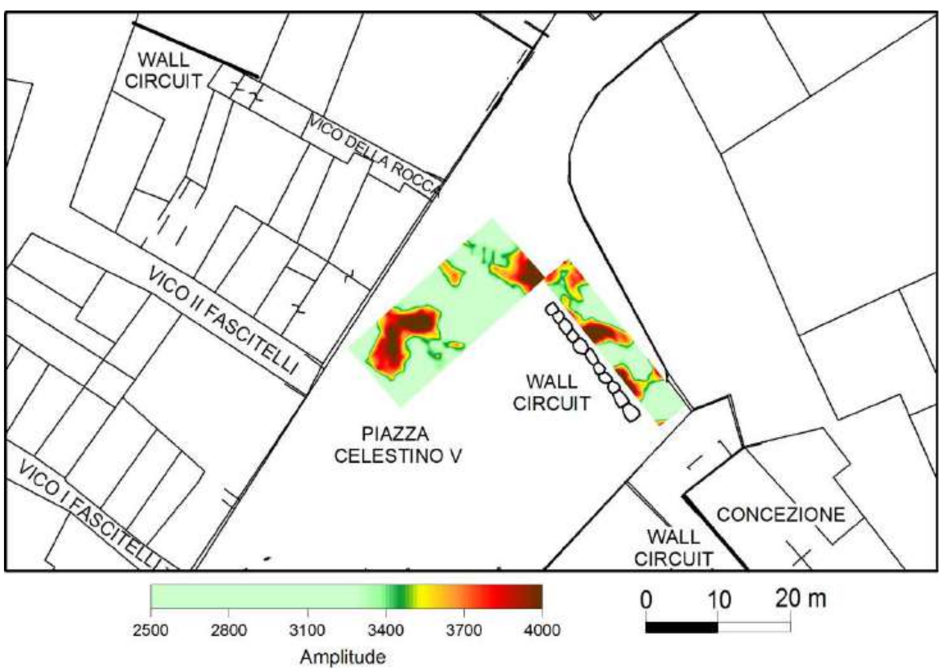

Fig. 4 - Isernia: time slice in the time window from 9–24 ns.

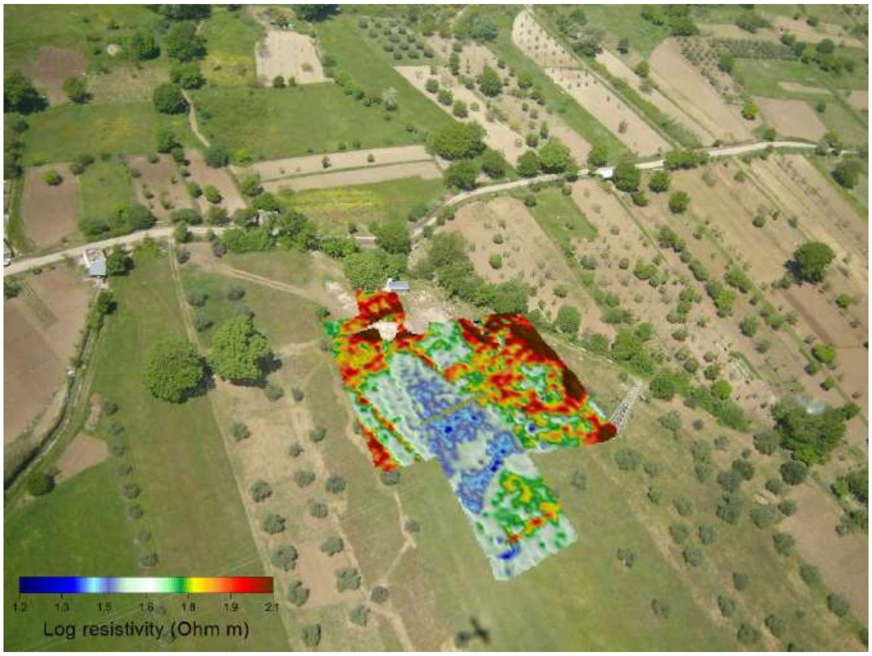

Fig. 5 - Roman villas of S. Maria Vecchia (Macchia d'Isernia): electrical tomography relative to 1 m in depth.

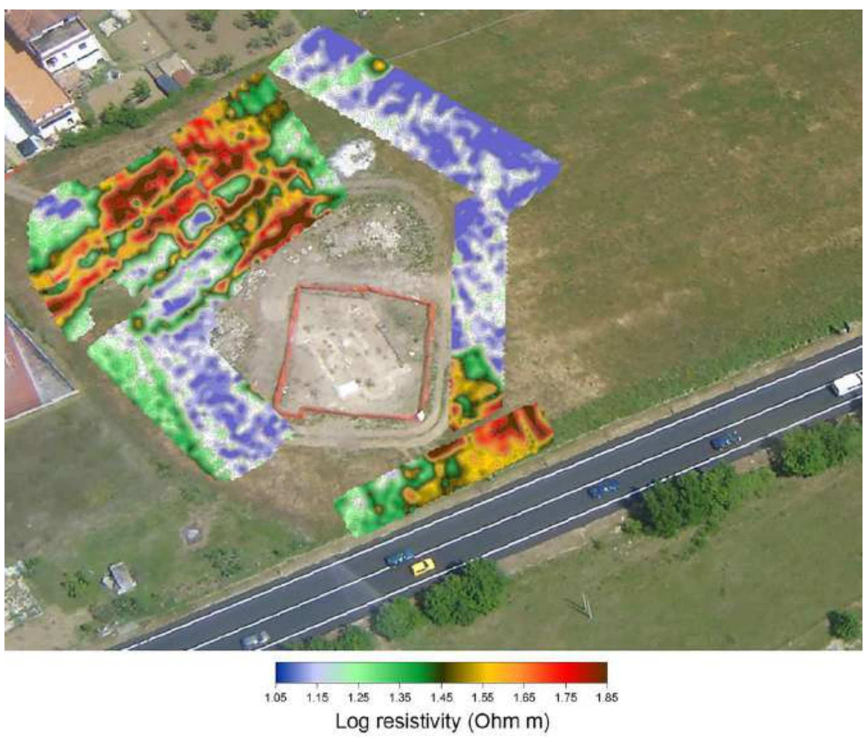

Fig. 6 - Roman villas of Valle Porcina (Colli a Volturno): electrical tomography relative to 1m in depth.

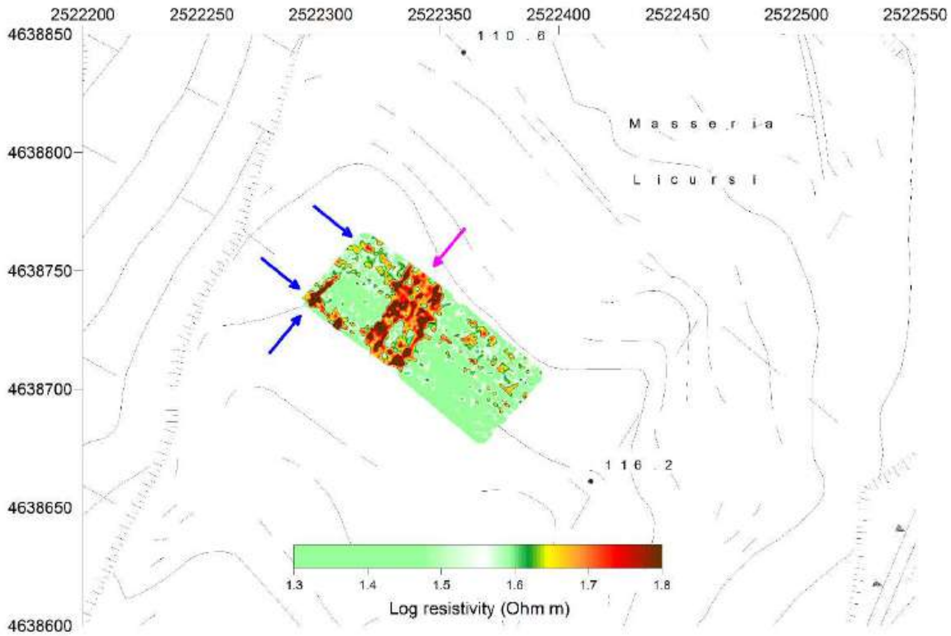

Fig. 7 - Portocannone: electrical tomography relative to 1 m in depth.

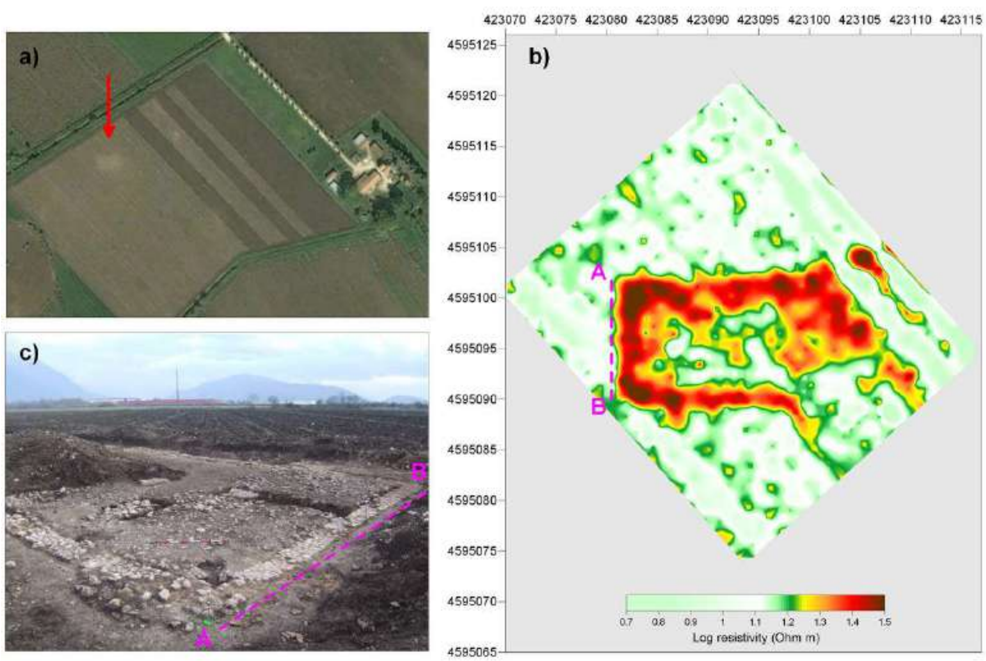

Fig. 8 - Industrial Area of Pozzilli. a) light-color trace visible on the satellite image ©2013 DigitalGlobe Inc. di Gloogle Earth™, October 15, 2005; b) geophysical anomaly; c) picture of the excavated structure.

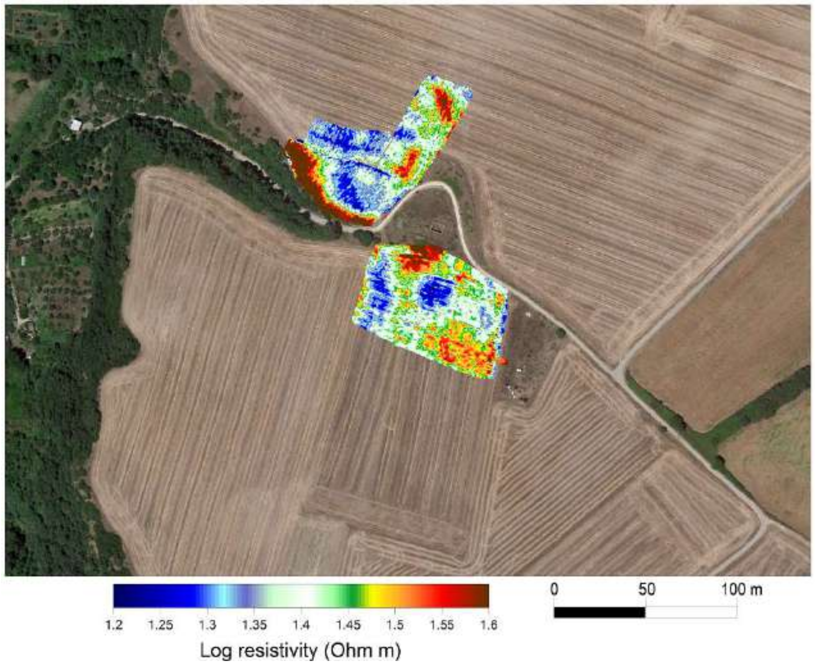

Fig. 9 - San Giacomo degli Schiavoni: EM results.

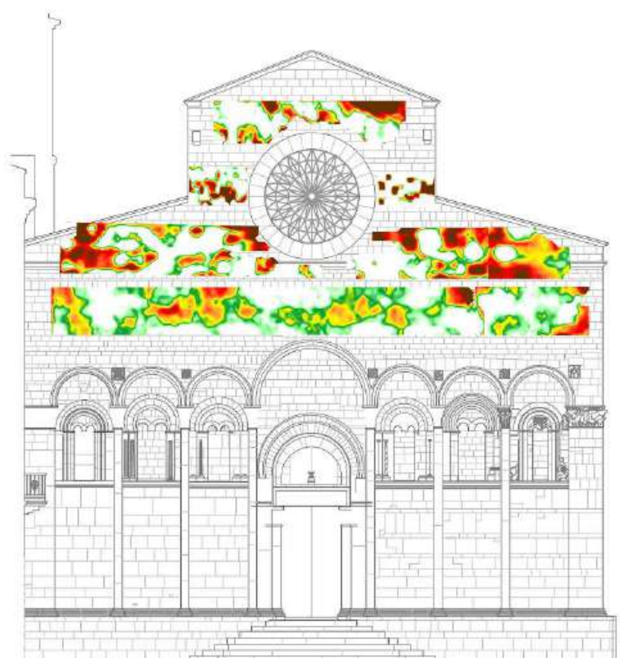

Fig. 10 - The Cathedral of Termoli: slice in the time window from 5-10 ns (two-way time).

TECHNOLOGIES AND TECHNIQUES APPLIED TO THE RESTORATION IN THE CIERA WORK-SITE SCHOOL

Giuseppe Fanfoni

Centro Italo-Egiziano per il Restauro e l'Archeologia

Abstract

The Italian-Egyptian Centre for Restoration and Archaeology has worked in the Architectural Complex of the Mevlevi Dervishes, which is situated in an area of about 10,000 square meters at the foot of the Cairo Citadel. The monumental ensemble shows archaeological, historical and architectural evidence, dating back to the seventh right up to the nineteenth century A.D. Therefore they are constructed using traditional and craftsmanship techniques and technologies. The modern technologies, developed also in Egypt with industrialization, are generally extraneous to the historical monuments. As for us, we have applied the innovations of modern technology only as utilities and technically recognizable supports for the conservation of monuments together with their original technologies and craftsmanship techniques. The organization itself of our work-site school recalls the artisanal laboratory, where each work is experienced in the cognitive and creative process and, with the technical application, one acquires in practice the awareness of the interaction of the intervention in every part of the monument.

The Italian-Egyptian Centre for Restoration and Archaeology (CIERA) operates as a work-site school in a monumental complex at the foot of the Citadel of Cairo, near the mosque of Sultan Hassan.

The Monumental area

The area is approximately 10,000 square meters wide, of which 2,500 meters are covered with debris.

The buildings of the area are (Fig.1):

- The palace of Qusun-Yashbak-Aqbardi; dating from 14th and 16th century.
- The madrasa of Sunqur Sa'di; 14th century, with the underlying archaeological area and remains of different epochs, starting from 7th century A.D., (restored by CIERA 2002).
- The mausoleum of Hasan Sadaqa, (restored by CIERA 2008), adjoining the madrasa with its minaret; 14th century.
- The takiyya, which is the Convent of the Mevlevi Dervishes (Fig. 2); 16th century, (restored by CIERA 2008).
- The Sama'khana, a theatre that was built by Mevlevi Dervishes, where they performed the circular dance, typical of their mystical confraternity; starting from 18th century, (restored by CIERA 1988).

All the architectural remains and testimonies of the area are covering the period from VII to XIX century; therefore, they are made with traditional technologies and artisanal techniques.

The traditional technologies were generally characterized, in architecture, by so-called heavy structures, made with techniques of juxtaposition of constructive elements, assembled with bedding mortars or simply interlocking blocks without mortar (also mud bricks): as for the pyramids and also every building till to the industrialization age.

The modern technologies developed, in the historical industrialization process, a particular evolution by the production of new materials as cement, iron and plastic. Their application elicited advanced technical solutions, e.g. joints, truss beam, frame, to create structures designed to be stable and someway elastic. The Eiffel Tower is the start emblematic reference.

The attraction to modern technologies have exalted human ambition in various technical applications. In the matter of restoration of historical buildings, however, the materials and the modern techniques are useful only to support and preserve the original one and with application of special attentions. Consequently, the continuous and prudent control applied during the restoration intervention, recalls, once again, the artisanal laboriousness to which the very same antiquities belong.

Therefore, the organization of the work-site school evokes an artisanal laboratory, where each work goes through a cognitive and creative process with a new application.

Sama'khana and Sunqur Sa'di madrasa

The Sama'khana has a cubic shape crowned by a semi-spherical dome with a diameter of 10.50 m. The building covers an area of 250 sq m (Fig**.** 3). The geometry and proportions of the plan as well as the vertical section reflect the elaborate symbolism connected with the Samà rite and Mevlevi philosophy (Fig. 4)

The walls of the Sama'khana were suffering from various causes of decay (Fig. 5). The movements of the perimetrical walls caused the interior wooden pillars to deviate out of plumb; those on the east and south were especially affected. At the gallery level, torsion of pillars in front of the mihrab on both sides pushed them outwards. The connecting corner beams were distorted due to the excessive load from the roof structure and from the opening of a stairwell at a later stage. A complex engineering operation was conducted for each of the pillars; this resulted in freeing them from the load, while necessary interventions were made on the pillars as well as the connected beams restoring them to plumb by means of system of steel members support.

In order to ensure the maximum safety load suitable for the public use of the building, beams supporting the floor were integrated (the new ones are painted with an inner red strip for identification). The roof was also restructured and insulated with fiberglass to make it about 50% lighter.

When we started the restoration work in the area, the dome of the Sama'khana was in danger of falling down as it had been flattened and distorted by a great deal of settling of the foundation (Fig. 6a).

The dome, which have a circumference of 34 meters and a structural thickness of 10 cm only, is among the largest and lightest wood-constructed structures in Cairo.

After supporting the dome from the inside with wooden scaffolding, we applied three iron belts on the outside (composed of six elements), one of which at its reins. By tightening the bands gradually and checking the reduction of each marked crack from inside, the dome recovered its original shape as far as it was possible, (Fig. 6b) reducing the perimeter, at the reins, by 20 cm, with the effect of raising the apex of the dome by 12 cm.

The laths forming a covering under and over them were sewn up with strips of wire netting (Fig.7). Glass wool, as a new recognizable material, was put inside the hollow spaces for thermal insulation. Finally, for didactic purposes, a movable panel on the dome extrados allows to see the restoration work that was carried out.

The effectiveness of the intervention for the dome structure stabilization was evident in 1992, when the iron bands, mechanically sliding on the ribs, allowed to absorb any movement solicited by the earthquake, without causing disconnections to the dome.

All parts of the edifice were also sewn together with the support of tie-bars and iron connections system, as an anti-seismic retrofit of the building structures (Fig. 8).

A perimetral concrete “cordolo” inside the thickness of the wall is fitted in deep by iron rods, linking the vertical walls with the wooden structure of the roof and the dome elements. The shape of the roof square has been strengthened by diagonal iron tie-bars anchored to the concrete “cordolo” beam.

Besides, excavations conducted for the consolidation of the foundations of the Sama’khana revealed that it was constructed on sub-structures belonging to the madrasa of Sunqur Sa’di (Fig. 9). We made the archaeological excavation under the Sama’khana in order to recover the madrasa under it. To support the floor of the Sama’khana, a construction of steel beams and columns, resting on the level corresponding to the floor of the madrasa, was introduced. Therefore, the new foundation and the iron floor linking the perimetrical walls was made as an anti-seismic connection at the ground floor level of the Sama’khana.

The excavations that we carried out under the Sama‘khana were very useful for the educational aspect of the work-site school since they required specific techniques and methodologies: the carrying out of an elaborate engineering and artisanal project complemented a methodical archaeological survey that allowed us to bring to light the general layout of the madrasa of Sunqur Sa‘di.

The plan of the madrasa of Sunqur Sa‘di, that was historically thought to have four iwans, was instead characterized by two iwans, one to the west and the other to the east in the qibla position, on the short sides of a central open courtyard with a central area paved with bricks; rooms were on the long sides of the courtyard (Fig. 9).

Half of the courtyard area had been deprived of the bricks (that were probably removed and reused for different purposes) and a fiskiya (fountain) was revealed, of which only the water basin remains. The fountain might have belonged to an older building, as this was an area of urban expansion at the time of Ahmed Ibn Tulun. We also reconstructed the perimeter of the fountain with a steel band, as a visual documentation for visitors.

<u>Rising dampness in the Sama’khana</u>

The walls of the Sama’khana were suffering from various causes of decay. As a result of the penetration of water from pipes in convent area and rising damp along the northern and eastern sides, walls were weakened by the loss of binding material; this caused a concave distortion of the eastern wall at the gallery level (Fig. 5) and salt formation, 2 cm thick in places. The rotting of the wooden beam inside the south wall (belonging to the madrasa) at the ground level resulted in an incline of 20 cm out of plumb of the south wall. On the exterior elevation of the east and south walls we have graphically documented the previous utilization phases.

The northern and eastern walls, made of mixed stones, were consolidated through grouting, i.e. injection of lime and powdered inert with addition of acrylic or vinyl resins, whereas the southern wall (made of bricks) was strengthened with injections of epoxy resins (with an autoclave machine devised by CIERA for didactic purposes).

For the elimination of humidity in the Sama'khana walls, we made two rows of holes, filled with injections of particular epoxy-resins spanning the entire thickness of walls directly under floor level, providing a damp-proof course to solve the problem within the structure (Fig. 18). But the complete elimination of dampness was ultimately ensured by means of a one-meter-wide air space excavated around the Sama'khana with two openings on the north and the south in order to provide continuous ventilation, which effectively solved the problem (Figg. 8, 18).

The paintings

Originally the Sama'khana (the actual shape of which dates back to the early 19th century) on the inside was simply painted in white and ivory yellow, with red and blue squares. The white dome was illuminated by eight windows (the number eight takes on a special mystic symbolism in the Mevlevi ideology).

The static difficulties due to the reuse of the madrasa south wall, very soon produced damage, as a result of which the Sama'khana underwent some repairs between 1854 -1863. The landscape painting of the dome date from this period.

A study of the original paintings with the following restorations and repairs was carried out using ultraviolet shots and analyses of microscopic sections.

In order to keep the paintings and to make it possible to see the dome in the original light, we installed eight simultaneously movable window panes. A special mechanical system was devised and installed around the base of the dome from the outside which allows windows around the dome to the opened and closed with a simple lever on the gallery floor (Fig. 7). Thus, the symbolism of the windows was retained, while the integrity of the painted decoration was saved (Fig. 10).

In the Sama'khana dome, the integration of the missing parts was carried out using reversible colors, technically applied by pointing, "tratteggio" (hatching), or full colour (Fig. 10). In all cases, one section was left without intervention to show the original work.

In the western iwan of the Sunqur Sa'di madrasa, (Fig. 11) the integration of the missing parts of the Quranic inscription was carried out by "tratteggio", in lighter tone that the original parts, in order to differentiate them from the original ones. This way the inscription appear to be homogeneous and undifferentiated when seen from ground level (Fig.12).

Sunqur Sa'di mausoleum

The internal space of the mausoleum has an irregular plan (length of the sides: 8.42 x 7.93 x 8.41 x 7.73m) and reaches, at the top of the dome, a height of 18.80m. The internal space is characterized by two bands of stucco inscriptions: the first is a visual reference at the height of 3 m, and the second, at the height of approximately 7.30 m, marks the transition to the intermediate level of muqarnas, which goes up to the springer of the dome (Fig. 13).

Interior lower stucco band

The lower stucco band was seriously damaged by rising damp and was restored several times; some parts were missing and others were already about to collapse at the time of intervention of the "Comité de conservation des Monuments de l'Art Arabe", from 1915 to 1919.

In some cases, the stucco layer had come off the stone wall as a consequence of the accumulation of crystallized salts between the two materials. In this case we gradually fastened the stucco on the wall, according to its elasticity.

At this level we avoided the use of acrylics in the stucco, because it prevent the porous material from transpiring and cannot endure on wet stucco saturated by salts (more than 11%).

The lower band, at the height of 3 m, is an essential visual reference for the appreciation of the architectural proportions inside the mausoleum.

In our intervention we planned different integrations to reconstruct the visual unity (Fig. 14a).

Frames and repetitive decorations were completely integrated with reproductions obtained from copies of the preserved parts. Inscriptions were completed according to photographs from texts or archives, keeping the new ones 5 mm lower than the original. Those parts that were not documented were integrated according to literary reconstruction; the new letters were reproduced in negative on a level 10 mm lower than the background of the whole inscription. We highlighted the perimeter of the letters with a groove 5 mm deeper, obtaining an optical effect by which the letters come out more visible, even if in negative.

The whole inscription band thus appears unbroken and its essential visual function, in the internal architectural space proportions of the mausoleum, is recovered.

Interior upper stucco band

The cleaning of the upper band required long and precise manual work to remove the many different layers of "scialbatura" until the original surface was reached (Fig. 14b). From a didactical point of view, this kind of practice is very useful to train both the concentration of the students and their manual skills, because when they work with chisels or similar metal tools they have to be very careful to remove the "scialbatura" without nicking the original stucco, preserving also the traces of patina previously formed on the piece.

The upper part of the mausoleum was not attacked by the effects of rising damp, and the percentage of salts here is very low (only trace). The stucco inscriptions and the decorations on the drum and the dome were treated with Paraloid B72 (3%) to protect the surfaces and to facilitate ordinary maintenance.

Restoration of the windows and gratings

Above the upper band of inscriptions, a muqarnas section, 4m high, marks the transition to the drum. The drum, 2m high, is decorated with stucco and eight pentagonal windows, spaced by two false windows. In the middle of each side in the muqarnas section is a group of three windows, geometrically defined by the lines of the muqarnas motif (Fig. 13). Of these groups, only the north side one is original; missing parts were integrated while the others were reinforced with acrylic resin (Acrilic AC 33). Glass was reintegrated with epoxy resin. Then we made a model of the window and enough copies to replace the windows on the other walls.

All the gratings protecting the windows on the outside were restored and a methacrylate plate was attached at the rear of every grating and then their edges were sealed after replacement, so as to ensure protection from dust and weather.

External restoration of the dome

Most of the external plaster of the dome, on the upper calotte, was missing. This plaster was applied by the work of the "Comité", from 1915 to 1919.

A reinforcing mesh was inserted in the new plaster layer to ensure better resistance. A "hilal" was placed on top of the dome.

Exterior stucco restoration and integrations

The consolidation of stucco to reintegrate the cracks and to ensure its adhesion to the wall was performed, as in the interior of the dome, with injections of mortar, brick powder and acrylic resins (Acrilic AC 33), using a total of 170 litres of material for the exterior inscriptions and decorations.

The missing parts of the band of Quranic inscriptions at the top of the dome were reintegrated to regain the complete architectural image of the dome. For this purpose, the letters and their connections were reproduced on the basis of external and internal inscriptions, recomposing missing words. The integration differs from the original inscription in the absence of background decoration and because letters are approximately one centimeter lower than the original (Fig. 14c).

<u>The restoration of the façade of the mausoleum</u>

On the façade of the mausoleum, rising damp interacted with atmospheric pollution causing the formation of black crusts on stone facings.

The crusts formed on the intermediate sector of the façade including the area of the evaporation of rising damp. Crusts are less evident in the soaked lower part and in the upper part not affected by rising damp.

Cleaning the façade stone (with sandblasting machine devised by CIERA), required an attentive action in order to gradually remove the black crusts, leaving only the last patina layer, typical of the stone, not touched by sandblasting (Fig 15). The controlled sandblasting action permitted to identify in some places the red layer of paint which is evident also in microscopic photographs of the thin sections on the stone (Fig. 16). It might be a colouring added in 1869, when, on the occasion of the opening of the Suez Canal, all the Islamic monuments were coloured in stripes of red and yellow. This colouring had penetrated the stone, which was already altered, demonstrating that the monument did not have any colouring before that date.

After completing the sandblasting, we reintegrated the stone ashlars corroded by the action of salts. We preferred an action of integrative restoration instead of a replacement of the ashlars (Fig. 21). We kept the original material and avoided the shock that would be caused by the replacement of ashlars and the consequent settling of the wall structures.

But, even more important, we gave the students the opportunity to practice in proportioning the components of mortars, colouring earths, and to have training for the stone conservation (Fig. 21). Finally, all the external surfaces of the mausoleum, decorations, stuccoes and stone facings were protected with ethyl silicate (Rhodorsil RC90) by Rhone Poulenc and then with water-repellent Rhodorsil H224.

<u>The technique of physically barring humidity in the madrasa and the mausoleum</u>

Leaking water, up to a few centimetres above the floor, has been attested in the mausoleum since the 1980, while the whole of the corridor was permanently flooded. Both inside and outside the mausoleum rising damp caused visible damage to stone facings, plaster, stucco decorations and even wall structures (Fig 13).

In this case, we have resorted to modern technologies as in the new buildings, where an insulated bitumen layer is used for setting a physical block against the water present in the foundations. But, since the new technique was applied to an old building, it consisted of cutting the walls at the base and inserting in it a waterproof layer throughout the entire thickness of the wall (Fig. 19).

We are using special machinery for cutting the walls, made in Italy and sponsored by the Italian firm Ansaldo. It works with a three meters long blade, made by CIERA in Egypt with a special steel alloy, and lodging the sprocket-chain operating the cutting.

The central wall between the iwan and the mausoleum was cut in June 1992 and, after the earthquake of October 1992, in light of the satisfactory results obtained, the intervention was gradually continued on the mausoleum and the madrasa.

After cutting 20-50 cm or more of the wall in the whole thickness, strips of PVC of special shape (from Italian Umiblok) were inserted in the void, with the injection of the particular mixture of expansion-controlled and sulphate-proof ferric cement without chlorides, sponsored by Italian Pagel.

This seam operation has also the characteristics of an anti-seismic structure, since it forms a joining "cordolo" of the all perimetrical walls at the foundation base.

Mevlevi takiyya

The entire Mevlevi complex is a built area of about 2,000 sq m. The restoration intervention was aimed at linking the structures, giving them the necessary support, without changing their structural and compositional characteristics.

An iron cage was made by iron elements placed inside the walls, surrounding and binding all the structures from the foundations up to the roof, where a "cordolo" closes the cage and acts as a support for the roof.

These are the same consolidation principles which have been applied in the Sama'khana, the madrasa and mausoleum, with tie rods in site of the wall, sewing up together the various parts as an anti-seismic retrofit of the building structures (Fig. 8).

The work-site school organization

A fundamental aim of the work-site school is the transfer of expertise to trainees at all levels of involvement in restoration, through participation in the various phases of the whole monuments conservation programme.

All the projects and works concerning archaeology, architecture, structures and the fine arts, were accomplished in the laboratories with the equipment of the Centre, by our staff and trainees.

The convent celles and rooms host the scientific and artisanal laboratories, workshops storage space, drafting rooms, library and the exhibition hall of the training Centre.

The various tasks are carried out, within a context of interaction, in the different specialized sectors from the technical and craft to the scientific and research levels. The wide range of the activities required by the project has called for the presence of workmen, artisans and inspectors offered essentially by the Ministry of Antiquities MoA, as well as students sent by Egyptian Universities for training or to write their academic thesis. Italian students, who volunteer come to gain experience or research for their thesis, engage in activities alongside their Egyptian counterparts, with participation of teachers from Italian Universities. Experts from Italian CNR and from Istituto Centrale di Restauro (ICR) and particularly from the Istituti Statali d'Arte (ISA) of Rome, Marino, and Anzio gave a special contribution to the work-site school.

The final exhibition "Restorations and Restorers" documents the restoration results and the activities carried out by each person who attended the training programme. The exhibition that was inaugurated in 2007 and after that circulated in Cultural Centres, Schools, Universities both in Egypt and in Italy, is now permanently exposed in the CIERA exhibition rooms.

In the work-site school people teach and learn how to operate by actually doing the work, which means to be aware of the action. In a sense, restoration is the instrument to live the feeling of the original craft. Therefore, each participant receives, as a certificate of acquired professional qualification, a document attesting the activity he or she has performed.

In conclusion, the restoration interventions of the fabric of the historic buildings were guided by the purpose of retaining most of the original material as it was possible in both technique and shape, without drawing preferences between those contributions dating from different periods.

Finally, we adopted the principles of the "scientific" study of restoration and, where necessary, we applied sophisticated solutions using both traditional and modern technologies and techniques, but looking at them only as tools, since the essential objective of our activities is to protect the feel of the cultural heritage, as it is clearly defined in the "Theory of Restoration" by Cesare Brandi: art is a product of the Human Spirituality to be handed down to future generations.

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Fig. 1. GENERAL VIEW OF THE MEVLEVI ARCHITCTURAL COMPLEX

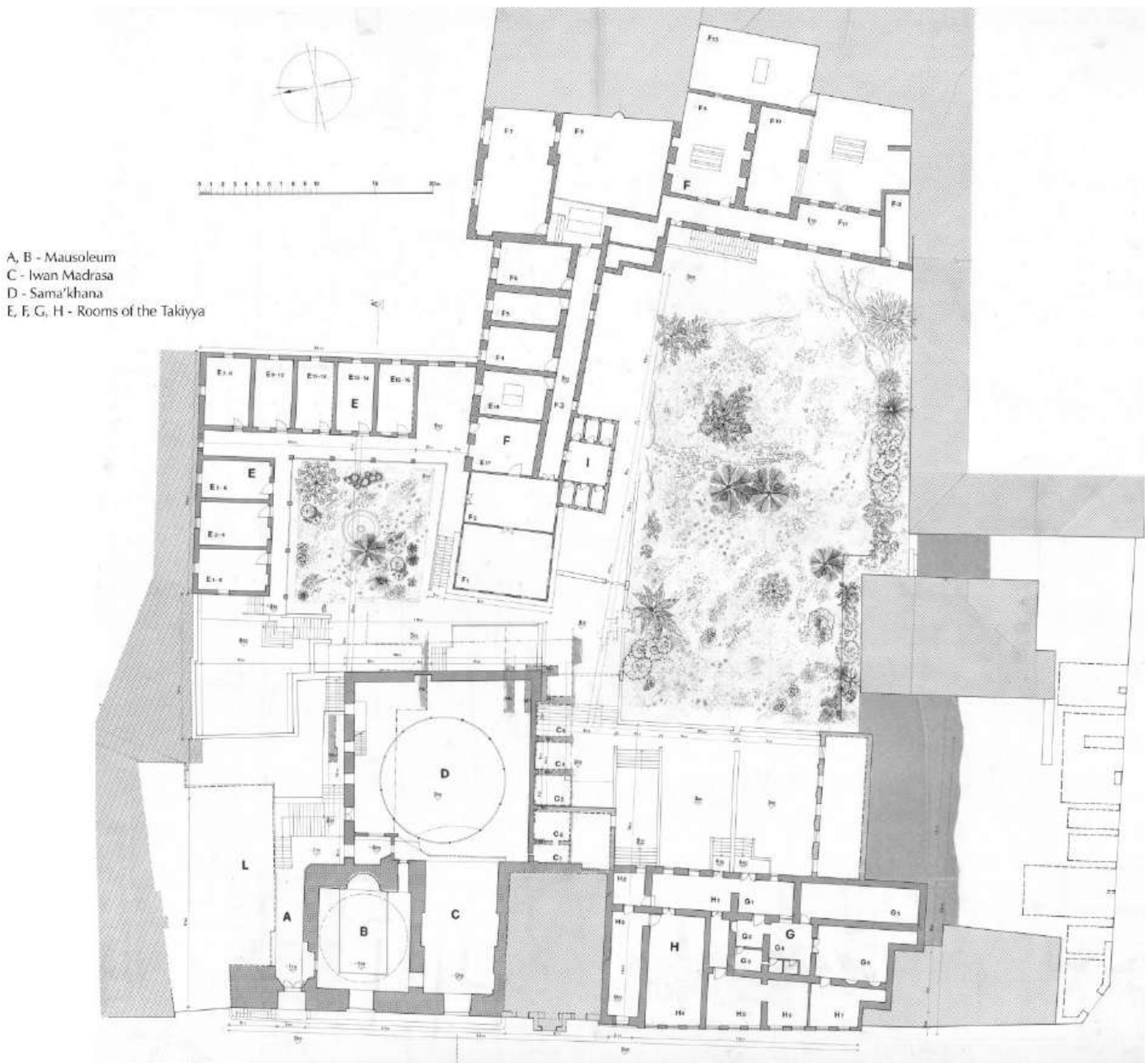

Fig. 2. TAKIYYA MEVLEVI PLAN

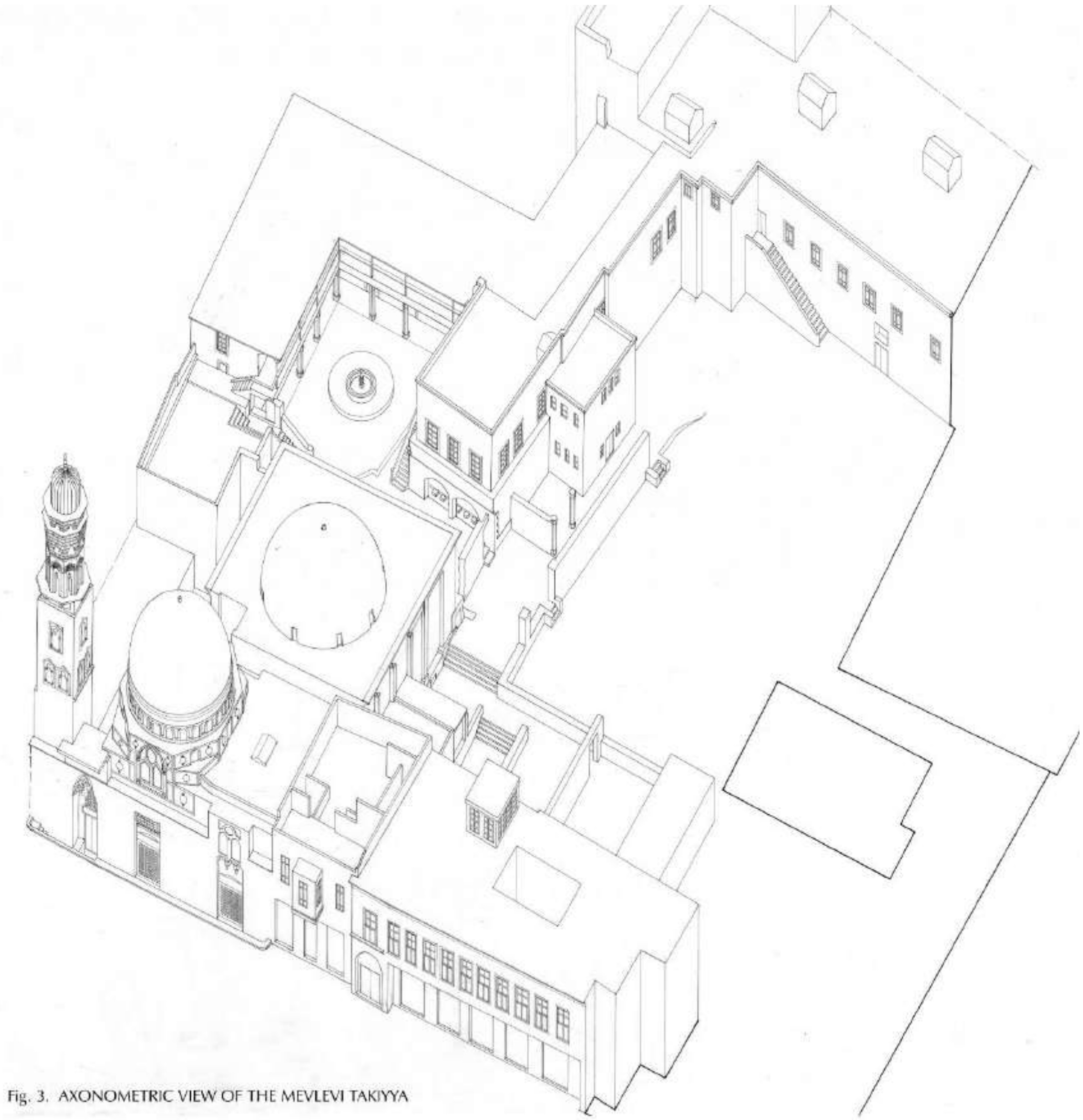

Fig. 3. AXONOMETRIC VIEW OF THE MEVLEVI TAKIYYA

Fig. 4. INTERIOR VIEW OF THE SAMA'KHANA BEFORE AND AFTER RESTORATION

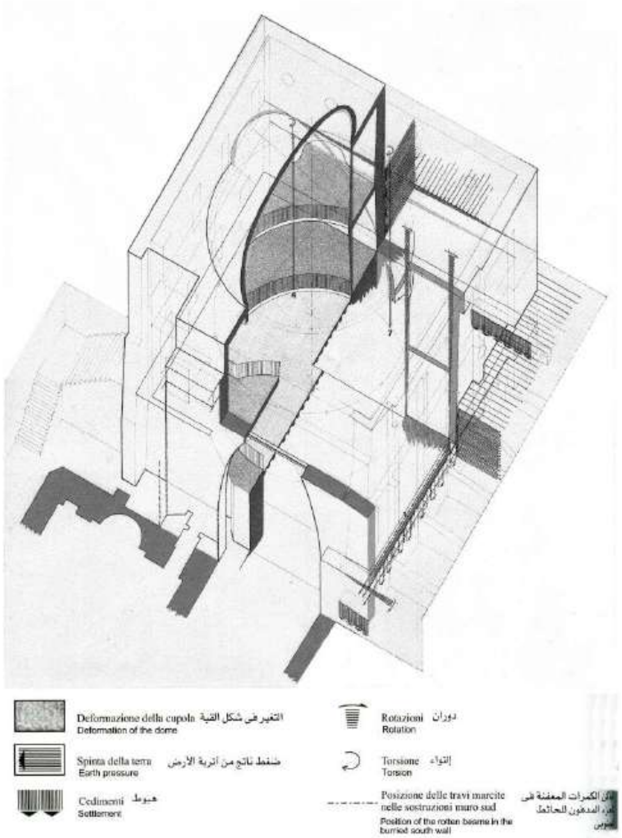

Fig. 5. SCHEME OF THE SAMA'KHANA SETTLEMENTS

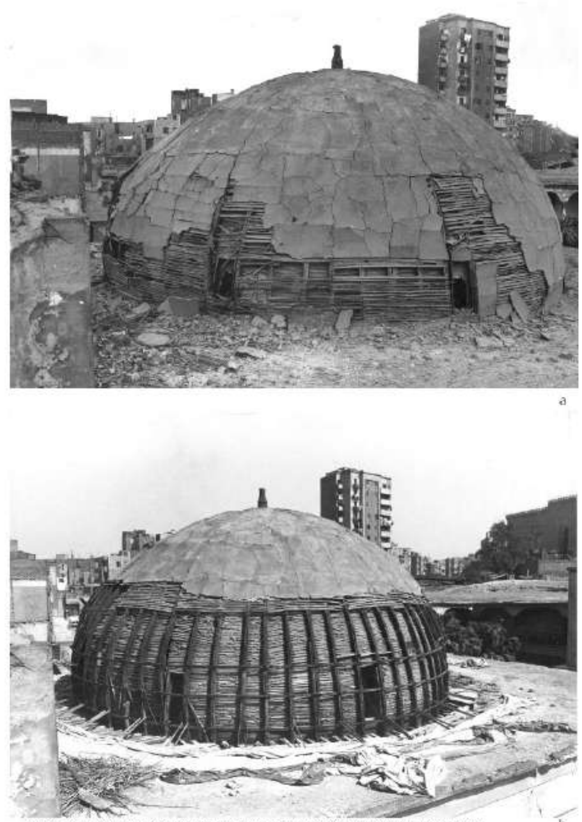

Fig. 6. THE SAMA'KHANA DOME AND THE RECOVERY OF ITS GEOMETRIC FORM

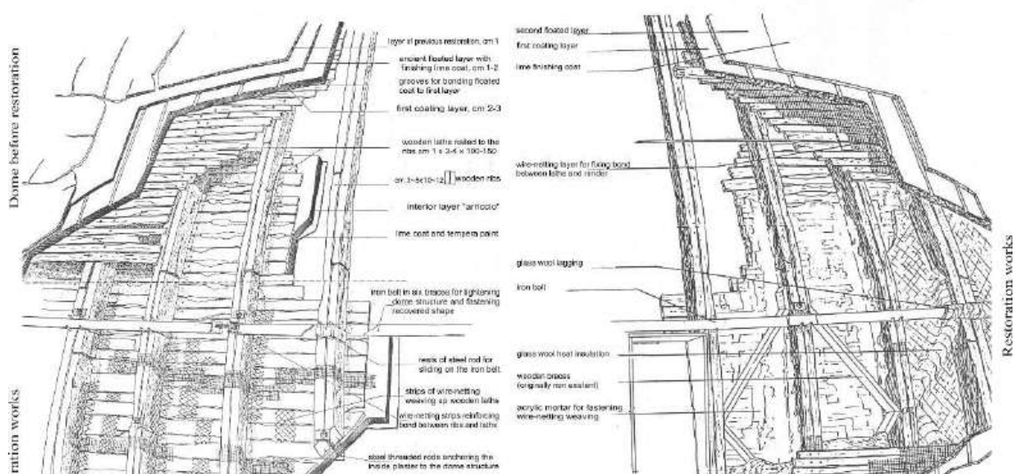

Fig. 7. STRUCTURAL ANALYSIS AND RESTORATION WORKS OF THE SAMA'KHANA DOME

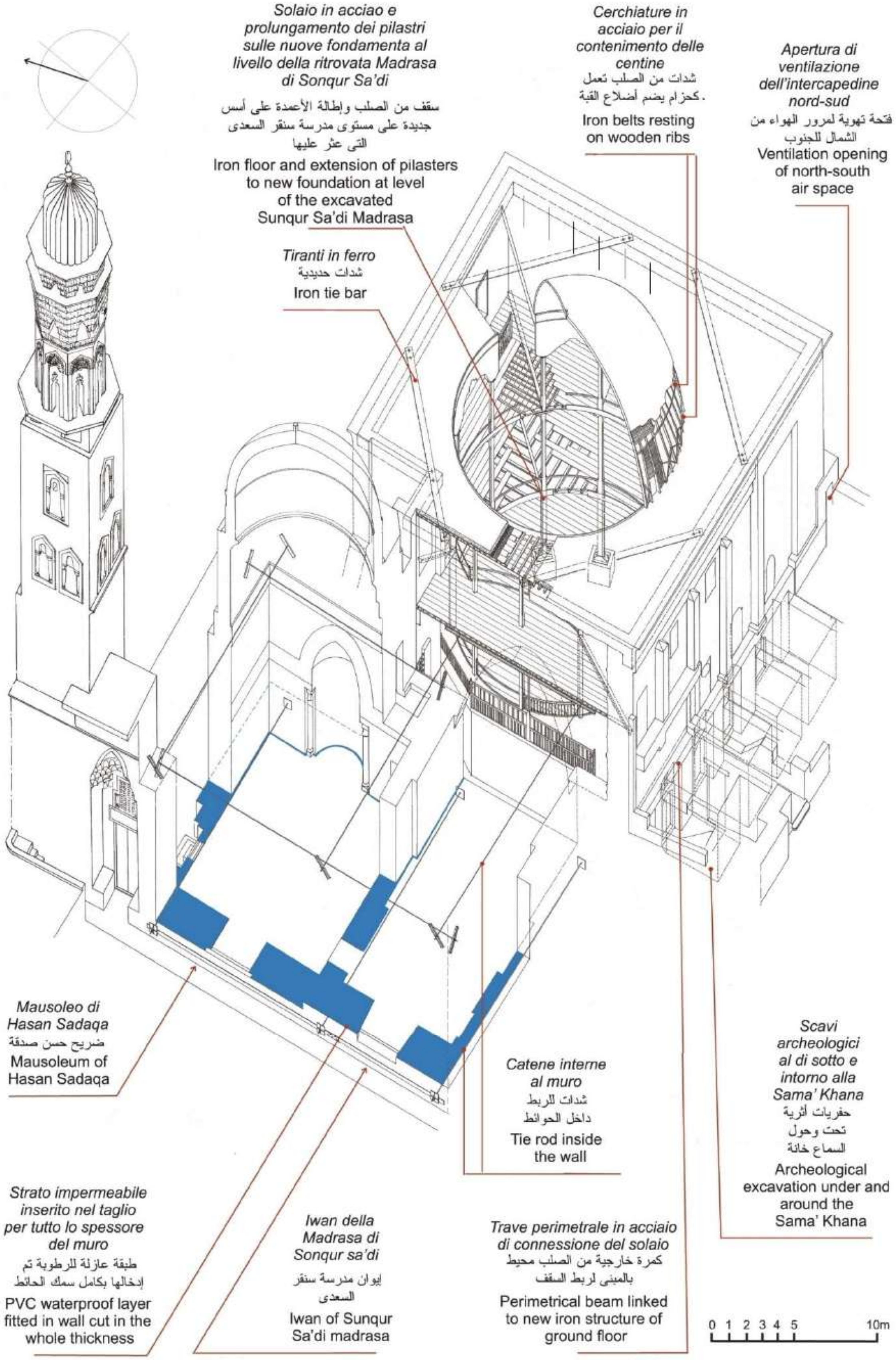

Fig. 8. AXONOMETRIC VIEW WITH DESCRIPTION OF THE RESTORATION INTERVENTIONS

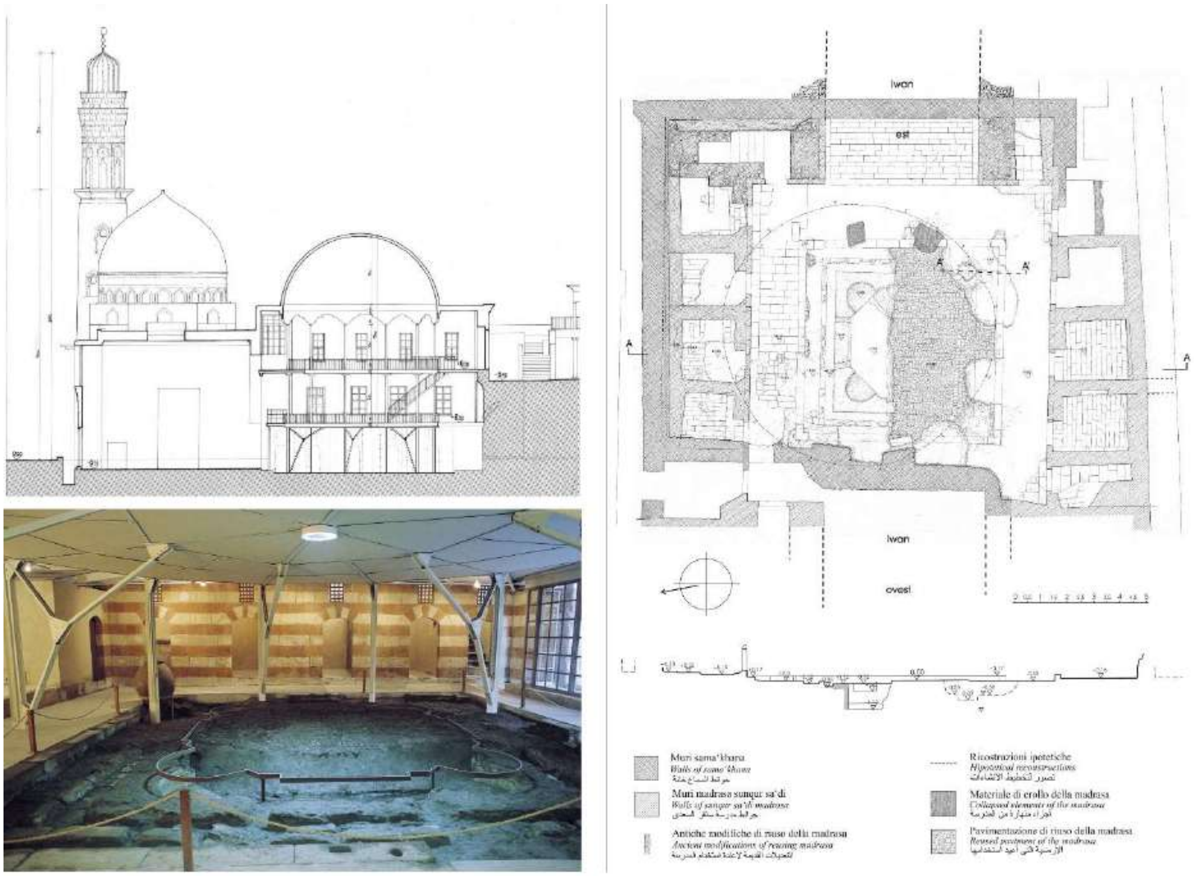

Fig. 9. SECTION OF THE SAMA'KHANA WITH THE ARCHAEOLOGICAL FINDS OF THE MADRASA

Fig. 10. THE RESTORATION PAINTINGS OF THE SAMA'KHANA DOME

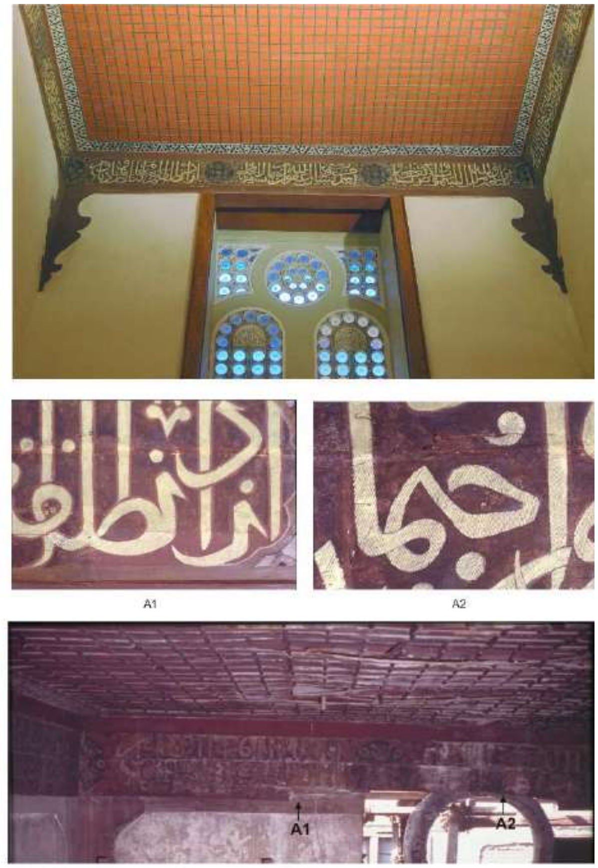

Fig. 11. THE RESTORATION PAINTINGS OF THE MADRASA IWAN

Fig. 12. THE MADRASA IWAN BEFORE AND AFTER RESTORATION

Fig. 13. SUNQUR SA'DI MAUSOLEUM BEFORE AND AFTER RESTORATION

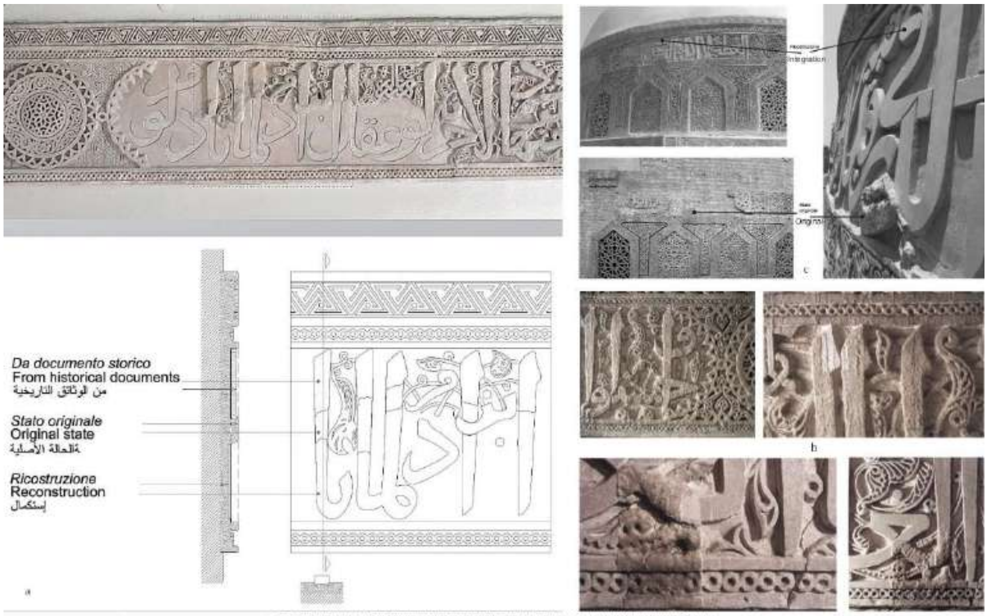

Fig. 14. VISIBILITY OF THE INSCRIPTIONS' RESTORATION ON THE INSIDE AND OUTSIDE OF THE MAUSOLEUM

Fig. 15. TEST OF THE STONE BLACK CRUST SANDBLASTING

Fig. 16. MICROSCOPIC THIN SECTIONS OF THE BLACK CRUST

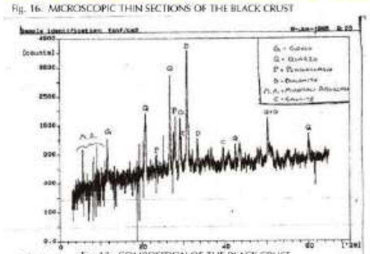

Fig. 17. COMPOSITION OF THE BLACK CRUST

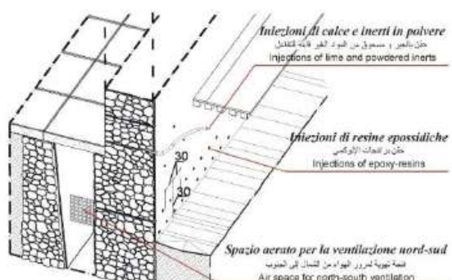

Fig. 18. ELIMINATION OF RISING DAMP FROM THE SAMA'KHANA WALLS

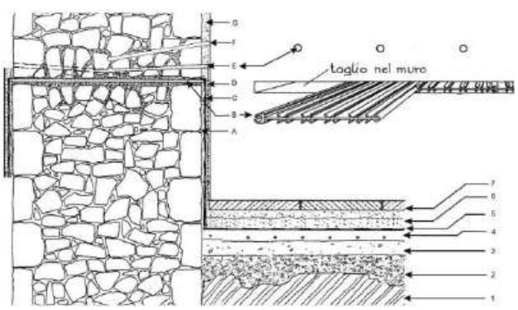

Fig. 19. THE PHYSICAL BARRIER OF MOISTURE IN THE MADRASA AND THE MAUSOLEUM

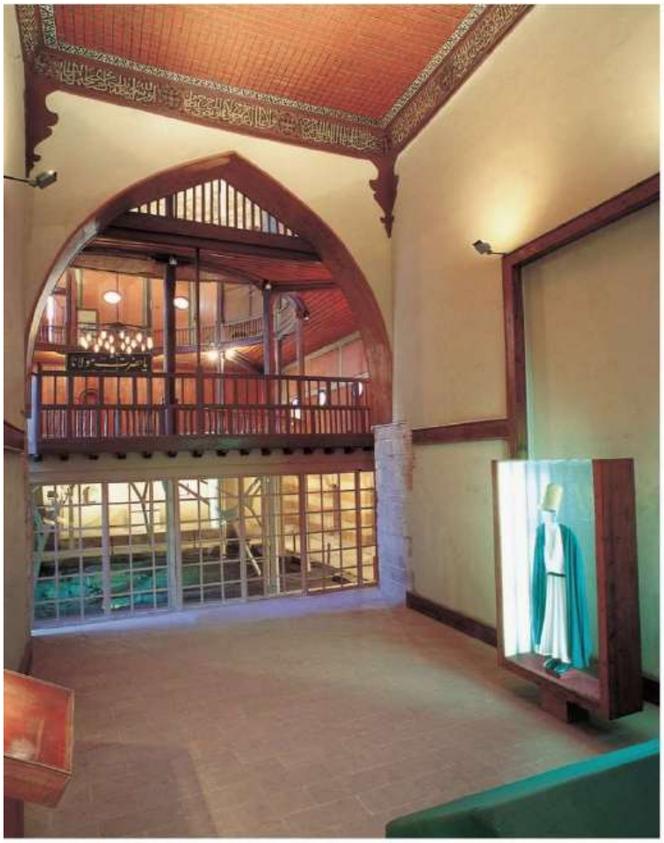

Fig. 20. THE VIEW OF THE SAMA'KHANA FROM THE MADRASA WEST IWAN

Fig. 21. EXTERIOR OF THE MAUSOLEUM BEFORE AND AFTER RESTORATION

The Sciences and New Technologies Applied to Archaeology in a Modern Museum: The Case of the Civic Museum of Rovereto Foundation

Franco Finotti, Barbara Maurina, Eleonora Zen

Fondazione Museo Civico di Rovereto, Rovereto (TN), Italy.

Abstract

The integration between the archaeological and the naturalistic sections has been a characteristic of the Civic Museum of Rovereto since the first excavations carried on in the second half of the Nineteenth Century by Paolo Orsi, who always showed interest in applying sciences to archaeological research. Keeping in mind a multidisciplinary approach, most recently the museum has developed scientific instruments and new technologies, to be used both in field work and post-excavation research and also for conservation purposes. For the development of the collections and the scientific divulgation of the data the museum has concentrated on its IT equipment, in particular a web TV and the digital archives, that have been placed on-line. Among them the data bank named "Secret Egypt" comes from a collaboration with the Supreme Council of Antiquities of Egypt; its use is regulated by a specific protocol signed in 2004 and amended in 2013.

As it is well known to those who work in museum settings, according to the ethical code of ICOM (International Council of Museums), a deontological document which puts together principles approved by the international community of museums and which defines the minimum standards of practice and conduct for museums and their staff, the main tasks of museums consist in acquiring, interpreting, conserving and enhancing the natural, cultural and scientific patrimony of humanity.

Again according to the ethical code of ICOM, the collections represent the basic element and reason for being of every museum. Thus the museums' fundamental duties are to collect, increase the collections, conserve and care for them, interpret them through studies and research, make them accessible, exhibiting the collections and data.

For this purpose, the modern museum makes use of scientific instruments and new technologies thus creating a virtuous circle, particularly where the sectors of the sciences and humanities work in synergy, as happens at the Civic Museum of Rovereto Foundation, a medium-sized Italian museum consisting of various sections from earth sciences to archaeology, botany to numismatics, zoology to art history.

Integration between the archaeological and naturalistic sections has in fact been a characteristic of the Civic Museum of Rovereto since its inception. The museum was founded in mid Nineteenth Century with the purpose of preserving the natural, historical and archaeological testimonies of the area of Rovereto[89]. In the archaeology sector the finds which made up the collection in the beginning mostly came from research in the field, from the first excavations coordinated by Paolo Orsi in Lower Trentino[90].

Among the pioneers of modern archaeological excavation, Paolo Orsi showed an immediate interest in applying science to archaeological research. Over time, despite several stoppages, mostly in connection with the two world wars, the museum has never abandoned its vocation for field work and has coordinated excavations in both Italy and abroad. Among the principal archaeological excavation sites in Trentino we can remember the Roman Villa at Isera[91], the castle and caves at Castel Corno (ancient Bronze Age, XXII – XVII centuries B.C.)[92], the settlement of the Pizzini of Castellano (ancient Bronze Age XX – XVII centuries B.C.)[93] and the *castrum* at Loppio – S. Andrea[94]. In 2012, after the architectural restructuring of the Loppio site, the Museum came to an agreement with the Trento Province Superintendence for the Archaeological Heritage on managing the archaeological area. The site was furnished with an installation of panels and opened to the public for free access. The panels in fact display a series of basic information and then have a QR-code which leads to the contents on the internet site of the Civic Museum of Rovereto Foundation (www.fondazionemcr.it). Museum staff make a weekly on-site check on the state of conservation of the area.

In recent decades the Civic Museum of Rovereto Foundation has developed the research sector, setting up laboratories and avant-garde scientific instrumentation to be used both in field work and post-excavation research. This technology, equipment and the laboratories are the basis of a week long course organized by the Foundation at Rovereto every year, which is attended by two collaborators from the Egyptian Ministry of Antiquity, following the convention signed in 2004 with the Supreme Council of Antiquities of Egypt[95].

By norm archaeological excavations are preceded by indirect, non-destructive and low-impact investigations able to reveal the presence of buried structures and therefore point the excavation in the right direction. In collaboration with Gread Elettronica and the University of Padova the FMCR acquired a specific geoelectric instrumentation for investigating the top subsoil: the multielectrode apparatus ERS (Elecrical Resistivity System) which, measuring resistivity - that is how far the ground poses resistence to the conduction of an electric current -, is able to identify geoelectric anomalies caused by the presence of buried structures.

Another important methodology of preventive, low-impact investigation used by the museum, always keeping in mind a multidisciplinary approach to archaeological and naturalistic questions, is the remote sensing based on the interpretation of aerial photographs (taken by satellite, aeroplane or elevated platform on land), using thermographics, a non-destructive analysis technique based on infra-red images (electromagnetic radiation transmitted by any object with a temperature above zero

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89 Rasera 2004.
90 Maurina - Sorge 2010.
91 de Vos - Maurina 2011.
92 Pasquali 1991.

93 Battisti 2010.
94 Maurina 2016.
95 Beretta - Zen - Zulian 2013.

and observable with a thermal imager)[96]. This permits the collection of a great quantity of scientific information on the environment, showing for instance the hydrogeological features of an area and also possible buried archaeological sites.
In the course of an excavation the museum team uses 3D technology to document strata and structures, like zenithal photographs from a dirigible and a laserscanner which makes a digital copy of an object showing three-dimensional models of buildings beginning with a group of points with known numerical coordinates ("point cloud"), as well as photoplans of the structures, particularly useful for documenting and studying the masonry.
Analytic and documentation activities post excavation are usually carried out in the museum, with the help of the science laboratories. In particular, in order to develop the study of the archaeological contexts and reconstruct the ancient landscape and economy, the museum has obtained laboratories and equipment for archaeobiological and archaeometric analysis. Researchers into archaeozoology and archaeobotany analyse and study the remains of fauna and botanical elements found in archaeological deposits (thanks to the use of a water sieve and fine meshes), while in the dendrochronology laboratory analysis is made of the annual growth rings of trees for their chronological determination[97]. In the optical microscopy laboratory analyses of samples are made with the biological microscope and polarizer.
The FMCR also has equipment for infra-red microspectroscopy, the Jasco Micro FTIR200, a valid support for the study of various kinds of materials (minerals, rocks, archaeological findings, zoological and botanical specimens) and their state of deterioration[98]. The infra-red microspectroscopy is a non-destructive analytic technique which combines microscopy and spectroscopy to carry out microanalyses and finds many uses in the conservation of cultural assets and for particularly valuable finds as well. Along with the possibility of making morphological and textural observations on the sample, the spectro supplies information on how the infra-red radiation reacts with the material. Just a few milligrams of a substance are sufficient for use with the spectro.
Most of an archaeologist's work consists, as we know, in documenting the findings post excavation. The 3D survey is very useful[99], not only for documenting the archaeological evidence during the excavation, but also for documenting moveable objects in the laboratory, thanks to the new equipment recently acquired by the FMCR, in particular 3D photographic equipment, the programme Zephir and a 3D printer (Fig. 1). This technology is particularly useful in the operational phase of conservation in the museum's repairs laboratory. For this purpose also the hyperspectral scanner is used, above all for repairing canvases. In fact, spectroscopy for images of reflected radiation has been seen to be a powerful diagnostic tool for extracting information on extensive painted surfaces.
Development of the collections and scientific divulgation of the data are two aspects to which the museum always gives particular attention. To this end in recent years it has concentrated on developing its IT equipment. In this field a decidedly innovative aspect, at least as far as Italian museums are concerned, consists of both the communication on the data related to the museum's patrimony and the results of research via a web TV (Sperimentarea TV) and the placing on-line of

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[96] TONELLI 1998. On remote sensing and geophysical investigations, see also the proceedings of the Workshops on Geophysic hold in Rovereto from 2004 to 2015 (http://www.museocivico.rovereto.tn.it/atti_geofisica).
[97] QUARTA *et al.* 2010.
[98] See *e. g.* FINOTTI - ZANDONAI 2011.
[99] LANDINI *et al.* 2013.

digital archives[100]. In particular the archaeological data banks, recently reinforced thanks to funding by the Fondazione Cassa di Risparmio di Trento e Rovereto and today freely accessible to the users of the site www.fondazionemcr.it, pertain to the archaeological patrimony, to the museum's collections of archaeological and numismatic findings, to the archaeological film collection and to the archives concerning the eminent citizens of Rovereto who carried out archaeological research in the 19th and 20th centuries: Paolo Orsi and Federico Halbherr. Of especial importance and success with the public is the archive "Secret Egypt" (Fig. 2) which comes from a long and fruitful collaboration with the Supreme Council of Antiquities of Egypt and aims to enhance the Egyptian archaeological patrimony through the georeferenced publication of the photographic documentation made by the honorary conservator at the museum, Maurizio Zulian, in almost thirty years of activity. Its use is regulated by a specific protocol signed in 2004 and amended in 2013[101]. The data base contains over thirty thousand photographs taken by Zulian during his explorations of Middle Egypt on sites rarely accessible and excluded from the tourist circuits, which the museum now makes available to the general public and to scholars and researchers on-line. The photographs, catalogued and described, may be consulted directly on-line, on a thematic site (www.fondazionemcr.it/egitto). Research can be undertaken freely through an advanced research engine, or by following previously established indexes or routes, viewable also on maps. From the homepage the Photographic Archive can be accessed via three research methods, all free: a) simply by consulting the index of places; b) research can be done on the map; c) an advanced research may be carried out. In the first two cases the work is facilitated by the research being already set up. Thematic routes are being developed, directly accessible from the homepage, like the one assigned to "Uncommon Egypt" which is for the moment the only one available on the site. Advanced research permits free research, while for the maps, by clicking on the icon corresponding to the site a link connects to all the photos of the site and their files. A subscription permits consultation of the in-depth studies and down-loading a high resolution photo. From the homepage there is direct access to the webgis and research on the map; connection may also be made with the web TV (Sperimentarea TV) which contains archaeological documentaries belonging to the museum's archive, films on various historical, scientific and naturalistic themes, recordings of congresses, conferences and interviews.

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[100] ZEN 2016.
[101] BERETTA - ZEN - ZULIAN 2013.

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Fig. 1 - 3D photographic documentation and printing of a terracotta head from the Paolo Orsi Collection of the museum.

Fig. 2 - The website of the museum and the archive “Secret Egypt” (www.fondazionemcr.it).

Microbial Ecology for Assessing Structure and Functioning of Communities of Microbes in Different Environments, from Natural Soil and Water to Cultural Heritage

Paola Grenni, Martina Cardoni, Martina Di Lenola, Anna Barra Caracciolo

Consiglio Nazionale delle Ricerche, Istituto di Ricerca sulle Acque (CNR-IRSA),
Monterotondo (RM), Italy
Corresponding author: grenni@irsa.cnr.it

Abstract
Microbial ecology is the study of microbes in the environment and their interactions with each other. Microbes are the smallest and most numerous living organisms on Earth. Despite their small size, natural microbial communities have a huge impact on our environment. They have a key role in biogeochemical cycles (e.g. nitrogen fixation, methane metabolism and sulphur metabolism) and in organic matter degradation. They harbour an amazing physiological versatility and catabolic potential for the breakdown of an enormous number of organic molecules, including xenobiotics, thanks to their great adaptability to different conditions. Natural microbial communities provide several regulating ecosystem services, maintaining soil and water quality[102]*. Soil and water ecosystem recovery from contamination relies on the presence of abundant and diverse microbial communities with the ability to degrade contaminants. Finally, the microbial community structure reflects the impacts of environmental and anthropogenic factors on ecosystems. Even if most natural microbial populations provide benefits to humans (ecosystem services), some microbial processes can have deleterious effects on the conservation of cultural heritage owing to their biodeteriorative potential. This phenomenon is particularly evident in the case of outdoor cultural heritage, which is continuously exposed to abiotic and biotic factors; at the same time, some selected microorganisms and/or enzymes have recently been used for its bio-cleaning and bio-restoration.*

Microbial ecology makes it possible to study structure–function relationships between microbial communities and their environment at different levels through, for example, the evaluation of microbial abundance, diversity and activity. For example, the knowledge of species involved in the deterioration of cultural heritage can be very useful for managing their conservation, through suitable recovery measures. Trends in modern microbiology emphasize the need to know and understand the structure and function of complex microbial communities. Most types of microbes remain unknown. It is estimated that we know less than 1% of the microbial species on Earth. Yet microbes surround us everywhere - air, water, soil. An average gram of soil contains one billion (1,000,000,000) microbes representing probably several thousand species. Culture-independent molecular techniques are valuable tools for investigating the diversity and structure of bacterial communities. These techniques can be used on cultivable as well as non-cultivable bacteria.

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[102] De Groot 1992.

Several techniques for assessing microbial abundance, viability, activity and diversity that have been successfully applied in several environmental projects, can also be applied in cultural heritage ones.

***Keywords**:* Microbial abundance and cell viability; Bacterial Phylogenetic characterization; biodeteriogens; cultural heritage conservation, biorestoration

Study of microbial communities in their natural environment

Natural microbial communities provide several ecosystem services (ES). ESs are natural processes and components which provide goods and services that satisfy directly or indirectly human needs[103]. For example, microorganisms, thanks to their adaptive responses to environmental changes, ensure contaminant degradation, soil fertility and water quality. The ecosystem homeostatic capacity for biodegrading contaminants (regulating ecosystem services) is due to their large (and unexplored) reservoir of genetic diversity and metabolic capability. The presence of an abundant and varied microbial community is a necessary prerequisite for an immediate and effective response to the various chemicals that can contaminate an ecosystem[104] (Fig. 1).

Contaminant occurrence can select specific bacterial populations able to remove them by both metabolic and co-metabolic patterns. However, it can also happen that a contamination causes disappearance or inhibition of some key functional species (e.g. those involved in nutrient cycles, organic matter decomposition, etc.) with consequences on water and soil quality.

The analysis of microbial communities (together with chemical analysis) is a useful tool to gain information on ecosystem quality and contamination occurrence. Methods that make it possible *in situ* observation of microorganisms and microbial activities have been particularly important in improving our understanding of the microorganism roles in their environment.

Morphological and physiological properties for classifying bacteria are not enough for studying microorganisms. The rapid and continued development of molecular biology and genomic techniques (e.g. Next Generation Sequencing, NGS) has been unveiling the immense microbial diversity in different ecosystems (the 16S rRNA gene is used as the main molecular marker in microbial ecology). However, the quantitative relationship between microbial diversity and ecosystem function remains to be investigated.

Microbial ecology started in 1990 with the direct amplification and sequencing of 16S rRNA genes from environment[105]. The adoption of molecular tools by microbial ecologists rapidly enhanced our knowledge of prokaryote abundance, diversity and functioning. The most common molecular tools currently used to study and identify microorganism (using mainly the 16S rRNA gene) comprise

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103 De Groot 1992.

104 Grenni 2014; Grenni 2018a; Grenni 2018b; Barra Caracciolo 2010; Barra Caracciolo 2018.

105 Giovannoni 1990.

PCR-based methods (e.g. DGGE, T-RFLP, qPCR, RT-qPCR) and epifluorescence direct methods. The latter do not need any DNA extraction from soil and make it possible to visualize microbial cells under an epifluorescence microscope. Epifluorescence direct methods involve the direct count of bacterial cells (DAPI count), cell viability assay (Live/Dead) and Fluorescence *In Situ* Hybridization (FISH).

The recent development of culture-independent, high-throughput sequencing-based metagenomic analyses has further allowed us to unveil microbial diversity. Metagenomics is the application of the methods of genomics to microbial assemblages[106] without the biases inherent to PCR amplification of a single gene.

Thanks to new methodological approaches, the exploration of microbial biodiversity has taken a quantum leap forward and permits the observation of microbial populations even in complex environment and specific conditions, including that related to cultural heritage deterioration.

Deleterious effects of natural microbial communities on cultural heritage

Although it is well recognised that natural microbial communities are key players in several ecosystem services, they can have a negative economic impact, as they accelerate the degradation and deterioration of a wide range of materials, including minerals, concrete and stone, metals, natural and synthetic polymers and not least cultural heritage[107]. These effects may be aesthetic, biogeochemical, and/or biogeophysical and are termed as the biodeterioration process. The latter is rarely caused by one distinct group of microorganisms, but is rather an interaction of coexisting groups in which there is a close association between the microbial component and the material surface. Consequently, cultural heritage monuments can be degraded by the growth and activity of living organisms creating a complex ecosystem on the external surfaces of monuments (e.g. biofilms). All surfaces (metals, stones, woods etc.) can act as substrata for bacterial adhesion and biofilm formation. The microbial attack on materials can take place either directly or indirectly, depending on the specific microorganism and on the biological, chemical and physical properties of the materials and their environment. Specifically, these abiotic and biotic factors may include material composition, the nature of the surface and the indigenous microbes. In addition, other factors affecting the physical environment influence the extent of bacterial adhesion, including the ionic strength of the solution, type of cation, hydrodynamic force, and surface properties (e.g. hydrophobicity or hydrophilicity). Recently, chemical signalling has been found to play a role in bacterial attachment to surfaces[4]. Moreover, cell-to-cell communication systems through intercellular signal compounds (quorum sensing, which regulate the expression of some genes) allow microorganisms to adapt to modified environmental conditions and make it possible to microbial cells to organize themselves structurally and control the development of highly structured and cooperative biofilm consortia, on both organic and inorganic substrata[108].

[106] Steward 2007.
[107] Gu 2006.
[108] Balaban 2008.

For example, stone-inhabiting microorganisms can grow on the surface (epilithic) or in more protected habitats such as crevices and fissures (chasmolithic) or can penetrate some millimetres/centimetres into the rock pore system (endolithic)[109]. True endoliths, occurring within the rock, have been detected in some calcareous and siliceous stone monuments and are predominantly bacteria. The taxonomic groups differ from those found epilithically at the same sites. These differences may be explained by the protective role of surface stone layers, by the difference in UV radiation distribution and by the varying availability of nutrients[6].

Although the nature of the stone substrate and the environmental conditions influence the extent of biofilm colonization and the biodeterioration processes, microbial colonization generally initiates with a wide variety of phototrophic microorganisms (mainly cyanobacteria, algae, mosses and higher plants.). These organisms accumulate biomass, usually embedded in a biofilm enriched with organic and inorganic substances and growth factors[110]. Lichens probably follow microorganisms on the stone surface[111]. The accumulation of photosynthetic biomass provides an excellent organic nutrient base for the subsequent heterotrophic microflora. The organisms involved in biodeterioration are not only bacteria, microalgae, fungi, and lichens, but also protozoa; in addition, small animals, such as mites, may be present and lower and higher plants may develop, once the earlier colonizers have modified the surface. Chemolithoautotrophic bacteria are also present; they can release acids such as nitrous (e.g. *Nitrosomonas* spp.), nitric (e.g. *Nitrobacter* spp.) or sulfuric (e.g. *Acidothiobacillus* spp.), changing the local pH. Moreover, chemoorganotrophic bacteria and fungi (*Acidithiobacillus ferrooxidans*, *Bacillus* spp., *Leptospirillum* spp., *Aureobasidium* spp.) can release chelating organic compounds or weaken the mineral lattice by the oxidation of metal cations such as Fe^{2+} or Mn^{2+}[112]. Interactions between these organisms and the surface can also enhance or retard the overall rate of degradation. For example, microbial cells can contribute directly to the deterioration of stone by using it as a substrate or indirectly by imposing physical stress, while serving as nutrients for other organisms, or providing compounds for secondary chemical reactions[113]. In the case of metals, biodeterioration includes their corrosion, a process commonly called 'microbiological induced/influenced corrosion' (MIC) by corrosion engineers. A wide variety of microorganisms is capable of degradation of metals, including both aerobic and anaerobic bacteria. For example, the strictly anaerobic sulfate-reducing bacteria (SRB), the thermophilic bacteria, iron-oxidizing bacteria, and exopolymer- and acid-producing bacteria were found to participate actively in corrosion processes in which metal ions are either transformed by or complexed with functional groups of the exopolymers, resulting in the solubilisation of metallic species[4]. Since ancient times, copper and its alloys, bronze and brass, have been widely used. Sculptures and other objects have also often been covered by layers of precious metal such as gold. The most common practice is gilding, both because of its excellent corrosion resistance and to ensure the object looks like it is made of pure gold. For example, metal fibres, used for embroidery in the manufacture of high cost textile objects such as

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[109] SCHEERER 2009.
[110] TIANO 2002.
[111] HOPPERT 2004.
[112] CRISPIM 2005; FERNANDES 2006.
[113] SAND 1996.

religious furniture, noble dressing and ancient costumes, can inhibit microbial growth, particularly when copper or other heavy metals are present[7].

Table 1 shows the main biodeteriogens of cultural heritage.

Table 1. Major biodeteriogens affecting cultural heritage materials and related physical and chemical damage[114].

Biodeteriogen	Physical damage	Chemical damage	Damaged materials
Higher plants	Cracks, detachment of stone	Roots excrete organic acids	Natural and artificial stones
Animals and insects	Holes, losses and surface erosion and disintegration, structural damages	Droppings and urine	Stone, wood, paper, parchment and leather, vegetal and animal fibres etc.
Mosses and liverworts	Physical intrusion by rhizoids	Extraction of mineral from substratum, production of carbonic acid	Natural and artificial stones
Lichens	Cracks and fissures	Releasing of highly corrosive organic acids	Limestone, sandstone
Algae and cyanobacteria	Powdering	Staining, disintegration of stone	Natural and artificial stones, wall paintings, wood
Fungi	Contraction and expansion of thallus, fissures, loss of materials	Production of organic and inorganic acids and pigments, chelating properties	Stone, wall paintings, wood, paper, parchment and leather, vegetal and animal fibres etc.
Heterotrophic bacteria	–	Staining, production of acids and pigments	Stone, wall paintings, wood, paper, parchment and leather, vegetal and animal fibres etc.
Autotrophic bacteria	–	Production of organic and inorganic acids, biofilm formation, staining	Stone, wall paintings, wood, paper, parchment and leather, vegetal and animal fibres etc.

Use of microbial cells and enzymes and other natural components for cultural heritage biorestoration

Outdoor artworks, especially lithoid materials, stones, frescoes and paintings, are susceptible to deterioration mainly caused by the environment (abiotic factors such as temperature, humidity and so on) and, in recent decades, pollution. For example, in urban areas, damage due to increased pollution

[114] Di Carlo 2017.

is manifested on monument surfaces through alterations such as black crusts, nitration, sulphation and the deposition of dust and residual hydro-carbons[115]. For example, marble and stone sulphation occurs when sulphur dioxide, a major urban atmosphere pollutant, is converted to sulphuric acid, which reacts with marble and other soluble calcareous substrates to form gypsum. During gypsum crystallisation, airborne organic pollutants and carbonaceous particles accumulate on surfaces protected from rainfall and wash-out and are subsequently trapped in the newly formed mineral matrix to form a so-called *black crust*. The cleaning of crusts is essential, not only for the conservation of deteriorated areas but also for preventing further erosion phenomena.

In addition to air pollutants, the surfaces of man-made artistic stonework can also be altered by organic matter that has been applied, but then not completely removed, during restoration; in many cases this can pose a serious danger even to the preservation of the artwork itself[116]. In fact, such 'leftover' compounds often act as a good growth substrate for microorganisms and mycetes that destroy the surface, and allow hyphae penetration to some depth. In addition, the process of detaching frescoes from walls prior to restoration needs notable quantities of organic compounds (such as glue and casein) that become distributed on both the painted surface and at the back of the fresco[117].

Cleaning is one of the first and most important steps in conservational restoration, as it removes the unwanted layers of dirt and deposits from the surface of an artefact. It must be done selectively, by adapting the cleaning operation to the different zones and removing successive layers of deposits without acting directly on the original surface materials. The use in recent years of safe microorganisms (non-pathogenic bacteria or yeasts, or non-spore-forming bacteria) and enzymes for biorestoration instead of the traditional approach (such as mechanical, chemical and physical treatments) has many advantages for both operators and the environment. Generally, cleaning protocols are based on chemical or physical procedures with potential negative effects for restorers' health and/or for the artworks. For example, most frescoes have been restored using traditional chemical and physical techniques in which residual organic substances and salts are removed by an ammonium carbonate solution and organic solvents. As alternative, solvent gels, rigid gels and resin soaps can be used for selective cleaning. Moreover, in recent years, an inherent resistance of biofilm microorganisms to biocides has been noted, leading to a search for alternative treatments[118].

From the end of the 1980s, selected bacteria have been successfully employed as cleaning agents, leading to the development of a new and green method of restoration known as biocleaning (or biorestoration in a wider sense)[13]. This recent method is not destructive and removes only extraneous substances or altered compounds from the cultural heritage. It is in line with the modern concept of cultural heritage restoration, where a minimal intervention approach is one of the main cornerstones established in several codes of ethics for restorers and conservators, such as in the European Confederation of Conservator Restorers' Organisations professional guidelines[119]. This approach

[115] RANALLI 2005.
[116] RANALLI 1996; RANALLI 2000.
[117] RANALLI 2000.
[118] CAPPITELLI 2011.
[119] E.C.C.O. 2003.

avoids unnecessary measures and focuses on the control and/or mitigation of the causes of decay, following the principles of 'preventive conservation'. Finally, an evaluation of costs and convenience has revealed the transferability of this technological innovation to other fields outside cultural heritage.

In principle, the method exploits the capability of specific bacteria to use undesired substances, such as oxidised sulphur or nitrogen compounds, as electron acceptors or, in the case of organic matter, as a carbon source, inducing their gradual degradation.

A careful selection of the appropriate microorganisms, enzymes or other natural components with a good record of removing the undesired substances is one of the first steps in planning biorestoration strategies (Table 2).

Table 2. Main bacterial strains or biological agent used for biorestoration.

Bacterial strain or biological agent for biorestoration	**Cultural heritage treatment**	**References**
Pseudomonas stutzeri strain A29; *Pseudomonas stutzeri* DSMZ 5190	Treatment of altered frescos	RANALLI 2003; BOSCH-ROIG 2013a; ANTONIOLI 2005; BOSCH-ROIG 2013b; LUSTRATO 2012
Carbogel or a mortar-alginate matrix used as a delivery system for a NRB strain of *Pseudomonas pseudoalcaligenes*	Removal of salts originating from the oxidation of various N-organic compounds from bodies	ALFANO 2011
Sulphate-reducing bacteria (SRB): *Desulfovibrio desulfuricans*	Removal of salt crusts (often gypsum) on stone surfaces in urban historic buildings due to atmospheric pollution and weathering	ATLAS 1988; GAURI 1992
Desulfovibrio in pure and mixed culture		RANALLI 1997
Desulfovibrio vulgaris subsp. vulgaris ATCC 29579 and Carbogel as cell carrier	Removal of the black crust	CAPPITELLI 2006

Desulfovibrio vulgaris	Removal of the black crust	POLO 2010; CAPPITELLI 2005
Carbogel matrix enriched with *Pseudomonas pseudoalcaligenes* KF707 and *Desulfovibrio vulgaris* ATCC 29579	Removal of black crust made of a mixture of nitrates and sulphates	ALFANO 2011
Laponite matrix (a colloidal clay consisting of a mixture of silicates of sodium, magnesium and lithium) containing three non-spore-forming bacterial strains: *Cellulosimicrobium cellulans* (able to solubilise calcium sulphate and carbonate), *Stenotrophomonas maltophilia* (a protein degrader) and *Pseudomonas koreensis* (able to solubilise inorganic compounds and to degrade protein material)	Solubilisation of the crust made of calcium sulphate, calcium oxalate, apatite and aged casein	MAZZONI 2014
Zosteric acid (p-sulfoxy cinnamic acid), a natural extract from eelgrass (*Zostera marina*) which revents biofouling by some organisms, such as algae, barnacles, and tubeworms, at nontoxic concentrations and N-vanillylnonanamide	Prevention of bacterial cell adhesion to the substratum	CAPPITELLI 2011
Halogenated furanones isolated from the Australian macroalga *Delisea pulchra*	Interference with bacterial signalling and colonization	DE NEY 1993

Thus, the best approach in finding an effective biocleaning agent is to perform a proper chemical-physical characterisation of the decay and to isolate microorganisms from the most similar chemical-physical environment[120]. Of course, selected strains have to be non-pathogenic for humans, harmless for the environment and, if possible, non-spore forming to facilitate their dislodging after treatment. Moreover, in order to optimise their activity on the surface that we intend to clean, the bacteria need to be applied by using a matrix able to: (1) provide them the suitable environmental conditions, (2) put them in contact with the extraneous substances without interacting with the original surface and (3) be quick and easy to prepare, to apply and remove[121].

[120] RANALLI 2000; TROIANO 2014.
[121] BOSCH-ROIG - RANALLI 2014.

Microbial ecology methods for studying natural microbial communities in cultural heritage

Although many instruments are actually available for studying the conservation of cultural heritages[122], they are not able to identify and characterize the microbial communities growing on them.

Most of information currently available on microorganisms inhabiting cultural assets come from the use of traditional (culture-based) methods (e.g. counting the number of colony forming units). However, these methods, based on microorganism cultivation are able to detect only a minor fraction (less than 1%) of the total microbiota. There are multiple reasons for this bias: the growth requirements of many species of microorganisms are unknown. In addition, a large fraction of microorganisms in natural communities are in an inactive stage of their life cycle, and thus carry out very limited metabolic activity in their environment at a specific time. For example, CFU method underlies general cultivation errors and may not distinguish between bacteriostatic or bactericidal effects of biocides when the latter are used for restoration of cultural heritage or in the case of use of bacterial strains used for biorestoration purposes.

As described in the paragraph 1, the culture-independent molecular techniques are valuable tools for investigating the diversity and structure of microbial communities, independently from their cultivability.

Some culture-independent techniques for assessing microbial abundance, viability, activity and diversity that our research group have been successfully applied in several environmental projects[123] can also be applied in cultural heritage ones. These techniques applied to cultural heritage have highlighted the role played by microorganisms (Bacteria, Archaea, fungi, algae, lichens), along with mosses and higher plants, in the deterioration of such diverse materials as historic stonework, wood, tapestries, papyrus, etc.[124]

The determination of cell viability and activity are important for both testing the capability of microbial cells in biorestoration processes and in biocide effectiveness for removing biodeteriogens.

The determination of **cell viability** and growth for application of viable cells in biorestoration or in the case of use of biocide or antifouling can be performed by cultivation methods or by measuring spectrophotometrically the optical density. Alternatively, cell viability can be evaluated by using two fluorescent dyes (e.g. SYTO9 and propidium iodide) for distinguishing between green viable and red dead cells in the LIVE/DEAD method[125], Fig. 2.

The **Dehydrogenase** assay is a valuable method for evaluating the overall microbial activity; in fact, dehydrogenases are exclusively intracellular enzymes related to the basic cellular function of

[122] Tiano 2017.
[123] Grenni 2014; Grenni 2018; Barra Caracciolo 2010; Barra Caracciolo 2018.
[124] Ranalli 2000; Ranalli 2003.
[125] Cappitelli 2011.

respiration, which play an important role in the initial stages of organic matter oxidation by transferring electrons or hydrogen from substrates through co-enzymes to acceptors. In aerobic conditions, O_2 is the final electron acceptor.

One of the most frequently used methods to estimate dehydrogenase activity is based on the use of triphenyltetrazolium chloride as an artificial electron acceptor. Dehydrogenase activity is measured by two methods based on the use of triphenyltetrazolium chloride (TTC) and iodonitrotetrazolium chloride (INT) substrate.

Dehydrogenase activity is frequently used in cultural heritage issues; for example, this method was used for determining the deteriogenic role of microorganisms grown on Santo Aleixo Church mural paintings, Portugal[126] and in granite, limestone and brick powdered samples in monuments at Alcala de Henares, Spain[127]. It was also used for rapid monitoring analyses of biorestoration processes[128].

Currently, there are several methods to obtain microbial community fingerprints from natural samples that can also be applied for cultural heritage conservation.

For studies of monuments and artworks, the technique most often used is denaturing gradient gel electrophoresis (DGGE). Briefly, it requires previous amplification of a specific portion of the 16S (or 18S for eukaryotes) rRNA genes. These DNA fragments are then separated in a chemical denaturing gradient (formed by urea and formamide) and then amplified with a set of specific primers which is required to stabilize the migration of the DNA fragments during DGGE.

Other techniques, such as analysis of terminal restriction fragment length polymorphisms (T-RFLP), have been frequently used in molecular surveys of microbial communities in ecological studies. In this technique, 16S rDNAs from phylotypes present in the community are firstly amplified by PCR, using primers targeted to conserved regions of the gene. Primers can be designed to be no discriminating, amplifying nearly all 16S rDNAs, or selective, targeting specific domains or groups. The 5′ primer is fluorescently labelled to tag the products. The amplification products are then digested with restriction endonucleases, usually 4-base cutters, and the primer-proximal products are sized on a sequencing gel[129]. T-RFLP analysis is a highly reproducible and robust technique that yields high-quality fingerprints consisting of fragments of precise sizes, which, in principle, could be phylogenetically assigned, once an appropriate database is constructed.

The phylogenetic identification is based on the sequencing of the gene codifying for bacterial 16S rRNA. Currently, molecular methods, including polymerase chain reaction (PCR), denaturing gradient gel electrophoresis (DGGE) and the creation of clone libraries are used. DGGE is the most frequently reported technique for separating DNA fragments during microbial diversity studies of art

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[126] ROSADO 2014.
[127] GÓMEZ-ALARCÓN 1995.
[128] RANALLI 2000.
[129] MARSH 2000.

objects. Genetic fingerprinting is a rapid and useful method for studying diversity in microbial communities including non-cultivable and inactive microorganisms.

The use of **molecular techniques** based on expensive Polymerase Chain Reaction (PCR) have some limitation, i.e. the impossibility of studying the microorganisms in situ. Nevertheless, a "non-PCR"-based technique is available that combines the precision of molecular techniques with providing information on the number and spatial distribution of microorganisms: Fluorescence *In Situ* Hybridization (FISH).

Fluorescence *in situ* hybridization (FISH) has been applied for analysing complex natural microbial assemblages, biofilm structures and for evidencing dominant populations in the microbial community. The development of new microbial detection and identification techniques is crucial for furthering our knowledge of microbial influence on heritage deterioration and designing appropriate preservation strategies.

Although it is a powerful, rapid and straightforward technique, only few studies in the field of cultural heritage conservation and restoration have exploited the potentials of using FISH method[130], despite it being the most commonly applied non-PCR-based method in other fields[131]. FISH allows the detection of microorganisms by a fluorescently labelled oligonucleotide target probes that hybridizes specifically to its complementary target sequence within the cell. The selection of rRNA probes enables phylogenetic specificity to be varied from universal to subspecies level.

The FISH technique, together with CARD-FISH could be used for characterizing the main microbial cells that are colonizing the cultural heritage, in particular because it is an i*n situ* technique useful also for characterize complex matrix such as biofilms.

FISH consist of the i*n situ* characterization (without cultivation and DNA extraction) of microbial cells using fluorescent labelled 16S rRNA-targeted oligonucleotide probes. Each molecular probe consists of 15-30 nucleotides, labelled with a fluorochrome, able to hybridize with a specific complementary sequence of 16S rRNA inside the microbial cell. Once a molecular probe enters into a cell, it can hybridize exclusively with a complementary rRNA sequence and the hybridization is visualized under a fluorescent microscope. FISH is very useful in environmental studies for identifying microorganisms at different phylogenetic levels (from domain to species)[132], Figure 3. This technique has been applied in some conservation and restoration studies related to the identification of microorganisms involved in biodeterioration. In a specific study, adhesive tape strips were used for performing a non-destructive sampling. The application of FISH was therefore done

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[130] URZÌ 2001; URZÌ 2004; LA CONO 2003; CAPPITELLI 2008; GONZÁLEZ 2014.
[131] e.g. GRENNI 2014; GRENNI 2018a; GRENNI 2018b; BARRA CARACCIOLO 2010; BARRA CARACCIOLO 2018.
[132] BARRA CARACCIOLO 2010.

on situ microorganisms, that is to say those present in a given area, without destruction of the valuable surfaces and with limited biofilm disturbance[133].

This technique was applied for direct detection of microorganisms on mortars[134], in particular for microbial detection on test and real mortars inoculated with fungal suspensions of *Nectria* sp. by the application the universal eukaryotic probe (EUK516) labelled with fluorescent dye (Cy3) (Figure 4). Moreover, it was used for detecting microbial cells in biofilms[135], (Figure 5).

Concluding remarks

An integrated microbial ecology approach by using commonly used methods, such as classic and molecular ones, and new methods such as metagenomic (e.g. Next Generation Sequencing) are useful to improve the knowledge for managing species involved in the deterioration of cultural heritage.

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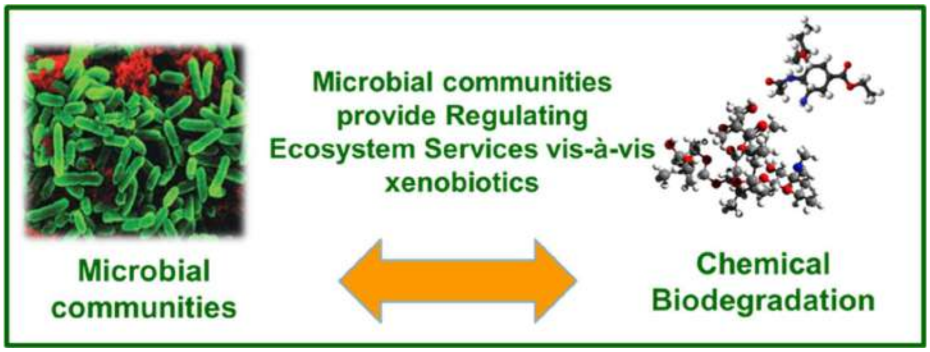

Fig. 1 - Example of a Regulating ecosystem service provided by microbial communities: biodegradation of organic contaminants.

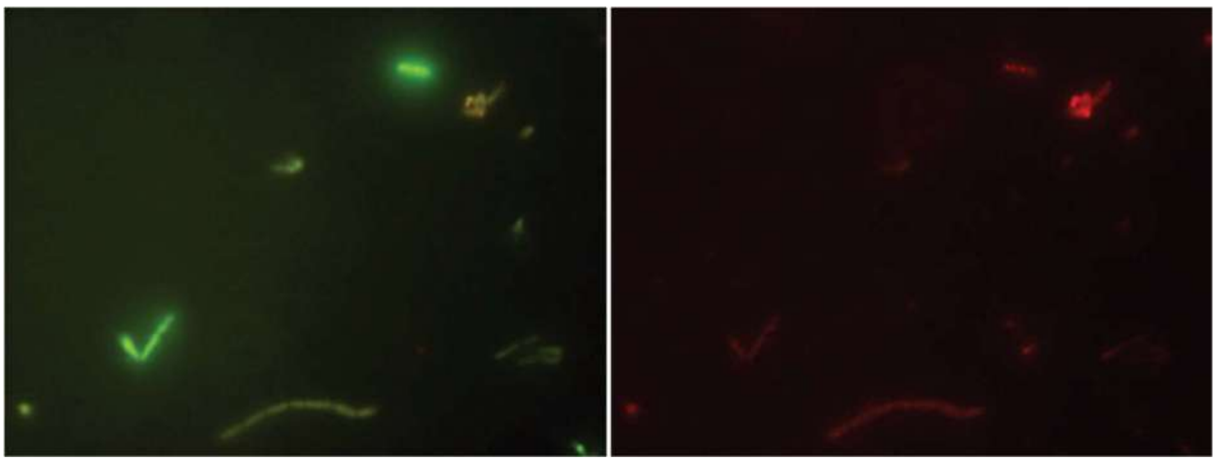

Fig. 2 - Image under the epifluorescence microscope of microbial cells treated with SYTO 9 (left) and propidium iodide (right) to estimate both viable and total counts of bacteria *(from Cappitelli 2011).*

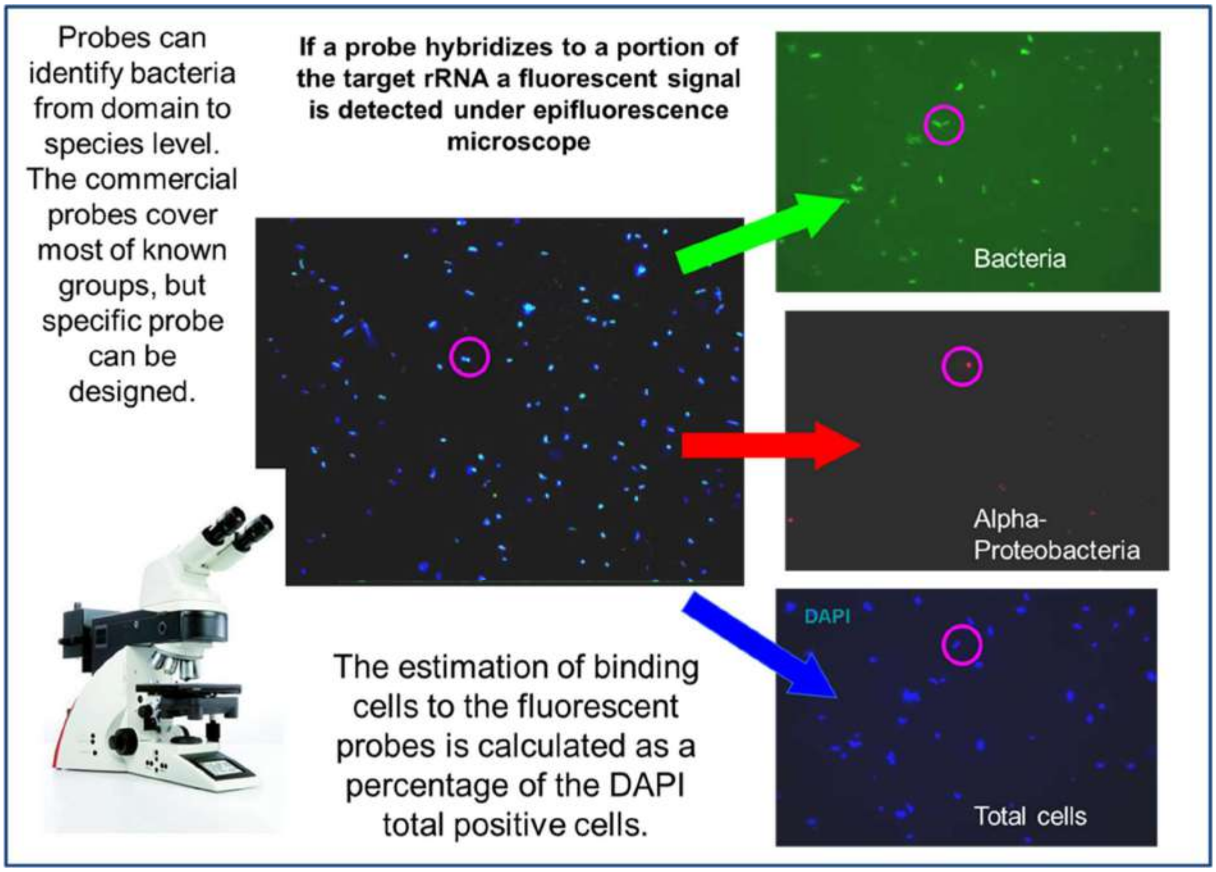

Fig. 3 - Fluorescence in situ hybridization applied to environmental samples for detecting Bacterial cells (in green with the EUBI-III probe), Alpha-Proteobacteria cell (in red with the Alf1a probe) and microbial cells (in blue, DAPI stain).

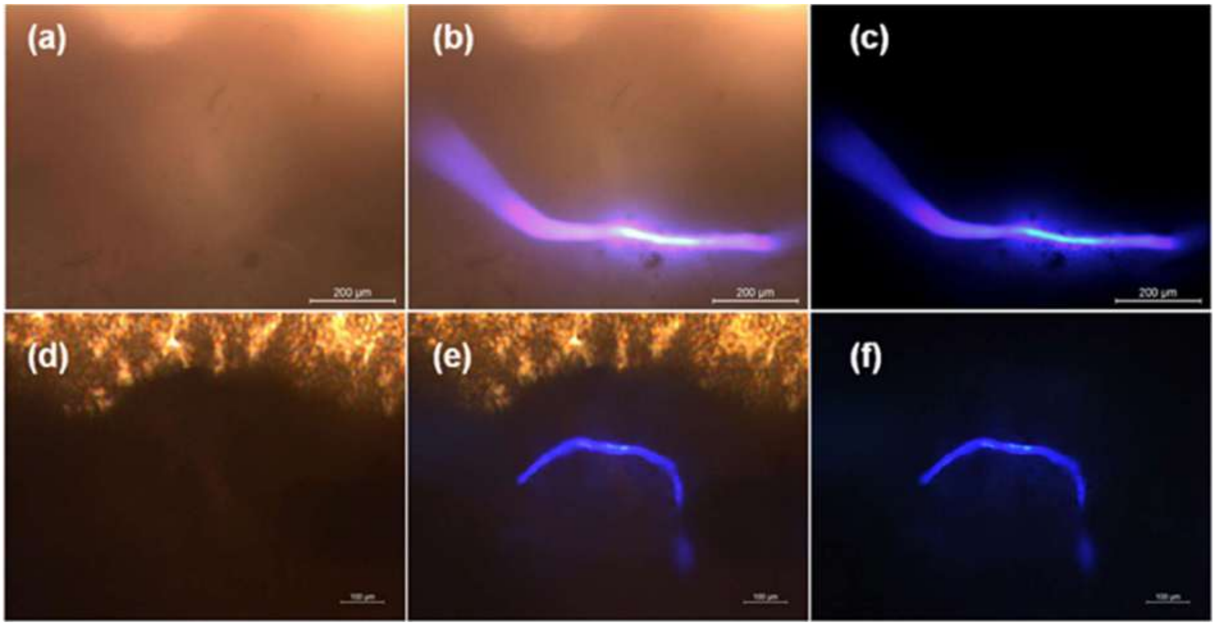

Fig. 4 - FISH of Nectria fixed with paraformaldehyde (a–c) and ethanol (d-f). The same area is shown in the bright-field (a, d), a combination of dark- and bright-field (b, e) and dark–field (c, f), *(from GONZÁLEZ 2014)*.

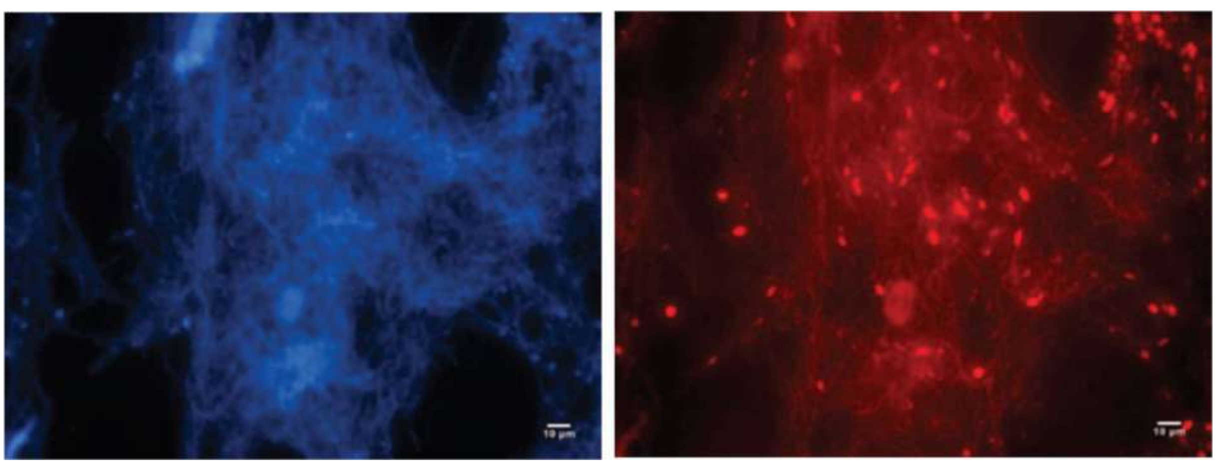

Fig. 5 - Epifluorescence images of biofilm on adhesive tape strips sampled from an outdoor wall showing DAPI staining (left) and hybridization with the universal Eukarya probe (right) *(from CAPPITTELLI 2011).*

GEOARCHAEOLOGY AND EVOLUTION OF SAQQARA-MEMPHIS FLOODPLAIN, LOWER NILE VALLEY, EGYPT.

M.A. Hamdan[(1)], R.J. Flower[(2)], F.A. Hassan[(3)]

(1) Geology Department, Cairo University, Egypt

(2) Department of Geography, University College, London, UK

(3) Cultural Heritage Program, French University, Cairo, Egypt

Abstract

The results of coring program in the floodplain of Saqqara-Memphis are introduced in order to enhance our understanding of the history of the modern River Nile and its relationship to the emergence and continuity of Egyptian civilization. The floodplain of the Saqqara-Memphis area reveals a sequence of aggradational and degradational events corresponding to variation in climatic conditions at the Nile headwaters and sea level changes. Deposition of predynastic floodplain resumed during a period of high Nile flow, rapid sea level rise and locally wet climatic conditions and Saqqara-Memphis area was occupied by swamps and anastomosing channels. Subsequently, during Old Kingdom, the Nile changed to a more stable meandering channel system with well developed levees and flood basins. This aggradational phase was subsequently eroded by the end of Old Kingdom (4.2 kyrcal BP). The degradational hiatus was followed by a widespread layer of alluvial silt and sand indicating very high Nile floods that coincide with historical records of very high floods during the Middle Kingdom and frequently high floods during the New Kingdom. During the last two thousand years floods generally diminished except for several notable lows and highs.

Introduction

River Nile created a linear fertile floodplain and a Deltaic plain fed annually by summer floods from faraway Ethiopia and Equatorial Africa[136]. Therefore, it can be said that the Egyptian civilization emerged and developed on the banks and floodplain of the Nile[137]. To the present day, the Nile remains the main source of water for Egypt[138]. Accordingly, ancient Egyptians were affected by climatic changes that determined the amount of Nile flood discharge and hence the areas that could

[136] WILLIAMS - ADAMSON 1980.
[137] BUTZER 1976; SAID 1981.
[138] HASSAN 2010.

be cultivated[139]. Changes in Nile flood discharge also had a major role in development of the floodplain and making it a very dynamic geomorphological environment[140].

Since 2007, a geoarchaeological project (scientific cooperation between Geology Department, Cairo University, Egypt and Department of Geography, University College, UK) has been carried out in the floodplain area between Dahshur in the south to Abusir in the north. About 30 cores were drilled in the floodplain in order to reconstruct the geologic evolution of River Nile[141]. In the present work, we used data recovered from six cores drilled in the floodplain of Saqqara-Memphis region (Fig. 1). The main objective of the paper is to reconstruct the paleoenvironment, floodplain evolution and geoarchaeological implications of Saqqara-Memphis region.

Lithostratigraphy of the Nile sediments at Saqqara-Memphis floodplain.

The Holocene sediments are subdivided into six lithostratigraphic units (units II-VII) overlying the basal Late Pleistocene (unit I), and underlies modern soil (unit VIII) (Fig. 2).

Unit I (Late Pleistocene): This unit is encountered below the Holocene floodplain sediments along the Nile Valley and the Delta and is dated to the Late Pleistocene[142]. It is recorded at the base of all studied cores and is characterized by 7.5YR 2/0 colour, gravelly coarse to medium grained quartzose sand without pottery or shells. It was recovered at different depths in the studied cores (Fig. 2).

Unit II Neolithic-Predynastic (c. 7500 to ca. 5000 cal BP)**:** This unit is encountered in only four cores; SAQA 1, 2, 3 and 21 and is represented by 2.5Y 3/0 to 2.5Y 5/4 colour; silty clay and fine to very fine grained, micaeous, quarzose sand with frequent silt streaks and frequent potsherds (SAQA1). It always shows an erosive basal and upper boundary with both underlying and overlying units. Potsherds were frequent in this unit in SAQA1 (at around 15.7 m bs). They mainly come from jars with a modelled rim and flattened base made from a burnished red, straw-tempered Nile silt fabric.

***Unit III (Old Kingdom)*:** This unit is recovered is all cores (except core SAQA18) and is described as 7.5YR 3/1 to 7.5YR 2/0 in colour; very fine grained sand, sandy silt, silt and rarely with clayey silt. It is rich in potsherds and sediment and shows high magnetic susceptibility (Fig. 2). The top most part and the base of unit III always show a sharp erosive contact with the overlying unit and is marked with abundant sands, and lag gravel with a cortex of desert varnish.

Diagnostic potsherds were recovered from core SAQA21, predominately roughly made Nile silt bread moulds (Fig. 3A), sherds of traditional offering jars (beer jar), with orange slipped sherds typical of the Fourth to Fifth Dynasty[143]; rim sherds of flat based bowls with flattened sides (Fig. 3B) and rim

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139 MARRINER *et. al.* 2012; WILLIAMS *et al.* 2015.
140 SAID, 1993; HASSAN 2010.
141 HASSAN *et al.* 2017; HAMDAN *et al.* 2018.
142 ATTIA 1954; BUTZER 1997.
143 HAWASS - SENUSSI 2008.

sherds of conical bread moulds also dating the Fourth to Fifth Dynasty. Sherds of sandy pink marl ware, white slipped on the outer surface, typical of the Fourth to Fifth Dynasty were also recorded[144].

Core SAQA22 yield a radiocarbon dated to 4410-4150 cal BP from depth of 10.85 m bs (Fig. 2). Around 12.0 m bs Old Kingdom potsherds made of Nile silt and red burnished were found and dating to the first half of the Fourth Dynasty, as were coarse thick walled Nile silt body sherds, probably part of an early wide mouth bread mould (Fig. 3C) dating to the Second or Third Dynasties and rim sherds of storage jars without a rolled rim (Fig. 3D). In core SAQA3, Fourth Dynasty potsherd fragments were recovered from only one level, 9.8 to 10.3 m bs, they include sherds from bread moulds, large basins and grey ware and rim sherds of a recurved bowl (Fig. 3E).

***Unit IV (Middle-New Kingdom*)**: This unit is mostly massive sandy silt, silt, and clayey silt, 10YR 5/2 in colour and rich in carbonate and iron-manganese concretions, with abundant potsherds and freshwater shells. Diagnostic potsherds dated to Middle Kingdom were found at the base of the unit and New Kingdom sherds at the top[145] (). In core SAQA22, these two pottery levels were recorded between 7.72 and 9.59 to 9.95 m below surface, separated by a sand layer without pottery. The former level is represented by New Kingdom sherds made of plain red Nile silt and rims and ring base sherds of grey marl ware (Fig. 3F). Middle Kingdom sherds are represented by plain red Nile silt and pink marl ware.

In core SAQA21, potsherds were recovered from two levels, 7.0–7.3 and 7.8–8.0 m below the surface and dated to Middle Kingdom. Pottery from the higher level is represented by body sherds from a roughly made offering jar (beer jar) with orange slip, rim sherds of a flat-based bowl with flaring sides and rim sherds of a conical bread mould[146]. The second (lower) pottery level yielded body sherds from plain Nile silt ware, sherds of a short carinated recurved rim bowl (Fig. 3G), which were named Meydum bowls[147] roughly made bread moulds and a rim of round bottomed bowl (Fig. 3H). All dated to New Kingdom.

***Unit V (Late Period)**:* This unit is mostly clayey sandy silt and sandy silt with abundant carbonate and manganese concretions, abundant freshwater shells and potsherds in cores, i.e. SAQA18, 21 and 22. A charcoal sample from SAQA22 at 7.75 m below surface yielded a calibrated age of 2710 to 2350 cal BP. This unit was found to contain pottery in cores SAQA1, 3, 21 and 22. At SAQA2 (6.0-6.70 m below surface), the following diagnostic potsherds were found: a rim sherd of round based bowl with simple rim (Fig. 3K), several body sherds of imported pink ware; and rim sherds of a plain bowl or cup dated to the Late Period.

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[144] ARNOLD - BOURRIAU 1993.
[145] HAMDAN *et al.* 2014.
[146] ARNOLD - BOURRIAU 1993.
[147] PETRIE 1909.

Unit VI: This unit is represented mainly by three lithologies; clayey silt, sandy silt and micaeous fine grained quartzose sand. It is recovered at depths from ca. 3.0 to 6.3 m below surface in core SAQA18. The sediment is 7.5YR 3/1 in colour, consisting of clayey silt with scattered potsherds and high magnetic susceptibility (Fig. 2). The sediment in this unit is predominantly of silty clay, clayey silt, sandy silt and silt (varying from 2.0 to 5.0 to 6.0 m bs). Ptolemaic potsherds indicate that this unit dates from 332 BC to 30 BC. Core SAQA18, 4.0 to 5.0 m bs, includes pottery sherds mostly made of Nile silt, with other sherds imported from Gaza and few sherds of Egyptian Brown Amphora, dating to the Ptolemaic period. SAQA2, (370-470m bs), contained five body sherds of plain Nile silt ware, a body sherd of Egyptian yellow marl ware, a body sherd of an Egyptian Brown Amphora, a body sherd of a Palestinian Gaza Amphora (Fig. 3K).

Unit VII: This unit is represented by clayey silt with intercalations of silty sand and sandy silt as well as calcareous gravelly sandy silt, often with abundant calcified root casts, freshwater shells and potsherds (Fig. 2). This unit occurs between depths of 2.5 to 4.0 m bs (core SAQA3), 1.0 to 3.5m bs (core SAQA22); 1.0 to 3.0 m (SAQA18); 1.0 to 2.5 m bs (SAQA21); 1.0 to 6.5m (SAQA1) and 2.0 to 6.5m bs (SAQA2). Lithology varies from clayey silt (cores SAQA21, 22, 18, 2, 1) and clayey silt with calcareous sand intercalation (core SAQA3).

Evolution of Floodplain of the Saqqara-Memphis region

Late Pleistocene

The lithological characteristics of unit I refer to deposition in a high energy braided river migrating laterally across the alluvial plane (Fig. 4A). During most of the Late Pleistocene, the total discharge of the River Nile was much less than today because wet seasons in the Nile headwaters were shorter but more intense[148]. As a result of reduction of stream competence and an increased sediment load, the Nile Valley was occupied by a number of braided channels[149]. We speculate that sediments of unit I were deposited by these braided channels. Moreover, during Late Pleistocene, the sea level was at least 120 m below present level[150] and the river gradient was far greater than that of modern times (about 1: 1,450 between Cairo and the shelf edge), and the whole Nile Valley was occupied by braided-river systems.). Late Pleistocene sediments found on the Giza floodplain are also interpreted as a "braidplain" system, which was formed under a high-energy flow and a steeper gradient during glacial-eustatic regression of the Mediterranean Sea[151].

***Neolithic-Predynastic* (c. 7500 to ca. 5000 calBP)**

Generally, the Nilotic sediments of the Early Holocene, (younger than 8.2 kyrcal BP) were characterized by a predominance of sand and silty clay indicating high Nile floods and filling a deep trough on the floodplain (Fig.4B). This period is represented by unit II and comprises two lithofacies;

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148 WENDORF - SCHILD 1976.
149 VERMEERSCH - VAN NEER, 2015.
150 STANLEY - WARNE 1993.
151 BUTZER *et al.* 2013; BUTZER 1997.

(1) massive silty clay (SAQA3) and clayey silt (SAQA1 and 2), with abundant calcified root casts, dark grey organic rich streaks and reworked limestone fragments, indicating a well vegetated swampy environment and intensive local runoff from the western plateau; (2) fine grained micaeousquartzose sand with silty intercalations referring to a channel fill environment. These channels indicate an anastomosing river with multiple, interconnected, coexisting channel belts on the floodplain[152]. Factors controlling formation of ansotomsing channels in the Saqqara-Memphis area include sea-level rise, increased water in the river channel, and low floodplain gradient. There was rapid sea level rise until between 7 and 6000 years ago, several metres per millennium at the shelf-edge of the Nile Delta, followed by a period of gentle sea level rise of 1.0 m per millennium until the present[153]. When the base of a river channel reaches sea level the channel bifurcates into two smaller and shallower channels[154]. As a result of rises in the sea level, our study area was located closer to the Nile Delta head. During the Old Kingdom and New Kingdom the delta head was in the Memphite region, but in the Middle it had moved south to near Lisht. Consequently, the Saqqara-Memphis area would have been part of the Nile Delta during the deposition of Predynastic silt. During Early to Mid-Holocene the Nile channel was dominated by an anastomosing style fluvio-deltaic channel system[155]. Such environmental conditions of unit II pre-date the deposition of a true Nile floodplain environment.

Early Dynastic to Old Kingdom **(ca. 5000- 4200calBP)**

The lithology of the Early Dynastic to Old Kingdom silt indicates that sediment was deposited by water in a low energy environment (flood basin). The abundant clay content in some cores (e.g. cores SAQA22, 2, and 1) and the relatively low $CaCO_3$ content probably indicates that they were deposited in a back swamp environment with relatively low evaporation. These shallow temporary lakes or ponds were formed at the edge of the floodplain following high floods across mainly flat, relatively featureless areas of floodplain. Back-swamps act as stilling basins at the margin of the floodplain, where silt and clay particles can settle from overbank flows after the coarser suspended debris has been deposited on levees[156]. They appear to have been well vegetated as indicated by abundant calcified plant roots and stems in this unit. The existence of fine-grained micaceous sand lenses within this unit in cores SAQA21 and 22 also favours its interpretation as a levee[157]. Generally, during the deposition of unit III, the river's gradient decreased and the ephemeral anastomosing channels of unit II, were changed to a more stable meandering river systems (Fig. 4C), as a result of the deceleration in rate of sea level rise by as much as 1 mm/yr since around 6000 cal BP until the present time[158]. The Nile Valley changed from a swampy basin during the deposition of unit II to a seasonally inundated river plain during the deposition of the following units, and the Nile Delta apex started to shift northward. Then Nile floodplain became more convex in cross section due to greater deposition of alluvium caused through overflow of suspended sediment (silt and clay), and also formed by

[152] MAKASKE 2001.
[153] STANLEY - WARNE 1994.
[154] BUNBURY 2013.
[155] PENNINGTON *et al.* 2016.
[156] ALLEN 1965.
[157] BUTZER 1976; SAID 1993.
[158] STANLEY - WARNE 1994; PENNINGTON *et al.* 2016.

repeated channel shifts and lateral accretion. The convex floodplain was marked by natural levees that rise several meters above the seasonally inundated alluvial flats. The slightly convex valley cross section was lowest in elevation away from the channel and the outer margins of the valley were often occupied by back swamp ponds during flood time[159].

The sediments of late Old Kingdom contain reworked limestone fragments from the nearby plateau (especially in cores SAQA1, 2, and 3), reflecting local run-off from adjacent wadis. A thick water-led deposit was recognized. inside late Sixth Dynasty tombs in the western part of the Saqqara necropolis[160], which they interpreted as local winter rainfalls. These rainy periods are characterized by their unusual intensity and relatively long duration[161]. Local wet conditions were also indicated by desert wash interfingered with floodplain sediments on the floodplain edge at the foot of the Giza Plateau, and form alluvial fans extending about 1500 m to the east of the floodplain margins[162].

***First Intermediate Period* (ca. 4200-4000BP)**

Our coring programme indicates the existence of a distinct erosional surface at the top of unit III (ca. 11.0 m below surface), which dates to 4200 to 4000 cal BP. This coincides with disconformity and soil formation in the Delta at 4150 cal BP[163] and this is approximately concurrent with the 4.2 kyrcal BP dry event[164] and coincides with our lower radiocarbon date in SAQA22. This dry event was accompanied with invasion of sand dunes from the nearby Western Desert. These dune sands are represented by a 1.0 meter thick unit in core SAQA6, which extended onto the floodplain as a ribbon of sand of variable thickness in almost all of the drill cores. This sand unit was part of a huge lee dune encroached from the Western Desert (Fig. 4D) and extended about 5 km from Saqqara to Abusir[165]. Rejuvenated dune activity probably started after Middle Kingdom and led to the deposition of 6.0 m dune sands i.e. core SAQA6. This massive sand dune reached out at least half a kilometre from the escarpment, and was probably still a prominent feature in the medieval period.

***Middle Kingdom to New Kingdom* (ca. 4055- 3070BP)**

Very high Nile floods coincident with historical records of extremely high floods during the Middle Kingdom are indicated by a widespread layer of alluvial silt in almost all cores at about 11.0 m below surface. In the Faiyum these floods proved to be catastrophic, destroying the Middle Kingdom dams constructed to regulate water flow into the Faiyum depression[166]. The sediments of unit IV (Middle-New Kingdom) comprise of massive, silty sand with cross-laminated medium to fine-grained micaceous sandy lenses, indicating various flood sequences. The muddy unit with freshwater shells

[159] BUTZER 1976.
[160] WELC - MARKS 2014.
[161] WELC 2011; SOWADA 2013.
[162] BUTZER *et al.* 2013.
[163] STANLEY 1990.
[164] HASSAN 2002.
[165] GIDDY - JEFFREYS 1992.
[166] HASSAN - HAMDAN 2007; HASSAN *et al.* 2012.

and plant debris (commonly calcified roots), could be interpreted as vertical1y accreted inter-channel deposits or flood basin. The silt and clay-size sediments in this unit are assumed to be the product of suspension/deposition on the flood basin during over-bank flooding. The abundant calcified root casts in the flood basin sediment support the conclusion that they were intensively cultivated after season of inundation. The existence of these fine grained sandy layers with abundant pottery sherds and other archaeological remains are interpreted as levees[167]. The levee deposits in this unit consist of a series of thin intercalated mud and fine-grained sand, which again contain root casts. The silty clay layers with ostracods shells and abundant charophyte oospores, described at depths 7.65 m and 8.45 m in core SAQA18 (Figs. 2, 4E) indicate deposition in low energy wetlands, possibly an abandoned channel (oxbow lake). Generally, these channels remain as lakes or ponds for a considerable length of time but will gradually silt-up, leaving the abandoned channel to become progressively protected from floodwaters. These static water bodies would slowly fill with clays deposited from suspension[168], but mainly broken ostracod valves in SAQA18, which indicate some initial flood induced turbulence effects. The middle part of unit IV is characterized by abundant sandy lithology with lag gravel with cortex of desert varnish, indicating an erosional surface at the contact between the Middle and New Kingdoms and most likely dated to the Second Intermediate Period. It is also coincident with the inference of declining Nile flood levels at that time in the Faiyum depression[169].

***Third Intermediate Period to the Modern Era* (ca. 3070- present)**

The sediments of the Third Intermediate Period to Late Period are represented by massive layers of Nile silty clay l with carbonate nodules, indicative of a flood regime followed by a drier more arid season (Fig. 4F). The top surface of unit V is erosional and may be dated extrapolating from radiocarbon age determination to be about a century younger than the date of 2710-2470 calBP from core SAQA22, placing this erosional hiatus at ca. 2600-2370 calBP (i.e. ca 2.4 kyrcal BP dry event), placing it in the Late Period, a period of political turbulence.

The upper parts of the studied cores are characterized by a predominance of sand and sandy silt indicating high energy fluvial periods separated by thin laminated, calcareous mud interbedded with fine-grained micaceous sand. The deposition of these latter units occurred in quiet water conditions but fluctuations in grain size may reflect changing discharge, unaccompanied by active bed-load transport. Abundant root casts and the occurrence of pedogenic features (caliche horizons) indicate subaerial exposure.

Geoarchaeological Implications

The a typical "modern" Nile black mud occurred mainly between ca. 7500 cal BP to 4200 cal BP, coincident with the rise of sea level during post-glacial global warming[170]. This was the period when the first Neolithic communities began mixed farming practices in the Nile Delta at sites such as

[167] MIALL 2014.
[168] MIALL 2006.
[169] HASSAN *et al.* 2012; HAMDAN *et al.* 2016.
[170] BUTZER 1976; HASSAN 2010.

Merimde Beni Salama and Sais (ca. 5000 cal BC). The other early centre was the Faiyum, where Early Neolithic communities herded ovicaprines and cattle ca. 5550 to 4650 cal BC and in the Late Neolithic 4650 to 4200 cal BP started cultivation of wheat and barley along with herding of sheep, goats, cattle and pigs[171]. The Nile Valley, which was previously occupied by hunter-gatherer-fishers, witnessed the arrival of farmers ca. 4,400 cal BC in the region of Badari. Cattle herding had been practised in the Western Desert and oases from 8,100 cal BP[172] but with the onset of aridity in North Africa and the south-eastern Mediterranean from 7800 to 6100 cal BP many of these pastoralist came into the Nile Valley[173].

The network of Saqqara-Memphis coring sites has revealed occupations at considerable depths below the surface, much lower than previously suspected, particularly at SAQA2, and SAQA22 in north-western and central Saqqara. The absence of potsherds as well as archaeological remains in unit II (7500-5000 cal BP) probably indicate that human occupation existed at higher elevations towards the plateau top, similar to the situation at El-Omari in the Helwan region on the opposite bank to Saqqara where Late Neolithic occupation has been found. Indeed, most of the discovered Neolithic and Predynastic sites in the Nile Valley and Delta are located along the higher desert plateaus and terraces such Maadi and Helwan on the Eastern bank of the Nile and Merimde Beni Salama at the western edge of the Nile Delta or on turtlebacks such as Minshat Abu Omar[174]. The stable period of floodplain development and low frequency of droughts coincided with the major period of pyramid building, from 4686 to 4200 BP (Dynasty III to VI).

The floodplain core sites in front of the pyramids of the Saqqara necropolis were selected in order to clarify the relationship between the buried settlements and these pyramids. Core SAQA1, located opposite the Step Pyramid Complex of Djoser had a unit of silty clay without pottery between 16.7 and 18.5 m bs and a unit of sandy silt intercalated with silty clay, clayey silt, and silty sand immediately below a typical floodplain sequence. The unit contains freshwater shells suggesting close proximity to a channel and/or ponds and pools. Importantly, this core contained evidence of human occupation at 15.2 to 16.7 m below surface and all the way up to 12.9 m below surface. This not only indicates that a settlement existed nearby, but also that settlements persisted throughout the Old Kingdom. Quite possibly, the site could mark the location of the royal residence of King Djoser (ca. 2686-2667 BC), opposite the building site of his Pyramid. We suggest that due to religion and tradition the king's pyramid complex was placed in the west of an East-West axis with the royal palace in the East. Potsherds found in the lower layer from 16.0 to 16.7 meters were initially scarce and perhaps represented the Predynastic level. This is followed upward with pottery in sandy silt and clayey silt from 16.0 to 14.50 m below surface (main occupation during the Third Dynasty) and an upper occupation, after a hiatus (13.0-14.50 m bs) followed by a thin layer of silty sand (from 12.9 to 13.0 m below surface), which may be contemporary to the final Old Kingdom occupations at that

171 TASSIE 2014.
172 LINSEELE *et al.* 2016.
173 KUPER - KRÖPELIN 2006.
174 ROWLAND - BERTINI 2016.

time (Fifth and Sixth Dynasty) when the royal residence was moved first opposite King Unas's pyramid and then to *Men-nefer*, opposite the pyramid of Pepi I (ca. 2321-2287 BC).

Core SAQA18 did not reach a depth beyond 12.0 m and hence Old Kingdom sediments are not represented. Early Middle Kingdom sand deposited during high Nile flood surges were overlain with a layer of silty clay overlain by a layer of silt before an erosional contact, which is correlated to the Ptolemaic recession (at 6.0 m below surface). Above Middle Kingdom pot sherds around 10.00 m depth (Fig 2) a temporary closed basin lake is indicated by dark sediments with aquatic microfossils and mollusc shells (c. 8.0 m). Above this wetland lake deposit, several worked limestone building fragments occurred and sediment became more silty and New Kingdom pot shreds appeared.

The sediments in core SAQA6 (at the foot of the plateau) reveal a lack of potsherds suggesting that the area of the core was part of the rural landscape. The sequence of deposits suggests that the area was a part of an active channel during the Late Pleistocene-Early Holocene. During the Old Kingdom it was a part of the floodplain. The area of core SAQA6 was again part of the floodplain after the short First Intermediate Period degradation event due to the high Nile floods during the Middle Kingdom. During the New Kingdom it was part of rural landscape.

Conclusions

The Saqqara-Memphis floodplain reveals both aggradation and degradation events corresponding to magnitudes of Nile floods and paleoclimatic conditions in the African Nile Headwaters. The sequence started by a unit of Late Pleistocene fluvial sand and gravel and relics of early Holocene fluvial sediments. Neolithic-Predynastic period is represented by a period of high Nile flow associated with steep sea level rises and wet local climate with the floodplain occupied by swamps and anastomasing channels. the River Nile changes to a more stable meandering channel with well developed levees and flood basins with the floodplain aggraded to an elevation of 9.0 m asl. The next aggradation is represented by a widespread layer of alluvial silt and sand in almost all cores at 12.0 to 9.0 m asl, indicating very high Nile floods, which is coincident with historical records of extremely high floods during the Middle Kingdom and frequent floods during New Kingdom. Normal floods with several lows and highs prevailed during the last two thousand years.

The coring program of Saqqara-Memphis has revealed occupations at considerable depths below the surface, much lower than previously suspected, particularly at SAQA2, and SAQA22 in north-western and central Saqqara. Early Old Kingdom potsherds were recovered at depths of 4.0 to 5.5145 m asl (SAQA1) associated with levee and flood basin deposits, probably corresponding to the royal residence of King Djoser (Third Dynasty). Evidence for late Old Kingdom settlement was recovered in cores SAQA21 and 22 at depths from 7.0 to 8.0 m asl, probably indicating a rapid eastward shifting of the western distributary channel. The topmost part of Old Kingdom (late Dynasty VI to Dynasty VIII), is marked by an erosive phase associated with very low Nile floods and aeolian sand encroachment from the Western Desert. As a result of such a major arid drought event, the floodplain disappeared and was replaced by desert during the First Intermediate Period. This cold arid event along with political changes led to the collapse of the centralized Old Kingdom government. This disastrous event is recorded at the top of unit III by a change to fine sand and where an Old Kingdom occupation layer is radiocarbon dated to 4410-4145 cal BP.

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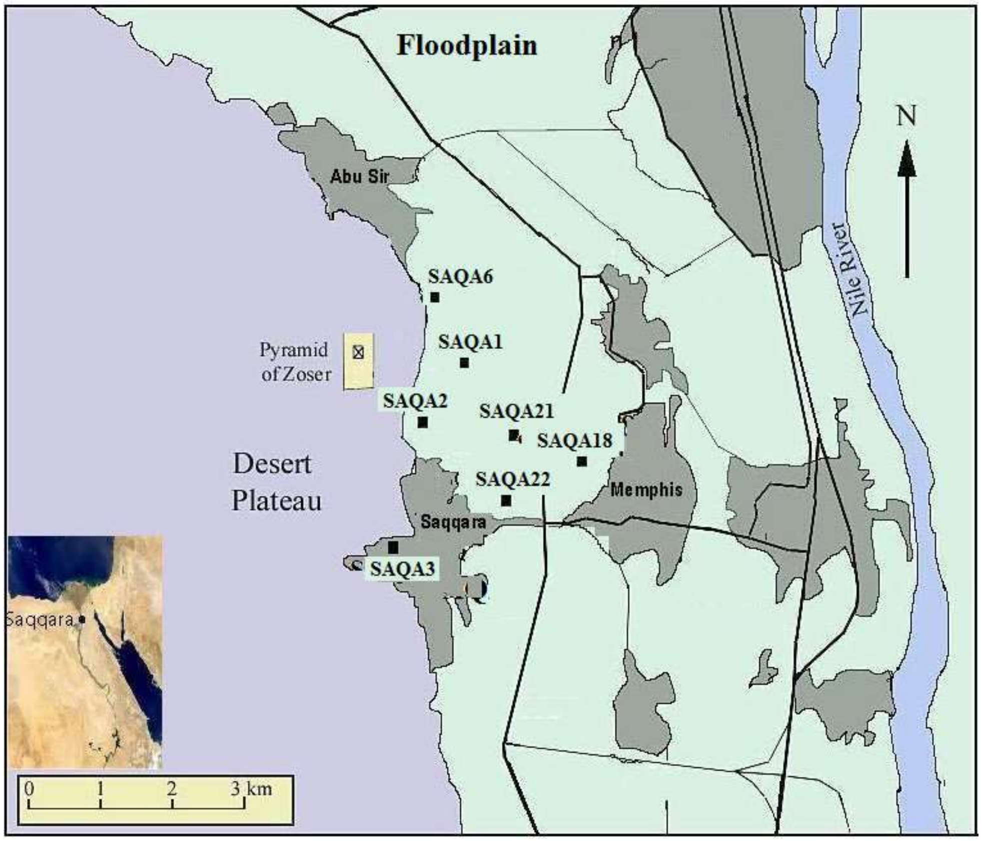

Fig. 1 - Google Earth image of the floodplain of Saqqara-Memphis area with the location of the studied cores.

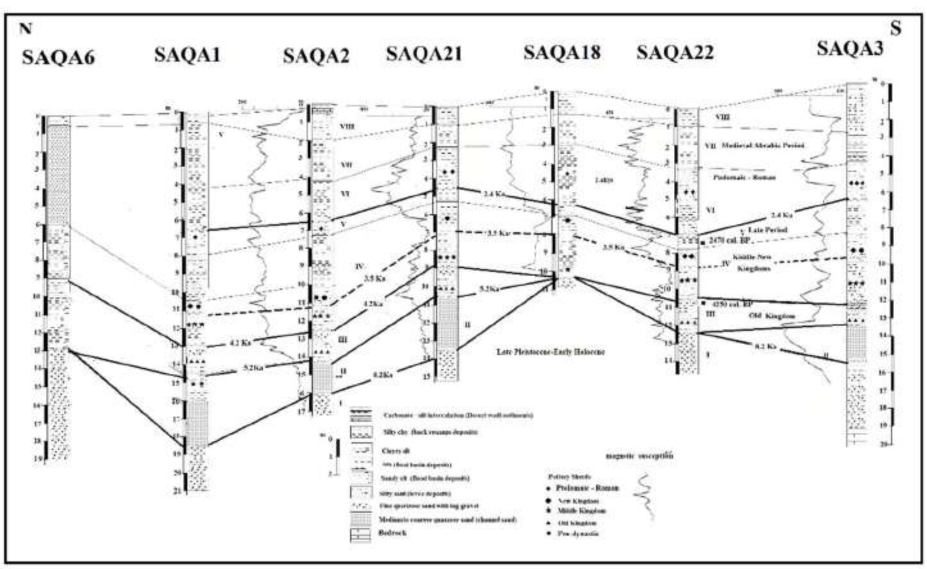

Fig. 2 - Lithostratigraphy and Magnetic susceptibly of the Holocene sediments of the floodplain of Saqqara-Memphis area.

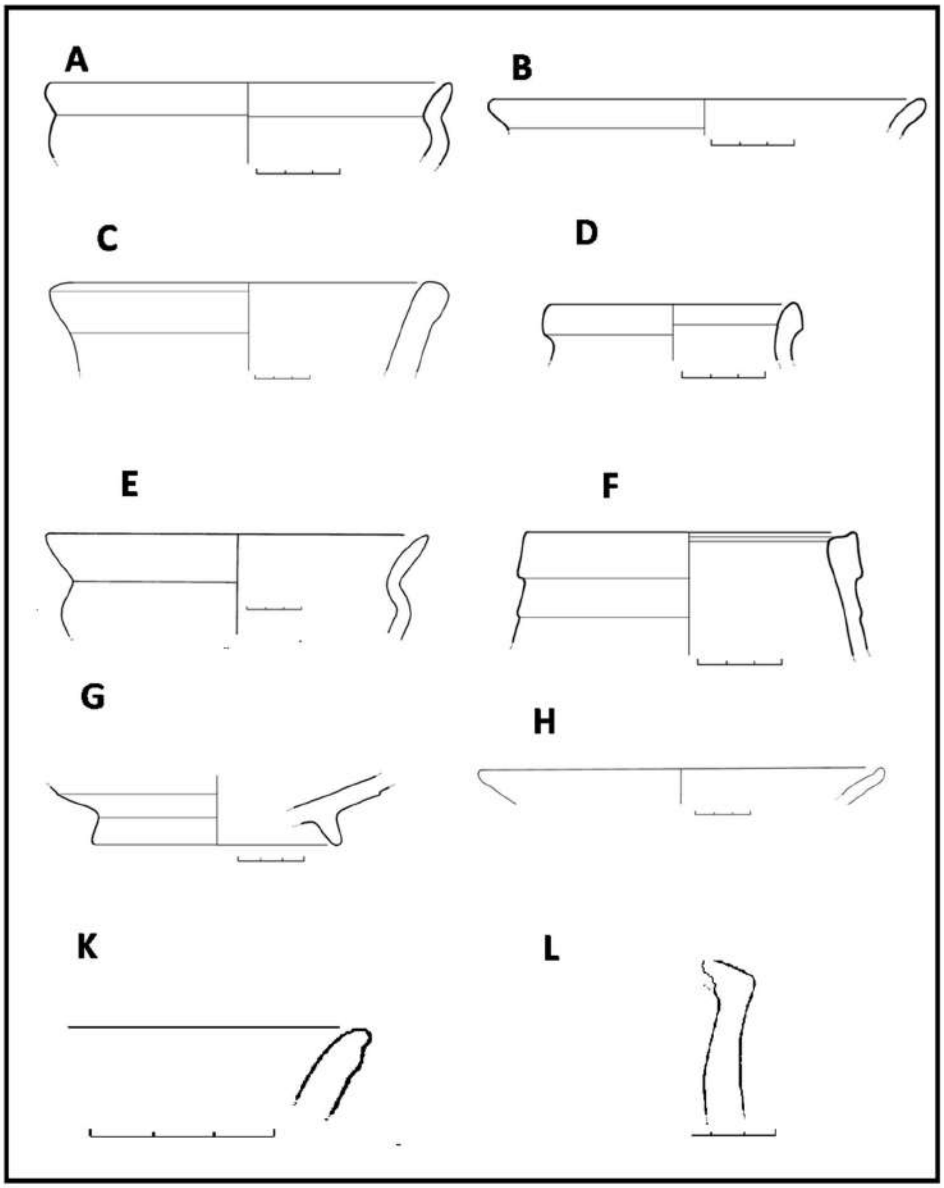

Fig. 3 - Typology of recovered, see text for details.

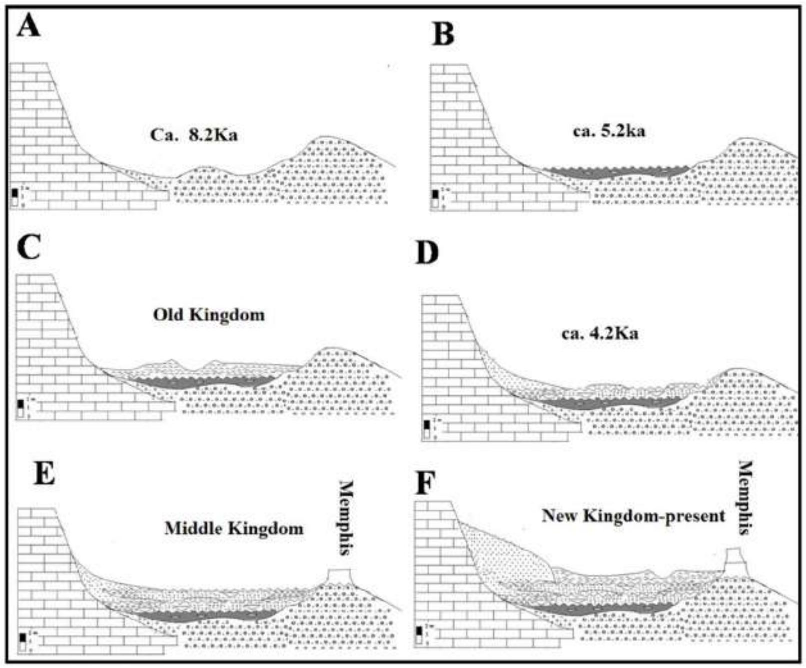

Fig. 4 - Evolution of Saqqara-Memphis floodplain through Holocene, see text for details

NILE AND RED SEA - WADI TUMILAT AND OLD TRANSVERSAL CONNECTIONS BETWEEN TWO MAIN COMMERCE ARTERIES

Bruno Marcolongo

Consiglio Nazionale delle Ricerche, Istituto di Ricerca per la Protezione Idrogeologica (CNR-IRPI)

Precise localization and shape of the old Pharaohs canal and those of Wadi Tumilat[175], connecting in ancient times Nile valley with Red Sea, has since ever attracted researchers and scholars' attention[176]. At the end of seventies of last century, during five excavation seasons done between 1978 and 1985, University of Toronto carried out the "Wadi Tumilat project" under the direction of John Holladay. Focus has been concentrated essentially to Tel El Maskhuta[177,178].
More recently, since 2007 the Polish Centre of Mediterranean Archaeology/University of Warsaw (PCMA) started excavations in Tel el-Retaba ("Tel el-Retaba Archaeological Mission"), an XVIII dynasty fortress and then civil settlement during Late Period till Ptolemaic Period[179,180].

Now, careful geomorphological interpretation, performed in the plain band between Nile and "Great Bitter Lake" with the high-resolution images broadly distributed by Google and Bing (Spot 5 colors 2,5 m and Digital Globe-Ikonos), brings to light a series of paleo-fluvial elements which sprawl coherently between Nile and the "Great Bitter Lake".

In fact, recalling previous paleo-hydrographic studies made around Ma'adi and on the easternmost portion of delta[181], I have drawn a detailed map of all the paleo-fluvial traces (paleo-riverbeds,

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[175] *"An ancient shipping canal, the precursor to the modern Suez Canal, once joined the Nile to the Red Sea by following the route of the Wadi Tumilat east to the Bitter Lakes and then turning south to a point near the modern town of Suez. Through a combined strategy of survey and excavation the Wadi Tumilat Project has been able to date, with a high degree of probability, the original construction of the canal to the late 7th century BC, i.e. during the reign of Necho II of the 26thSaite Dynasty. That this dating coincides with classical sources says something for both contemporary archaeological method and classical histories. This canal was enhanced and completed in the early 5th century BC by the Persian emperor Darius, who erected four commemorative stelae along the route. A period of neglect of the canal was rectified by Ptolemy II and the canal was renewed by the Roman emperor Trajan (Diodorus 1967: Bk. 1.33.8-12; Herodotus 2008: Bk. 11.158; Plinius 1967: Bk. VI.xxxii.165-167; Strabo 1960: Bk. 17.1.25; Holladay 1982)."* (from: PAICE 2015).
[176] ALVARO 2012.
[177] Middle Bronze IIB settlement (18th-17th centuries BC), associated with the Hyksos, followed by a long break until the late 7th century BC, when there was rebuilding.
[178] AUBERT 2004.
[179] Following the Team's view: "*The importance of Tell el-Retaba during the Pharaonic times was highlighted by the existence of water supplies in the immediate vicinity of the site. It seems plausible that an ancient water channel connecting the Delta with the Red Sea was running past this site. Drinkable water supplies were vitally important not only for the soldiers stationed at the fortress, but also for the Bedouins migrating through the Egyptian border in the area of the Bitter Lakes that are nowadays part of the Suez Canal*". (http://aigyptos.sk/en/tel-el-retabi).
[180] HUDEC - FULAJTAR - STOPKOVA 2015.
[181] MARCOLONGO 1992; CANEVA - MARCOLONGO - PALMIERI 1995.

terraces and paleo-fluvial overflow, etc.) starting from Nile “talweg” and spreading numerous along ancient Tumilat valley (see below Figg. 2-3-4-5-6-7-8).

In the urban texture of Old Cairo (easternmost part, just starting from the area of Coptic Museum) are recognizable structural discontinuities, which in force of their shape, direction and extension could be superimposed to a paleo-flow branch of Nile eastward to “Great Bitter Lake”.

Further to the east, textural and morphological discontinuities are represented by bands of agrarian parcels with higher soil moisture content and “meander” like shapes, often in lower topographical area.

Moreover, the entire wide band of the so-called Tumilat valley is flanked by almost continuous old fluvial terrace, marking the land subjected to the morpho-dynamic of the paleo-riverbed.

In particular, about 10 km downstream of Tell Retaba and 7 km upstream of Tell Maskhuta, traces of an old river overflow can be recognizable on the satellite images, which cut the terrace itself and extend towards southeastern lowlands.

The legend of the thematic map, so produced, carries the following categories of paleo-hydrographic evidences:

- bands of "brown" color: paleo-riverbed traces in urban area
- bands of "green" color: paleo-riverbed traces in farming (rural) area, with iso-orientation of agrarian parcels
- lines of "red" color: ancient fluvial overflow
- line of "violet" color: fluvial terrace of ancient W. Tumilat course
- band of "light green": wetter band (tract of old Pharaoh’s canal, starting from Bubastis???)

The whole riverbed of old W. Tumilat, shown in the above sequence of images, materializes its shape and exact position through the broad band of rural terrain intensively cultivated, oriented West-East with an average width of 3-4 km.

Important archaeological sites as Tell Retaba[182] (Heroöpolis), Tell Mashkuta and also Tell Basta (“Bubastis”) show tight space contiguity with the abandoned course of the easternmost Nile’s branch.

[182] Some scholars identify Tell el-Retaba with the ancient city of Pithom, name probably derived from the Egyptian name Per-Atum, meaning “House of Atum” (KITCHEN 1998). But designation for the temple of Atum (“*pr-itm*”) can be found in inscriptions at both sites - both at Tell El Retaba and at Tell El Maskhuta -. This seems to prove that the name 'Pithom' was used originally for the earlier site, Tell El Retaba, before it was abandoned. And when the newer city of Tel El Maskhuta was built, the same name was applied to it as well – as the temple of Atum was moved to El Maskhuta. Thus, in effect, 'Pithom' was moved to a new location.

Availability of surface flow water appears in these cases as the most attractive environmental element, guiding settlement strategy and influencing very much growth, development and decline of sites themselves

Obviously, this study, completely preliminary one, should be followed by detailed geomorphological and geo-archaeological survey on the spot, which only can confirm and enrich the provisional frame here suggested.

Specific care has to be devoted to the collection of possible existing micro-relief topographical data and stratigraphic data in the corridor of Wadi Tumilat valley, as well as of pedological and agronomic data, which all together are able to indicate soil and sediment differences due to the fluvial history and landscape morphogenesis.

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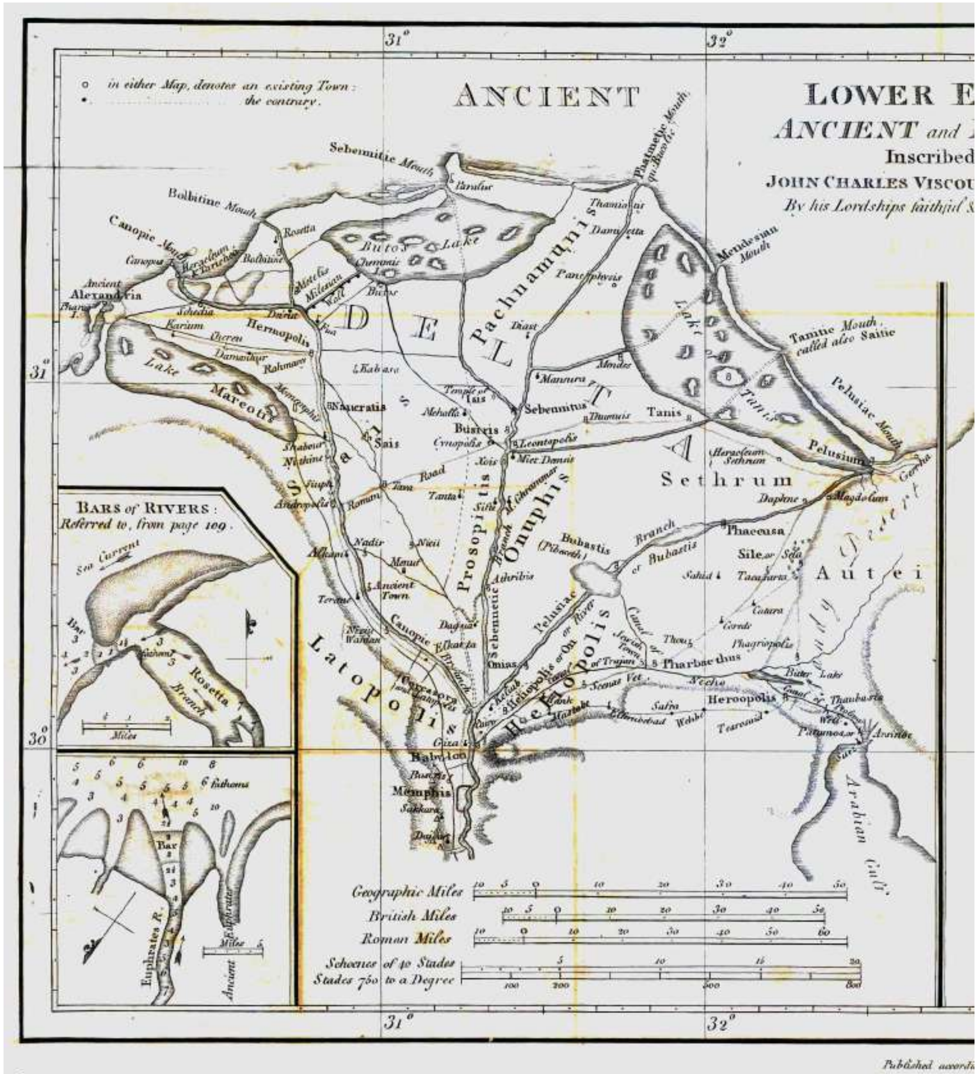

Fig. 1 - Nile’s delta at Herodotus time, after the great geographer James Rennell (1800)

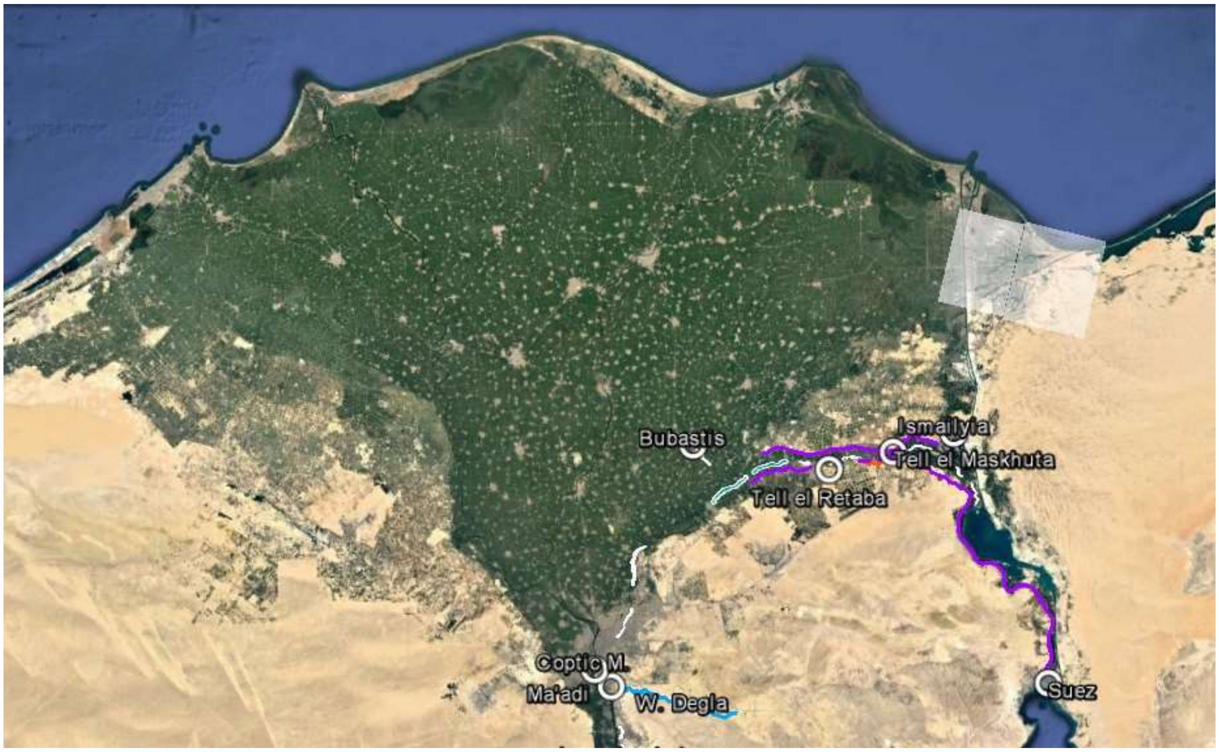

Fig. 2 – Palaeo-fluvial traces along old Tumilat Wadi valley from interpretation of Spot 5 and Ikonos satellite images.
Following Fig. 3, 4, 5, 6, 7, 8 are enlargement of successive palaeo-fluvial stretches from Cairo to Red Sea

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

MULTISPECTRAL REMOTE SENSING AS A TOOL FOR ENVIROMENTAL AND ARCHEOLOGICAL STUDIES

Rosamaria Salvatori

Consiglio Nazionale delle Ricerche, Istituto sull'Inquinamento Atmosferico (CNR-IIA), Monterotondo (RM), Italy; e-mail: rosamaria.salvatori@cnr.it

Abstract

Multi and hyper-spectral remote sensed images are currently a well-established and effective tool for environment monitoring and archeological studies. The benefit supplied by the use of remote sensed images lies either in the capability to perform synoptic analyses of large surfaces when using lower spatial resolution sensors or in supplying detailed information when using new high spatial resolution images. The availability of satellite images, collected in the last three decades, can also provide a historical record of environmental changes and anthropic modifications.

Since the spectral characteristics of the surfaces are related to their physical and chemical properties, the processing of multi- and hyper-spectral images, acquired at wavelengths between 0.35 and 2.5 µm, takes advantage when integrated with field or laboratory spectral data and with physical and chemical measurements of the investigated surfaces. The characteristics of multispectral images allow to follow the evolution of the landscape from the vegetation point of view as well as from the geomorphological one.

The paper presents an overview of theory behind optical remote sensing and of the fundamental principles of image processing, mentioning data interpretation, information extraction from multispectral data and image processing techniques.

Dealing with the images and their spectral properties can easily represent the starting point for the collection of data coming from different sources and for their organization in a complex system devoted to reconstruct the archeological environment together with its natural framework.

Introduction

Since the invention of photography, top down images have been widely used as a tool for scientific purposes not only for environmental studies but also for urban, archaeological or military purposes.

The first photographs used to analyze the territory were shot by Felix Gaspard Tournachon, known as Nadar, in 1858. By carrying one of the first photographic camera on a balloon, Nadar not only shot images of Paris but also managed to make a first stereoscopic images of Arc de Triomphe-Etoile'[183]

Nadar recognized the potentiality of aerial photography and patented his device, saying that his project allowed him to use photography for topographic, hydrographic and cadastral mapping, and to direct strategic military operations for identifying fortifications and men in march[184].

From then on, the vision from above has become an essential tool for landscape studies and has been developed following the technological development of both photographic and aeronautical systems (airplanes first, satellites and drones now). The importance of these techniques already from early times can be proved by the use of miniaturized and automated cameras, fixed to homing pigeons, for military reconnaissance at beginning of the 20th century (1908). Also in the same period, the first aircrafts started to fly and, consequently, the platforms for aerial photography begin to evolve. In 1909, on behalf of the Italian government, Wright brothers carried out the first aerial photographs collection, flying over the Italian landscape near Rome. The shootings of their flyover show the remains of Roman aqueduct and other archaeological remains[185].

The first world conflict saw the rise of aerial photography as a protagonist in the areas reconnaissance activities and since then this technology has remained a milestone of military activities.

Fortunately, topography and cartography surveys for civil and scientific purposes in geology, biology and natural sciences, have joined military activities. From the '30s the ability to collect near-infrared radiation, that human eye could not perceive, on photographic films, disclosed a new opportunity to landscape investigations. After the Second World War, a rapid evolution of technology promoted the passage from photographs on film (analog image) to digital images and from airborne to satellite sensors.

In the '60s, American and Russian space programs launched the first systems to take photographs of the surface of Earth and Moon (Lunar Orbiter Program) and the term "remote sensing" (RS) was established. As consequence of NASA's Apollo missions, that brought the man on the Moon in 1969, the Landsat program was started in 1972 and it is still running. At the first launch of the Landsat satellite series, which had a spatial resolution of between 80m and 30m per pixel, followed the French satellite SPOT in 1986, with a spatial resolution of 10m pixels for Pancromatic (HRV) image and 20m for multispectral ones. Since 1996, the resolution of satellite imaging has continued to improve. In September 1999, Space Imaging Inc. launched the IKONOS satellite, which has 1 m pixel resolution panchromatic sensors and now, images of the WorldView-3 satellite with panchromatic band at 0.31 m per pixel and 8 bands at 2 m resolution are commercially available.

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[183]LILLESAND *et al.* 2004.
[184]GOMARASCA 2009.
[185]CAMPBELL - WYNNE 2011.

Moreover, from 2014 the European Copernicus mission have made available, free of charge, the images of the Sentinel satellites constellation. This new opportunity will make more and more widely available satellite data: these facilities are really easy to use, considering that several user- friendly and open source software for image processing are now also available. For all these reasons, presumably, in the future the remote sensing application in archeology can only increase.

All satellite images collected from the seventies represent now an "historical" record of the evolution of the landscape. These images can portray the surface changes occurred on the whole planet in the recent past and represent a valid document of cultural heritage; it is possible, for example, to observe an area before and after an earthquake or before and after the destruction of monuments caused by war events.

With the introduction of satellite digital images, landscape analysis has radically changed its nature extending from the survey of an area for cartographic purposes to the ability to obtain quantitative data on the physical-chemical characteristics of the terrestrial surfaces even on very large portions of our planet.

Nowadays, satellites carrying different kind of sensors move around our planet: there are passive sensors able to collect the solar radiation reflected from the Earth's surfaces and active sensor able to send an electromagnetic impulse toward the Earth surface and measuring the signal sent back from the surface. Using all these active and passive sensors, extremely detailed images of Earth, not only from the geometric point of view, but also from the spectral one, are easy accessible. The details in these images can vary from centimeters to hundreds of meters, thus adding precious information to the analysis of the territory.

The plain examination process of the images (photo-interpretation) allows the operator to interpret the images extracting just qualitative information, while the digital image processing adds quantitative data to the visual interpretation. For this reason, the digital image processing is commonly referred as "remote sensing", the discipline that allows you to capture data about an object without being in touch with it[186].

The aim of this paper is to provide an overview on multispectral remote sensing; in order to understand its possible uses as a tool for environmental and archeological studies too, the document will briefly describe the basic physical principles that are the bases of RS and the statistical techniques used in the image processing.

Basic principles of remote sensing

In RS the measured parameter is the electromagnetic (EM) energy coming from the surfaces. To measure this physical quantity means quantifying the alterations the object causes on radiation, i.e. its characteristics such as intensity, frequency, or polarization. This quantification leads to a physical

[186] JENSEN 2000; LILLESAND *et al.* 2009.

knowledge of the studied surface, rock, soil, vegetation, water and atmosphere. It follows that the scope of RS investigations is indeed extremely wide.

The electromagnetic spectrum

The multispectral RS technology and applications are related to the electromagnetic energy coming from the Sun and therefore the remote sensors are designed to register energy in the spectral range between 0.35 and 2.50 µm. This interval includes the visible range, 0.38 - 0.75 µm, corresponding to human eye sensitivity, the reflected infrared (near infrared 0.75 - 1.30 µm) and the short wavelength infrared (1.50 - 2.50 µm) (Fig. 1).

For each remote sensor, these ranges are divided into different, smaller, bands, depending on the specific applications for which the sensors have been designed. Several remote sensors are also able to collect the signal coming from the thermal infrared range (10.00 - 14.00 µm)

Rather than deepen into the physical laws that govern electromagnetic radiation, it is useful to remember that it propagates like a wave but can be imagined as a particle (quanta or photons).

Wave theory teaches us that electromagnetic radiation is defined by the wavelength (λ) and frequency (ν= number of peaks in the unit of time) their product is constant and represents the wave propagation velocity. The velocity is given by:

$$c = \lambda\nu \qquad \text{and} \qquad \nu = c/\lambda$$

where c is the velocity of light ($c = 3x10^8$ m/s)

The particle theory suggests that energy transfers occur for discrete quantities (quanta: Q).

$$Q = h\,\nu = c/\lambda \quad \text{where } h \text{ is the Planck's constant}$$

This means that the energy of a photon is directly proportional to the frequency and thus inversely proportional to the wavelength. The longer the wavelength involved, the lower its energy content.

These concepts have important implications in remote sensing because sensors are designed to measure this energy content. The Sun radiation is in fact selectively "affected" when it encounters a surface. It can be absorbed, transmitted or reflected in different ways and intensity depending on the chemical and physical characteristics of the object with which it interacts.

Remote sensors, through a complex system of lenses and detectors scan the surface recording data into discrete elements, the picture element (pixel), the ordered array of which represent the remote image. Pixel sizes are closely related to the range of wavelengths the sensor is sensitive to. The sensors that record the infrared wavelengths with low content of energy must "see" pixels large enough to detect a signal with sufficient energy; in fact, all sensors, even those most sophisticated, have sensitivity limits. On the contrary, sensors designed to record the entire visible wavelengths range can detect a sufficiently energetic signal also from pixels with small size. It follows that the spatial resolution of the images is closely related to the spectral range, to the field of view and to the sensitivity of the sensor.

Energy / surfaces interactions

Purpose of remote sensing is to analyze the amount of electromagnetic energy reflected or emitted from the Earth surface to investigate its nature, assuming that every constituent, soil, vegetation or artificial materials, can reflect, absorb and transmit incident radiation in different percentages depending on its chemical-physical characteristics.

Considering the Sun-Earth-Sensor system (Fig. 2) the first element that the solar radiation comes across is the atmosphere: the radiation crossing the atmosphere interacts with it, reaches the surface and is reflected, then crosses back the atmosphere before reaching the sensor on the satellite.

In its dual path through the atmosphere, the incident radiation is partially scattered and partly absorbed by the gases and the particles present in the atmosphere. The interactions of radiation with the atmosphere components is related to the wavelength of the incoming radiation.

The wavelength ranges, in which the interaction between EM radiation and atmosphere is minimal, are called "atmospheric windows" and the remote sensors are designed to record the radiation exactly in these windows in which small adjustments are sufficient to obtain atmospherically corrected data.

Nevertheless, in the visible and near infrared wavelengths it is still possible to have images in which haze and / or clouds can disturb the vision (the same that happens to human vision); in these cases, complex procedures are required to correct data, even if such disturbances cannot be completely removed.

When EM radiation interacts with the Earth's surface (Fig.2) the radiation is reflected at different wavelengths with different intensity depending on the nature of the target.

The reflectance, defined as the ratio between the incident and the reflected energy, as a function of wavelength, is diagnostic of the different materials. Therefore, the function that describes the spectral reflectance of a material is defined "spectral signature".

The Fig. 3 shows the spectral signatures of different types of surfaces (vegetation, soil, water), their differences and characteristics. Vegetation spectral signature usually presents the "peak and valley' configuration due to the structure of the leaf and the presence of pigments.

In the visible region (0.40 - 0.70 μm) the leaf reflectance values are low because approximately 70% of the incident radiation is absorbed by the presence of foliar pigments (chlorophyll, xanthophyll, carotene). Chlorophyll, for example, strongly absorbs energy in the wavelength bands centered about at 0.45 and 0.66 μm. In the near infrared region, (0.75 - 1.30 μm) about 50% of the incident energy is reflected by scattering phenomena in the inner structure of the leaf (mesophyll) and only a small portion is transmitted. In the mid infrared (1.35 - 2.50 µm), minima in reflectance occur at 1.400 and 1.900 µm, the water absorption bands, linked to the presence of water in the leaf tissue.

The analysis of the vegetation spectral signatures therefore allows the recognition of different species, their physiological and phenological stage.

The spectral response of the rocky outcrops depends on the mineralogical-petrographic composition of the rocks. Each mineral has a spectral signature depending on its chemical composition and its crystalline structure. Mineral signatures integrated in a non-linear way, represent the spectral signature of the rock surface that is also affected by the degree of alteration and level of surface roughness.

The soil reflectance spectrum is function of its chemical composition (e.g. the presence of iron oxide or carbonates), moisture content, soil texture (proportion of sand, silt, clay), surface roughness, and organic matter content. All these factors contribute to define the spectral signature of the soils as a smooth, uniform curve without particular peaks of absorption (Fig. 3).

Considering the spectral signature of a water body, probably the most distinctive characteristic is the energy absorption at near infrared wavelengths. In the visible range, the reflectance of a water body is determined by several factors such as water depth, suspended solids and/or algae content and, in case of very transparent and low depth water, the type and color of the substratum (sand, rock or vegetation cover).

The spectral response of the water obviously depends also on its physical state. The clouds reflect more than 50% of the radiation even in the infrared; the snow reflects more than 85% in the visible (function of the impurities on the surface), while in the near infrared, the reflectance is inversely correlated with the dimensions of the snow grains; the behavior of ice reflectance is similar to the liquid water spectrum.

Taking into account the amount of reflected radiation at different wavelengths, it is therefore possible to discriminate different materials; this is the reason why satellite sensors are design to view the same portion of surface at different wavelength intervals (spectral bands) chosen to be diagnostic of the nature of the surface to be analyzed.

From spectral measurements to remote sensed images

How the multispectral images are formed

Remote sensors record the radiation coming from the Earth's surface according to a grid sampling; the numeric value associated with each grid cell (the **pic**ture **el**ement = pixel) represents the radiometric response of that portion of the Earth’s surface, integrated in a specific wavelength range. The ordered array of cells (or pixels) constitutes the remote image (Fig. 4).

Therefore, an image can then be represented as a two-dimensional vector, ordered for rows and columns. Rows and columns identify the position of the pixel on the image; for at each pixel is assigned a Digital Number (DN) representing the average intensity of the energy reflected or emitted from its area on the surface.

DN is a number that is generated following the technical characteristics of the sensor (radiometric resolution); DNs will vary from 0 to 255 if the reflected energy intensity is recorded using 8 bit, or between 0 and 65535 if the signal is recorded with 16 bits. The higher is the number of bit used to codify the signal, the higher is the possibility to discriminate small difference in reflectance between pixels.

Whatever is the radiometric resolution of the sensor, surfaces with high reflection values are codify with high DN values; therefore, when a grayscale palette is used to display the image on a screen, pixels with a high spectral response are associated with lighter gray tones (i.e. 255 will correspond to white and 0 to black pixel).

The size of the pixel represents the spatial resolution of the image and can range from a few tens of centimeters to few kilometers depending on the sensor technical characteristics.

The pixel size defines the capability to interpret the details recognizable in an image; in fact, when the pixel shape becomes visible, the human eye is no longer able to distinguish the details of the represented objects. The geometric limit of remote sensed images is therefore based on the size of pixels: enlargements do not increase the resolution but generate perception of the single pixel as a discrete element. When processing data, however, images with different spatial resolutions can be merged to improve the operator's ability to analyze the territory.

The major benefit in using remote sensing images to study the earth surface materials is mainly due to the possibility to analyze images acquired in an exact wavelengths range (bands), diagnostic of the specific material (Table 1). The number of bands, their amplitude and their position in the electromagnetic spectrum define the spectral resolution of the image.

Table 1. Landsat 8 OLI & TIRS spectral bands characteristics.

Band	Wavelength (μm)	Pixel resol. (m)	Common Applications
Band 1 – Coastal Aerosol	0.435 - 0.451	30	Coastal and aerosol studies
Band 2 – Blue	0.452 - 0.512	30	Bathymetric mapping, distinguishing soil from vegetation, and deciduous from coniferous vegetation
Band 3 - Green	0.533 - 0.590	30	Emphasizes peak vegetation, which is useful for assessing plant vigor
Band 4 - Red	0.636 - 0.673	30	Matches chlorophyll absorption-Discriminates vegetation types
Band 5 - Near Infrared (NIR)	0.851 - 0.879	30	Emphasizes biomass content and shorelines
Band 6 - Short-wave Infrared (SWIR) 1	1.566 - 1.651	30	Discriminates moisture content of soil and vegetation; penetrates thin clouds and smoke
Band 7 - Short-wave Infrared (SWIR) 2	2.107 - 2.294	30	Improved moisture content of soil and vegetation and thin cloud penetration. Used to map mineral deposits
Band 8 - Panchromatic	0.503 - 0.676	15	Sharper image definition
Band 9 – Cirrus	1.363 - 1.384	30	Improved detection of cirrus cloud contamination
Band 10 – TIRS 1	10.60 – 11.19	100	Thermal mapping and estimated soil moisture
Band 11 – TIRS 2	11.50 - 12.51	100	Improved thermal mapping and estimated soil moisture

A remote sensed image can thus be considered as composed by many pixel arrays (bands) each of them corresponding to one of the wavelength ranges of the sensor. Multispectral images are generally composed of 3 to 8 bands while hyperspectral images can be composed up to more than one hundred bands.

Each band can be analyzed individually or together with other bands in order to extract the information needed to recognize surface materials. The greater the number of bands, the greater the detail available to perform the analysis. Most sensors record the reflected energy in three spectral bands centered at the wavelengths of blue, green and red (visible range); two or more bands are reserved for the spectral range that corresponds to the near infrared and generally only one or two bands are devoted to measure the thermal infrared radiation.

Remote-sensed images are processed using specific software able to supply procedures for displaying bands on a computer screen, individually producing then gray tones images, or merging three bands with appropriate color combinations, obtaining a color image in a RGB color system.

Selecting, for example, the three bands relative to the visible wavelengths and assigning them to their respective primary colors, the resulting representation will match the image that you would have seen with your eyes (true color image where the vegetation is shown in green). When the red band is replaced with the data taken in the near infrared range, a false color image is obtained, in which the vegetation will be red intense rather than green. Combining different bands in the RGB color system makes possible to obtain several different false color images suitable for emphasizing the surface of interest (Fig. 5).

Probably the most widely used and familiar multispectral images are the true color aerial and satellite images used in web applications such as Google Earth, Google Maps, and Bing Maps. However, these applications only allow the display of such images, and do not allow to access to radiometric information precluding therefore many forms of analysis.

Earth Observation satellites are programmed to acquire data of the same portion of the Earth's surface periodically. Revisit time of the satellite defines the temporal resolution of the images. The satellites used in the field of meteorology take up large portions (about ⅓) of the Earth's surface and stay steadily on the same region as they travel at the same angular velocity of Earth (geostationary satellites). These images therefore have a very high temporal resolution but low spatial resolution (each pixel correspond to about 3 km^2). Satellite with high spatial resolutions (of the order of meters or even centimeters) have revisit time ranging from 15 to 3 days and their orbits are design to see the same area of the Earth's surface always at the same time of day (heliosynchronous orbits). The images taken by these sensors, while reaching extremely high spatial resolutions, however cannot monitor fast-evolving phenomena.

Image processing

As seen before, a multispectral image appears as a set of ordered numeric values that therefore can be statistically described and processed to derive quantitative data relating to the analyzed surfaces features.

Image processing and analysis procedures can be grouped into four major categories:

1. Pre-processing
2. Image Enhancement
3. Image Transformation
4. Image Classification and analysis

Pre-processing

The pre-processing procedures include radiometric and geometric correction procedures that should be carried out prior to the interpretation and analysis of the images.

Radiometric corrections are applied to correct irregularities due to signal reception or scanning anomalies. In this pre-processing phase, the DN values are also converted and calibrated to obtain radiance or reflectance values in order to be able to compare data acquired at different times or with different sensors.

Atmospheric corrections are needed to eliminate the effects of the solar radiation absorption or diffusion due to the interactions with the atmosphere. These effects can be quantified using measures of atmospheric properties collected on the ground while acquiring the images. These data are then used as input in radiative transfer models that allow separating the atmospheric contribute from the pixel reflectance value. Sometimes, a less complex corrections algorithm can also be applied by exploiting the characteristics of the image itself. The need to correct images and the methods to be used are strictly related to the type of image and to the expected results.

In some cases, before using images for cartographic purpose, geometric correction must be applied in order to transform the image coordinates (row and column) to geographic coordinates (latitude and longitude).

To perform this kind of transformation, the coordinates of a known point on the image (row, column), called "ground control point ", should be identify and associate with the geographic coordinates of the same point, measured in the field or derived from a geographic map. After selecting a sufficient number of ground control points, each pairs of coordinates are processed to define a specific transformation equation (Fig. 6, left). Through appropriate software procedures, the value of each pixel of the image to be corrected is processed, according to the transformation equation, and positioned in a new image in agreement to its real geographic coordinates (Fig. 6, right). The procedures used to make these transformations (resampling) can alter the original reflectance value of pixels. Therefore, it is good practice to apply these corrections in the final step of the data analysis process (i.e. after images classification).

Currently, most of these preprocessing procedures on the images are made directly by the data producers and the images are already distributed as "georeferenced". It is common practice, anyway, to test the correspondence between images coordinates and projected geographic coordinate before starting the image processing phase.

Image enhancement

Image enhancement procedures are essentially applied to facilitate image visual interpretation and can be grouped in i) contrast stretches and ii) filtering procedure. Contrast stretches are used to improve the contrast between the surface features, while filtering procedures allow emphasizing or minimizing specific linear trends.

These techniques have been developed since the sensors are designed for recording data in a wide numerical range (with 8 bits covering range 0 - 255, with 16 bit range 0 - 65535) but often only a limited portion of the available range is sufficient to describe the image. The contrast stretch techniques are designed so that the numeric values actually present in the image are reallocate throughout the whole available range, thus increasing the contrast between the elements in the image.

The first step for a proper application of stretch procedures is the creation of a histogram with the DN values of the image. (Fig. 7) DN values are reported on the abscissa and the frequency of each value on the ordinate axis. To apply a linear contrast enhancement, simply locate the minimum and maximum DN value on the histogram and then assign the value of 0 to the lowest DN value and 255 to the maximum, redistributing linearly the remaining DN values. In this way, the contrast increase will therefore enhance the image and improve the image features detection.

Spatial filters are used to emphasize or to minimize specific image features taking into account their spatial frequency, that is, the frequency of the tone variations in the image. A "rough" area, an area where tone changes are abrupt, has a high spatial frequency, while smooth areas, with small pixel tone variations, have a low one.

A common filtering procedure involves moving a window of limited size (3x3 or 5x5 pixels) through the image and applying an algorithm that, by using the pixel values contained in the window, allows to assign a new value to the central pixel. The specifications of the algorithm used, emphasize or mask the original characteristics of the image.

With a low pass filter, homogeneous large areas that have similar tones can be emphasized and the minute details of the image can be reduced, making it look smoother. High pass filters, on the other hand, are used to emphasize the details of the image, while directional filters make the linear structures, such as roads, field edges, geological structures, or archaeological remains, more evident.

Image transformation

Environmental information can be extracted from an image by exploiting image transformation procedures. These can be executed on the different bands of a single multispectral image or on a sequence of images of the same area acquired at different times (multitemporal images). In both case, processing the original data, these procedures generate new images that better highlight particular features or physical properties of the surfaces. For example, land cover changes can be identified by images subtracting procedures, while subtle variations in the surfaces spectral responses can be highlight computing bands ratio of the bands showing major spectral differences.

One of the most popular procedure is the normalized ratio between the red and infrared bands, known as NDVI Normalized Difference Vegetation Index that reveals the conditions of the vegetation cover.

Some other image transformation algorithms are based on multivariate statistical procedures that reduce data redundancy and evaluate the degree of correlation between different bands. One of the most commonly used methodologies is principal component analysis (PCA) that reduces the dimension of the spectral data, compressing the information into a smaller number of PCA synthetic bands, thus simplifying the interpretation of the newly obtained false color image.

Image classification

For each pixel of the multispectral image, it is possible to extract the reflectance values (DN values) and plot a curve that expresses DNs as a function of the wavelength. These curves, which represent the spectral behavior of the pixel surface, are nothing more than the spectral signatures of the individual pixels. (Fig. 8)

Image classification consists in analyzing those reflectance values in order to cluster image pixels in homogenous classes representing the surface materials present on the image, for example, bare soil, beech wood, cotton crop, urban area.

The result of the classification process is a thematic map that, after been geometrically corrected, can be easily loaded in a geographic information system (GIS).

Procedures to classify images differ for their statistical approach. The classification algorithms that assign each pixel to a single class assuming that the same material composes the entire surface within the pixel are called hard classifiers. On the contrary, soft classifier algorithms assume that the radiometric value of each pixel represents a mean radiance value resulting from two or more surface types and therefore associate to each pixel a percentage of membership to the considered classes.

In either cases, an operator can supervise or not the classification process. A supervised classification process is based on the field knowledge of some sample areas representing surface classes, well known and well located on the image, which are used as a training set to classify the entire scene. The spectral values of each pixels of the image are then compared to those of the training sets and then assigned to the most similar class.

An unsupervised classification algorithm automatically defines all the classes leaving to the user the task of specifying only the number of classes to recognize. The algorithm clusters the pixels according to statistically determined criteria and, finally, the user has to label the identified classes.

New classification procedures, able to take into account also the geometric characteristics of the objects to be classified (object oriented), are recently been developed. In this case, the elements present in the image are first recognized according to their shapes and then associated with the spectral classes, properly defined by the operator.

Whatever the method used, the result of image classification algorithm is a thematic map describing the land cover or the land use (Fig. 9). The choice of the algorithm to be used, must be based on the spectral characteristics of the available images and the type of classes to identify. The last step of this process is to assess the classification accuracy with statistical analysis (error matrix calculation) that requires ground control data.

Territorial analysis can benefit from integration of different data. Continuous innovations in space technologies have made available a wide range of remote sensed images, so it is now possible to integrate images with different spatial and spectral resolution. Moreover, multitemporal data, acquired in different seasons and/or years, can be successfully used for monitoring land cover changes as well as images with different spatial resolution can be useful to determine land use destination. Integration of data from different sources reaches its maximum potential when using a Geographic Information Systems.

Multispectral remote sensing in archeology

The archaeological community began using remote images for its research activities since the beginning of the 20th century[187]; in 1910 aerial photographic survey of Ancient Ostia and Pompeii (Italy) were performed and the images obtained showed that buried archaeological structures could, under certain conditions, become visible on the surface through indirect indicators[188].

Aerial photography was therefore adopted by archaeologists, mainly to visualize the characteristics of the Earth's surface that were difficult, if not impossible, to be perceived and/or conceptualized from the ground level[189].

Since the 1970s, with the advent of Earth observation satellites, archaeologists have been able to switch to these new tools to carry out complex territorial analyzes using multispectral data.

Remote sensing techniques perfectly match with the archeology's tendency to develop non-destructive techniques to analyze archaeological sites and frame them in their environmental context

[187] SEVER 1995; ABRAMS *et al.* 2013.
[188] PARCAK 2009.
[189] WISEMAN 1989.

on a regional scale. The regional scale analysis promote the interaction between different technologies and different disciplines like geology, geophysics, botany, climatology[190].

As previously seen, the multispectral images allow the analysis of parts of the electromagnetic spectrum that humans cannot perceive. Moreover, this kind of images can be processed and analyzed individually or combining bands with different wavelengths, thus supporting the technicians in identifying subtle reflection changes in the surface features (such as vegetation cover, soils moisture and other environmental entities) that can be traced back to underground archaeological features.

Reflectance in the visible wavelengths range is diagnostic to discriminate either the different types of vegetation formations or the different physiological and phenological status supplying an indirect measurement of chlorophyll and carotenoid content of the leaf tissue. The reflectance values in the near infrared (NIR) are function of the structure of the leaf tissue while the values in the medium infrared (SWIR) are indicative of the water content and therefore of their health. Reflectance data in these intervals are used to calculate vegetation indices thus obtaining synthetic images that provide indications of the state of the vegetation otherwise not visible.

One of the most used indices for describing vegetation is the Normalized Difference Vegetation Index (NDVI = (infrared-red) / (infrared + red)), which varies between -1 and 1. In the images obtained computing this index, pixels with negative values correspond to water and those with values close to zero (from -0.1 to 0.1) generally correspond to arid areas with rock or sand outcrops. Positive NDVI values represent vegetation: between 0.2 and 0.4 shrubs and pastures are shown, while the high values approaching 1 indicate healthy vegetation and forested areas. Moreover, mineralogical characteristics, soil grains size and partly moisture content can be also recognized in this kind of images.

Buried archaeological structures, pits, ditches and other earthworks, or constructions erected using building material, e.g. brick, stone and mortar, can significantly alter both the soil and the vegetation that cover them[191]. The alterations may be morphological (reliefs or pits) or may involve a mineralogical or chemical variation of the soil as well as differences in the content and type of soil organic matter. Soil alteration implies variations also in the vegetation that settles on such soils; this means that different types of plant can develop and/or the same species can differ in their physiological and phenological state (Fig. 10).

In fact, sub-superficial archaeological remains, such as trenches or wells, are frequently filled with organic material and/or new soil, which often has a higher moisture retention capacity and contains more nutrients than the surrounding matrix. For these reasons, in periods of drought, these fillings may have a favorable effect on the vegetation that grows on it, allowing the plants to develop abundantly and for a longer period in respect of the adjacent areas. The adjacent plants will be lower, thinner, and will mature at different times. When a building is lying under a surface, the soil may be

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[190] SHENNAN - DONOGHUE 1992; PARCAK 2009.

[191] STEWART 2017; VERHOEVEN - VERMEULEN 2016; VERHOEVEN - SEVARA 2016.

thin and with few nutrients. In this case, the archeological artifact would have an opposite effect: such an adverse situation stress the vegetation, blocking the growth, the development or the metabolism of the plant with the decay of chlorophyll. All these stressors modify the reflectance properties of plant's leaves, which are therefore less healthy and "green".

These differences, often not noticeable to the human eye, can be detected in multispectral images, especially if the images are processed to obtain NDVI images. In these synthetic images, very high values will underline the healthy vegetation present in fillings and lower values will be recognized in adjacent areas. In unfavorable situations (e.g. growing on buried floors or stonewalls), weaker and lower plants may develop, resulting in areas showing very low NDVI values.

In arid regions, where the vegetation is poor, differences in soil spectra behavior can be used to support archaeological investigation based on analogous criteria.

In some cases, however, vegetation can play also a negative role producing an impenetrable cover that masks the underlying archaeologically significant features (for example, barrows and hillforts covered by forest). In these cases, it is possible, however, to use other remote sensing techniques, such as active sensors on satellite platform, airplanes or drones[192]. Active sensors are able to measure the distance of a target by illuminating it with a pulse of electromagnetic energy and measuring the pulse reflected back. Source of energy can be laser or radar.

The LiDAR (Light Detection And Ranging) systems pulse laser light and the differences in laser return times can be used to make digital 3-D representations of the Earth's surface, even below the vegetation cover. Synthetic Aperture Radar (SAR) systems transmit a radar pulse at specific wavelengths and measure the pulse reflected back towards the sensor. The radar bands are sensitive to the linear and geometric characteristics of the landscape, as in passive remote sensing, the different wavelengths of the VIS-NIR are sensitive to different types of vegetation or environmental features. Another advantage of radar is its ability to penetrate dry land surfaces, which has allowed archaeologists to identify topographical and archaeological features buried by sand[193].

Both active systems can be integrated efficiently with the data acquired from the multispectral passive sensors to supply an exhaustive vision of the archeological landscape.

Final remarks

The landscape surrounding us contains the remains of countless traces of human activities and natural processes. The human traces disclose themselves in different, complex ways, appearing as vegetation and soil marks in agricultural land, braided systems of palaeochannels, earthwork remains hidden within modern forests or any of the other myriad of alterations of the land surface and the environment.

[192] SONNEMANN *et al.* 2016.
[193] BALZ *et al.* 2016.

Information obtained from multispectral images has been transforming the human understanding of the physical environment. Using data taken in a wide portion of the electromagnetic spectrum, including what is not seen by the human eye, the multispectral satellite images have the advantage of providing a synoptic view of the territory at different spatial and spectral resolutions.

The space technology can effectively supply the appropriate tools to emphasize the detection of specific characteristics of the Earth’s surface: sensors, in fact, are designed to acquire the reflectance response in the most diagnostic wavelengths range.

Through appropriate statistical procedures, digital images can be transformed in order to make patterns and features easier to identify. In some cases, for example, it is possible to smooth the most obvious and visible features of the territory, either natural or man-made, such as forests or urban areas buildings, and emphasize the structures related to ancient remains otherwise invisible.

Using image processing procedures, multispectral satellite remote sensing can also provide archaeologists with new, high resolution material for traditional photo interpretation

In some cases, the linear distribution or any other pattern of vegetation cover that appear on the images after specific processing, can indicate the presence of an archaeological site, while in other cases, an archeological remain will be revealed by the models of growth of vegetation, or alterations of the soil chemistry in the surrounding of a buried structure. These elements can also be observed directly in the field but certainly at a completely different scale. Furthermore, taking into account the logistics point of view, exploring a wide region to observe these critical parameters on the ground and to collect soil or vegetation samples to be analyzed in the laboratory will require very long times and high expenses.

Anyhow, in archeology as in any other disciplines, remote sensing cannot be separated from the "Ground Truth". The analysis of the images enables the identification of the features of interest to geologists, botanists and archaeologists on the basis of the scientific data analysis, but the validation of the observations must always be carried out with appropriate measures and/or field surveys.

Satellite remote sensing, integrated with the expertise deriving from different disciplines, with the ground survey results, allows the holistic reconstruction of the landscape, giving the opportunity to detect and evaluate apparently hidden sites. Traditional and innovative methodology can be combined to give a better understanding of the anthropogenic effects on past and current landscapes.

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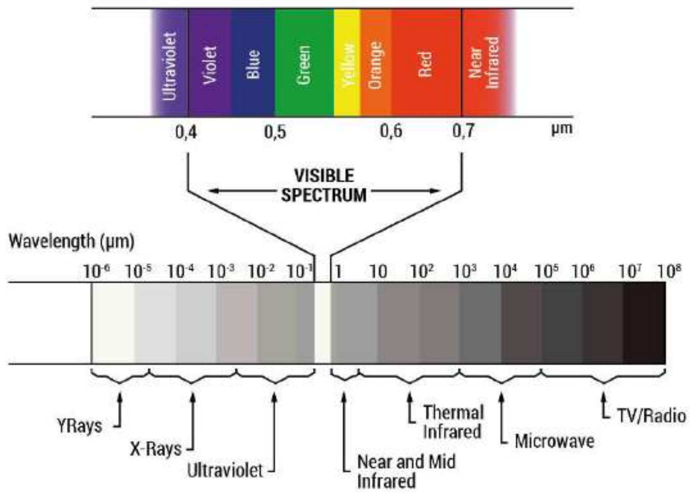


Fig. 1 - The electromagnetic spectrum. The narrow range of visible light is shown enlarged on the top.

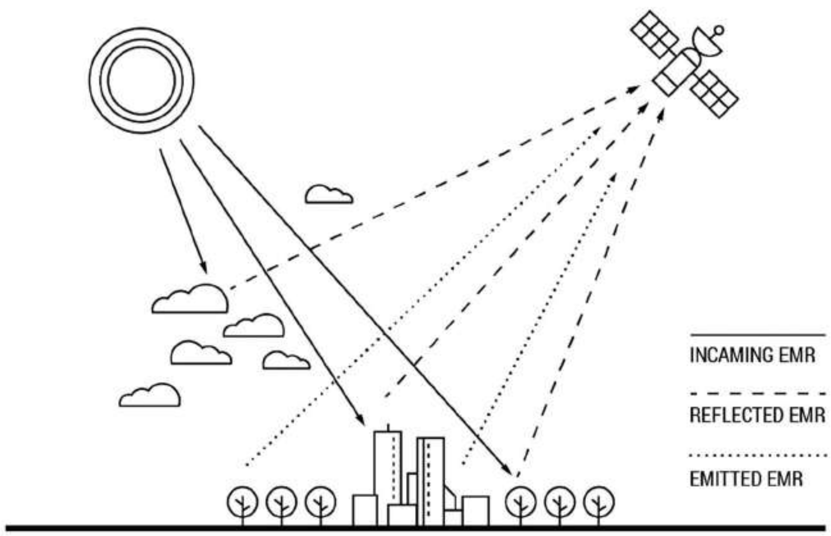


Fig. 2 - Passive remote sensing system. The Electro Magnetic Radiation (EMR) coming from the Sun after passing through the atmosphere is reflected towards the satellite.

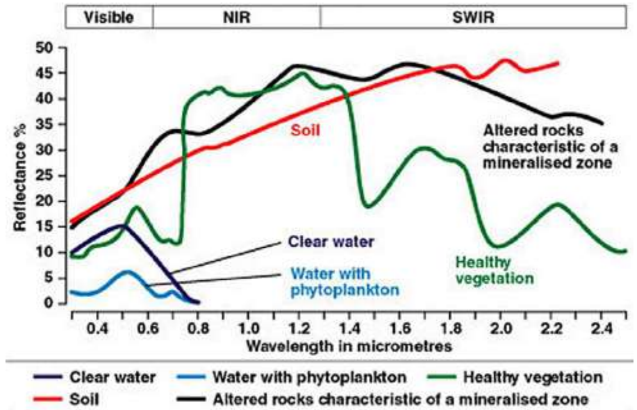


Fig. 3 - Spectral signature of different Earth's surface materials (LILLESAND et al. 2009).

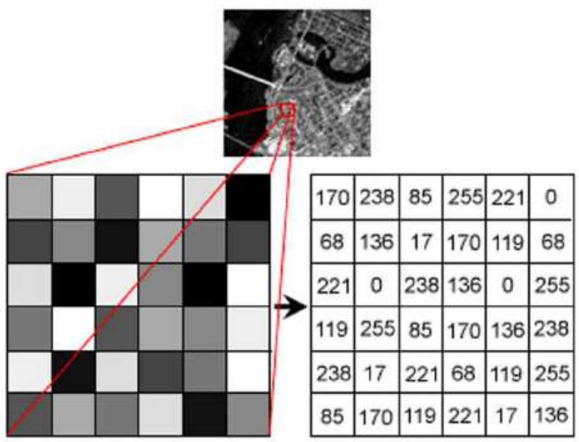


Fig. 4 - Structure of a digital image coded using 8 bit (modified from Canada Centre for remote Sensing http://www.nrcan.gc.ca).

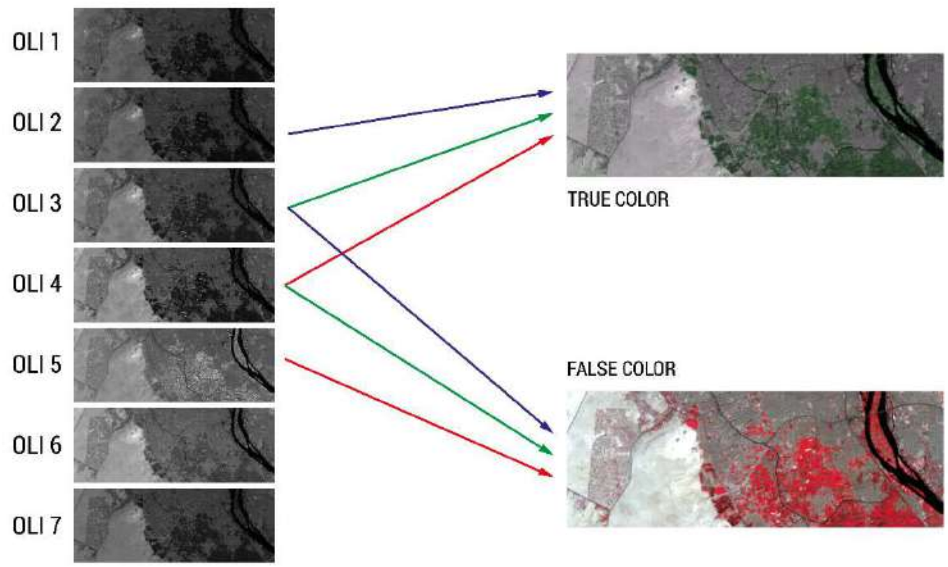


Fig. 5 - Merging three bands in a RGB color system produce a color image. In this example, three Landsat OLI bands are used.

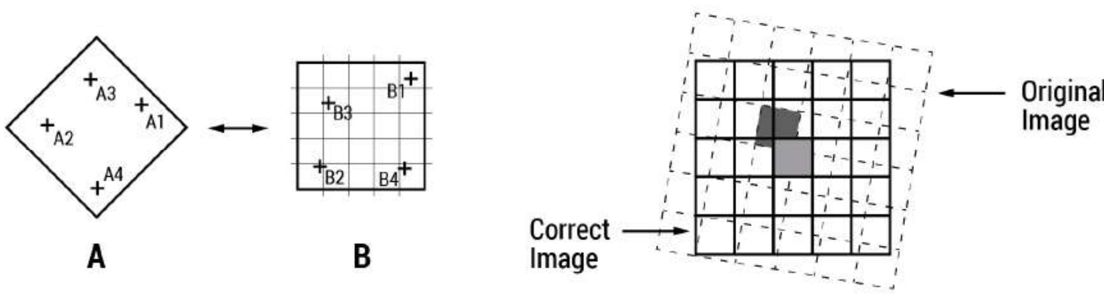


Fig. 6 - Ground Control Points for geometric correction (left) used for georeferentiation of satellite image (right).

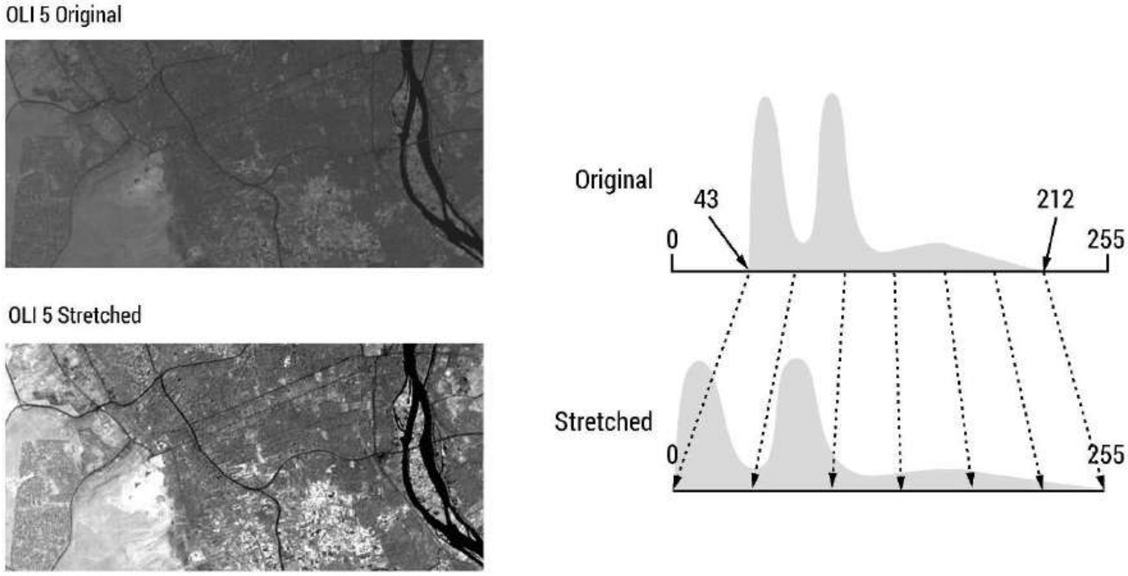
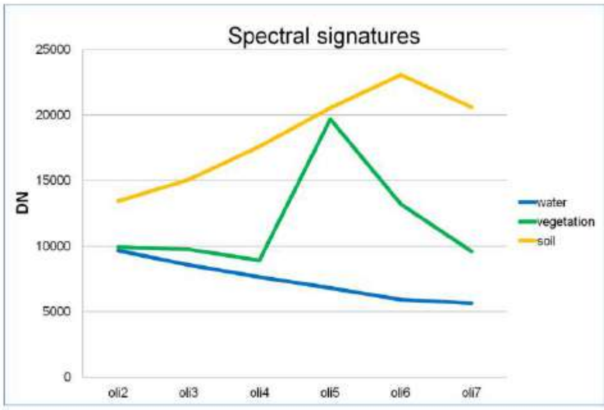


Fig. 7 - Liner contrast stretch procedure applied to Landsat 8 OLI5 band.



	oli2	oli3	oli4	oli5	oli6	oli7
water	9674	8567	7647	6807	5901	5631
vegetation	9944	9764	8918	19692	13215	9608
soil	13434	15088	17594	20554	23068	20608

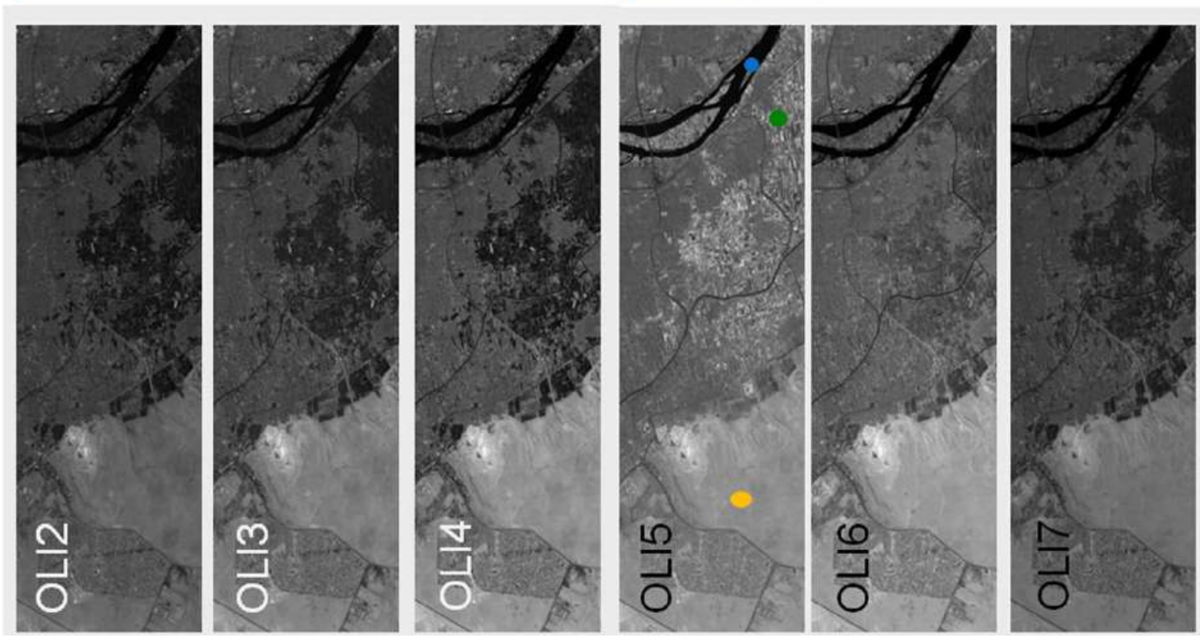


Fig. 8 - Landsat OLI multispectral image and pixel DN values and corresponding spectrum.

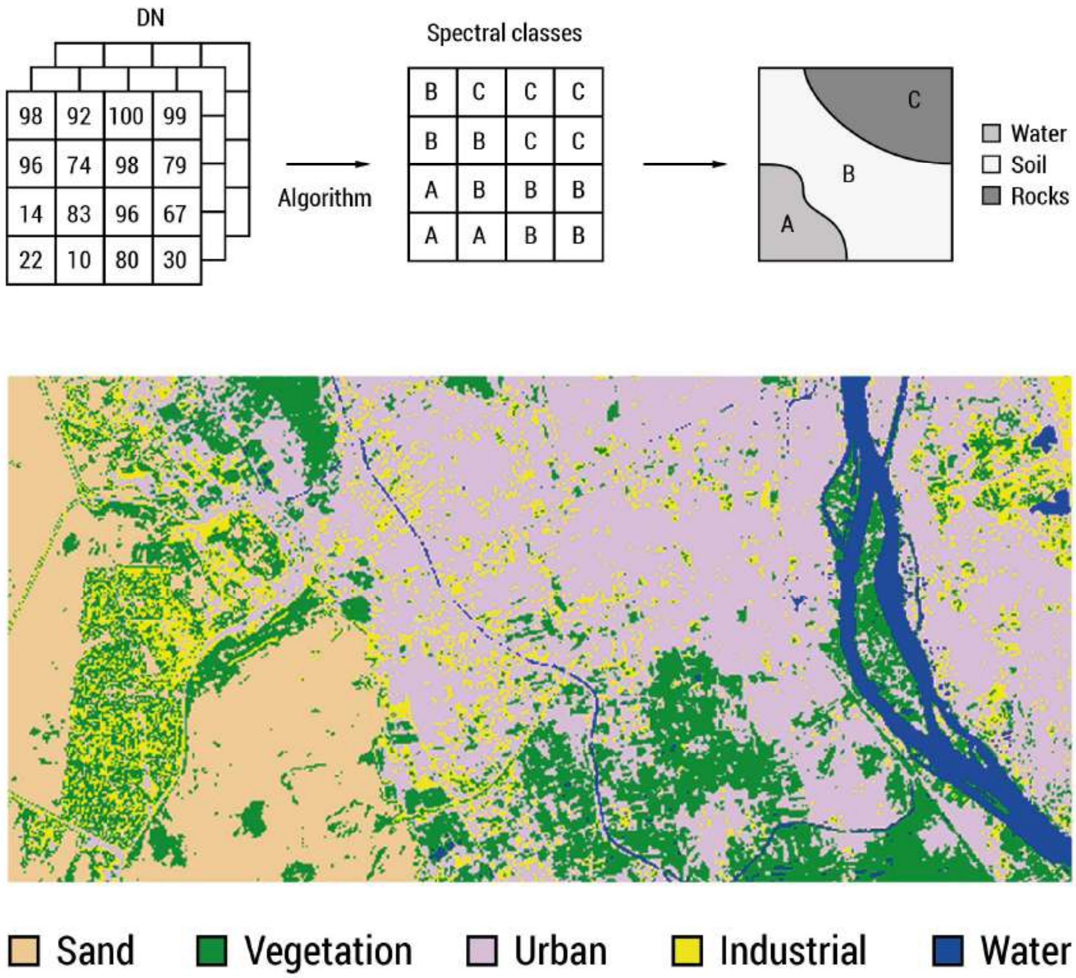


Fig. 9 - Image classification procedure and Landsat OLI image classification resulting map.

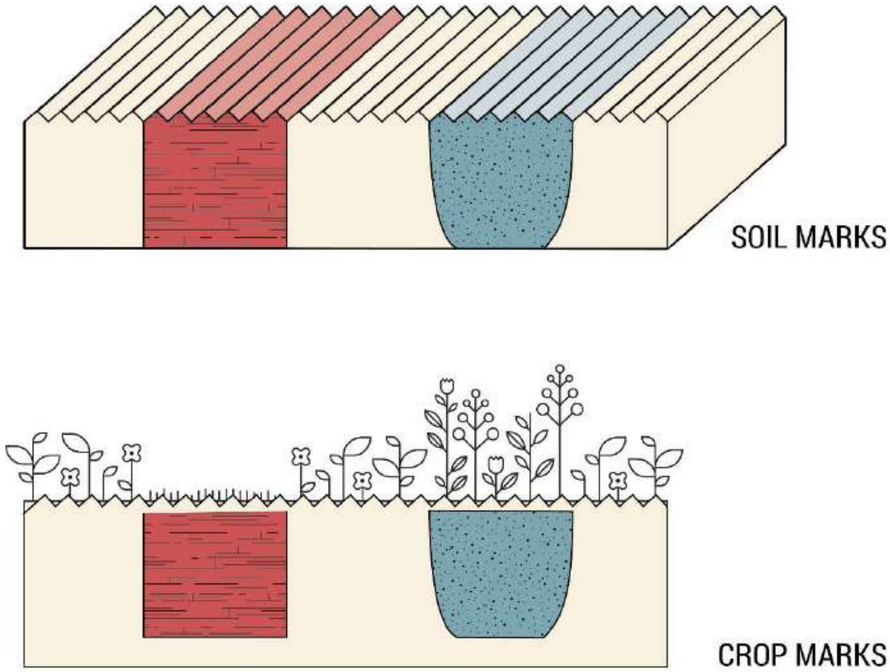


Fig. 10 - Surface marks of buried archaeological structures (wall and ditch).

THE AREA OF THE MODERN SUEZ CANAL IN THE GRAECO-ROMAN SOURCES

Giuseppe Squillace

Università della Calabria, Italia

Abstract

The paper aims at collecting all the Greco-Roman accounts on the so called 'Canal of the Pharaohs', in the Nile Delta area, in order to shed some light on the goals of this important project and to compare it with other famous works of the Antiquity.

Several Greek and Roman sources, dealing with the Nile Delta, mention an ancient canal between the seventh mouth, Pelusium, and the Red Sea[194]. The story of this canal is reported, in particular, by Herodotus, Aristotle, Diodorus, Strabo, Pliny the Elder, Ptolemy the Geographer, Lucian, and Tzetzes – who, we must remember, figured the inhabited world very differently from modern geographers[195]. In my paper, I will not offer new solutions to the many open questions on the topic[196] that only the interdisciplinary collaboration between historians, archaeologists, geologists, engineers, etc., can hope to solve; rather, I will try to clarify why the canal was built and which political goals their builders hoped to reach.

Herodotus of Halicarnassus, who visited Egypt in the 5th century BC[197], describes this land in the second books of his *Histories*[198]. After defining Egypt 'the river's gift'[199], he reckons the distances between its main sites, illustrates its orography, lists his rivers and coasts, and emphasizes his natural resources[200]. In chapter eleven, the historian of Halicarnassus cites the "Gulf of the sea entering in from the Sea called Red"[201] (that the he identifies with the modern Indian Ocean)[202], whose length he describes as "a forty day' voyage for a ship rowed by oars from its inner end out to the wide sea"[203]. Many chapters later, dealing with the reigns of Psammetichus and Necho, he again mentions the Gulf:

[194] A short history of the canal from the age of Pharaohs to the modern times in BUTZER 1980, cc. 312-313. See Maps (Fig. 1a-1b).
[195] See: MAZZARINO 1959, pp. 85-101; MAGNANI 2003; BIANCHETTI 2008; BIANCHETTI – CATAUDELLA – GEHRKE 2016. See Map (Fig. 2).
[196] See, for instance, SHEA 1977, pp. 31-38 and GOEDICKE 1986, c. 1125, but also the bibliography cited below.
[197] See LLOYD 1975, pp. 61-76.
[198] Hdt. 2, 5-13. See ASHERI - LLOYD - CORCELLA 2007, pp. 247-251.
[199] Hdt. 2, 5, 1.
[200] Hdt. 2, 5-13.
[201] Hdt. 2, 11, 1. Translation: GODLEY 1926.
[202] Hdt. 2, 8, 1; see Map (Fig. 2).
[203] Hdt. 2, 11, 1-2. Translation: GODLEY 1926.

> Psammetichus had a son Necho, who became king of Egypt (610-594 BC)[204]. It was he who began the making of the canal into the Red Sea, which was finished by Darius the Persian (521-486 BC). This is four days' voyage in length, and it was dug wide enough for two triremes to move in it rowed abreast. It is fed by the Nilus, and is carried from a little above Bubastis by the Arabian town of Patumus; it issues into the Red Sea. The beginning of the dinning was in the part of the Egyptian plain which is nearest to Arabia; the mountains that extend to Memphis (in which mountains are the stone quarries) come close to this plain; the canal is led along the lower slope of these mountains in a long reach from the west to east; passing them into a ravine it bears southward out of the hill country towards the Arabian Gulf. Now the shortest and most direct passage from the northern to the southern or Red Sea is from the Casian promontory, which is the boundary between Egypt and Syria, to the Arabian Gulf, and this is the most direct way, but the canal is by much longer, inasmuch as it is more crooked. In Necho's reign a hundred and twenty thousand Egyptians perished in the digging of it. During the course of the excavation, Necho ceased from the work, being stayed by a prophetic utterance that he was toiling beforehand for the barbarian. The Egyptians call all men of other languages barbarians. Necho then ceased from making the canal and engaged rather in warlike preparation (...)[205].

As already Oldfather remarked, the canal between the Pelusiac mouth of the Nile Delta and the Red Sea, cited by Herodotus in the above passage, must "not to be confused with the modern Suez Canal, left the Nile a little above Bubastis, followed the Wadi Tümilât to the Bitter Lakes, and then turned south, along the course of the present canal, to the Red Sea"[206].

One century later, in the mid of the 4th century BC, Aristotle gives further information about the canal (which partially modify Herodotus' account). According to him, Sesostris (perhaps Sesostris III, 1878-1843 BC, XII dynasty)[207] began to excavate the canal, but, like Necho (which Aristotle did not mention) and Darius I of Persia many centuries later, he did not complete the work[208].

Diodorus of Sicily, a contemporary of Julius Caesar, in the first book of his *Historical Library* offers a rather accurate picture of Egypt's geography, that he maintains to have visited around 60-57 BC[209]. After briefly touching other topics (distances, natural features, the Nile course etc.)[210], he describes

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[204] On Necho II: REDFORD 1982, cc. 369-371.
[205] Hdt. 2, 158-159. Translation: GODLEY 1926. See the commentary by ASHERI - LLOYD - CORCELLA 2007, p. 358. For Necho's expedition against Syria, which caused the interruption of the excavations, cf. Herodotus, *Histories* II 158.5-159. See: BUNSON 2002 (ss.vv. *Canal of Necho II*, and *Necho II*), pp. 79; 265-266.
[206] OLDFATHER 1968, p. 112, note 2. On the Wadi Tümilât area GOEDICKE 1986, c. 1125. See Maps (Fig. 1a-1b).
[207] On Sesostris III: SIMPSON 1984, cc. 903-906.
[208] Arist. *Mete.* 1, 14, 352b: "Since there is necessarily some change in the whole world, but not in the way of coming into existence or perishing (for the universe is permanent), it must be, as we say, that the same places are not for ever moist through the presence of sea and rivers, nor for ever dry. And the facts prove this. The whole land of the Egyptians, whom we take to be the most ancient of men, has evidently gradually come into existence and been produced by the river. This is clear from an observation of the country, and the facts about the Red Sea suffice to prove it too. One of their kings tried to make a canal to it (for it would have been of no little advantage to them for the whole region to have become navigable; Sesostris is said to have been the first of the ancient kings to try), but he found that the sea was higher than the land. So he first, and Darius afterwards, stopped making the canal, lest the sea should mix with the river water and spoil it. So it is clear that all this part was once unbroken sea" (Translation: WEBSTER 1950). See REDMOUNT 1995, p. 128; but also BOURDON 1925, p. 2.
[209] On Diodorus: MEISTER 1997, cc. 592-593; MUNTZ 2017.
[210] D.S. 1, 30-32.

the Nile Delta, divide in "seven mouths, of which the first, beginning at the east, was called the Pelusiac, the second the Tanitic, then the Mendesian, Phatnitic, and Sebennytic, the the Bolbitine, and finally the Canopic, which was called by some the Heracleotic"[211]. "From the Pelusiac mouth", Diodorus continues,

> there was an artificial canal to the Arabian Gulf and the Red Sea. The first to undertake the construction of this was Necho, the son of Psammetichus, and after him Darius the Persian made progress with the work for a time but finally left it unfinished; for he was informed by certain persons that if he dug through the neck of land he would be responsible for the submergence of Egypt, for they pointed out to him that the Red Sea was higher that Egypt. At the later time the second Ptolemy (285-246 BC) completed it and in the most suitable spot constructed an ingenious kind of lock. This he opened, whenever he wished to pass through, and quickly closed again, a contrivance which usage proved to be highly successful. The river which flows through this canal is named Ptolemy, after the builder of it, and has at its mouth the city called Arsinoë[212].

In the 17th book of his *Geography*, Strabo, who visited Egypt in 25-24 BC and perhaps remained in Alexandria until 20 BC[213], deals with Egypt. After speaking of the Nile Delta with its mouths and its cities[214], the geographer describes the canal which connected Pelusium with the Red Sea:

> There is another canal which empties into the Red Sea and the Arabian Gulf near the city Arsinoë, which some call Cleopatris. It flows also through the Bitter Lakes, as they are called, which were indeed bitter in early times, but when the above-mentioned canal was cut, they underwent a change because of the mixing with the river, and now are well supplied with fish and full also of aquatic birds. The canal was first cut by Sesostris before the Trojan war – though some say by the son of Psammetichus, who only began the work, and then died – and later by Darius the First, who succeeded to the next work done upon it. But he, too, having been persuaded by a false notion, abandoned the work then it was already near completion; for he was persuaded that the Red Sea was higher than Egypt, and that if the intervening isthmus were cut all the way through, Egypt would be inundated by the sea. The Ptolemaic kings, however, cut through it and made the strait a closed passage, so that when they wished they could sail out without hindrance into the outer sea and sail in again[215].

In the 1st century AD, in his *Natural History* Pliny the Elder mentions this canal after talking about the Red Sea and the lands – like Arabia – soaked by it. In the Red Sea, he mentions two main Gulfs: the Persian Gulf in the East, and the Arabic Gulf in the West[216]. In the latter Pliny places the canal between the Nile Delta and the Red Sea:

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[211] D.S. 1, 33, 5-8. Translation: OLDFATHER 1968. See: BALL 1942, pp. 46; 48 ff. See: Map (Fig. 1b).
[212] D.S. 1, 33, 8-12. Translation: OLDFATHER 1968.
[213] On Strabo: RADT 2001, cc. 1021-1025, part. c. 1021.
[214] Strab. 17, 1, 24 CC 785-804.
[215] Strab. 17, 1, 25 C 804. Translation: JONES 1967. See: RADT 2009, pp. 449-452. On Darius' deed: TUPLIN 1991, 237-283.
[216] Plin, *N.H.* 6, 107-162.

> The lie of the land is as follows: on leaving the Laeanitic Gulf there is another Gulf the Arabic name of which is Aeas, on which is the town of Heroön. Formerly there was also the City of Cambyses between the Neli and the Marchades; this was the place where the invalids from the army of Cambyses were settled. Then come the Tyro tribe and the Harbour of the Daneoi, from which there was a project to carry a ship-canal through to the Nilus at the place where it flows into what is called the Delta, over a space of 62½ miles, which is the distance between the river and the Red Sea; the project was originally conceived by Sesostris king of Egypt, and later by the Persian king Darius and then again by Ptolemy the Second, who did actually carry a trench 100 feet broad and 30 feet deep for a distance of 34½ miles, as far as the Bitter Spring. He was deterred from carrying it further by fear of causing a flood, as it was ascertained that the level of the Red Sea is 4½ feet above that of the land of Egypt. Some persons do not adduce this reason for the abandonment of the project, but say it was due to fear lest making and inlet from the sea would pollute the water of the Nilus, which affords to Egypt its only supply of drinking-water[217].

Our last sources are Claudius Ptolemy, who lived at Alexandria in the 2nd century AD, under the emperors Hadrian, Antoninus Pius and Marcus Aurelius[218], and mentioned a canal excavated by the emperor Trajan but perhaps no longer navigable[219]; Lucian of Samosata, he too living in 2nd century AD[220], who in a satiric work hints at a canal between the Nile Delta and the Red Sea[221]; and the Byzantine grammarian Iohannes Tzetzes (12th century AD)[222], who in his *Chiliades*, mostly following Herodotus, writes:

> Firstly Necho, Psammetichus' son, dug along the Nilus, as far as the Red Sea. The canal was four days sailing in length, and wide enough for two triremes to pass easily abreast. But, while digging it, twenty thousand people perished. Because some persons told that the level of the Red Sea was higher than that of the land of Egypt, he ceased his digging, lest it ever suddenly overflows the land. Afterwards Darius, king of Persia, completed Necho's canal, and later Ptolemy had one mouth of the Nilus, which takes the name 'Ptolemaios' from him, extended to the Red Sea, by closing ingeniously, and opening yet again, and he accomplished that with large expenses[223].

The accounts of the literary sources are confirmed by a few epigraphic documents. A bilingual stele (in hieroglyphics and cuneiform) found along the ancient course of the canal, says that king Darius I of Persia, to commemorate the excavation of a canal between the Nile Delta and the Red Sea, erected four stele in the main points of it[224]. Moreover, an inscription called the 'Pithom Stela', discovered at

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217 Plin, *N.H.* 6, 165-166. Translation: RACKHAM 1969.
218 On Claudius Ptolemy the Geographer: HÜBNER 2001, cc. 559-570.
219 Ptol. *Geog.* 4, 5, 54; see AUBERT 2004, p. 228.
220 On Lucian of Samosata: NESSELRATH 1999, cc. 493-501.
221 Luc. *Alex.* 44: [..] "The young man cruised up the Nile as far as Clysma, and as a vessel was just putting to sea, was induced to join others in a voyage to India". (Translation: HARMON 1969).
222 On Iohannes Tzetzes: KARLA 2002, cc. 959-960.
223 Tzetz. *Chil.* 7, 446-458 Kiessling.
224 On this document: SCHEIL 1930, pp. 93-97; POSENER 1936, pp. 48-87; 180 ff.; POSENER 1938, pp. 271-273; SERVIN 1949-50, pp. 75-96; REDMOUNT 1995, pp. 127 ff.; AUBERT 2004, pp. 225-226.

the end of 19th century at Tell el Maskhuta (the Greek Heroonpolis), celebrates the deeds of Ptolemy Philadelphus and the cutting of the canal, dating it (probably) at 270/269 BC[225].

Scholars, for the most part, connect the cutting of the canal to commercial and/or political interests of their builders, who would have aimed not only at improving trade between Egypt and some East countries (like India and Arabia), but also at extolling themselves as the makers of a so great enterprise[226].

Leaving out Sesostris – a very obscure figure – we must consider Necho II, Darius I, Ptolemy Philadelphus, and Trajan. Actually, they all seem to have started the cutting for reasons of propaganda. Herodotus says, for example, that Necho II, when finished digging the canal which leads from the Nilus to the Arabian Gulf, "sent Phoenicians in ships, instructing them to sail on their return voyage past the Pillars of Heracles until they came into the northern sea and so to Egypt"[227]; under him, "hundred and twenty thousand Egyptians perished in the digging of it. During the course of excavations, Necho ceased from the work, being stayed by a prophetic utterance that he was toiling beforehand for the barbarian"[228]. According to the same historian (and to Tzetzes), Darius completed the work; other sources - Aristotle, Diodorus, Strabo, and Pliny the Elder - report, on the contrary, that Darius too, like Necho, left the canal unfinished[229].

The Nile Canal was not Darius' sole enterprise. At the end of 6th century BC, he had charged his admiral, Scylax of Caryanda, to explore the coast between Egypt and India, travelling from West to East[230]. According to Herodotus, in particular,

> (...) most of it (*sc.* Asia) was discovered by Darius. There is a river, Indus, second of all rivers in the production of crocodiles. Darius, desiring to know where this Indus empties into the sea, sent ships manned by Scylax, a man of Caryanda, and others whose word he trusted; these set out from the city of Caspatyrus and the Pactyic country, and sailed down the river toward the east and the sunrise until they came to the sea; and voyaging over the sea west, they came in the thirtieth month to that place from which the Egyptian king sent the above-mentioned Phoenicians to sail around Libya. After this circumnavigation, Darius subjugated the Indians and made use of this sea. Thus it was discovered that Asia, except the parts toward the rising sun, was in other respects like Libya[231].

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225 De Romanis 1996, p. 90. On this document: Naville 1888, pp. 18 ff., 24 ff.; Kamal 1905, pp. 171-177, pl. 57, CG no. 2218; Aubert 2004, p. 226; but also Naville 1902, pp. 71-73; Oertel 1964, pp. 23-24; Fraser 1972, I, p. 177; II, pp. 298-299, notes 346-347.
226 See Sidebotham 1986, pp. 3; 67-68; Lemaire 1987, pp. 58-59; Sidebotham 1991, pp. 15-17; Young 2001, pp. 74-79; Raepsaet 2002; Aubert 2004, pp. 245-248.
227 Hdt. 4, 42, 2. Translation: Godley 1938. See Bianchetti 2008, p. 20.
228 Hdt. 2, 158, 5. Translation: Godley 1926.
229 Hdt. 2, 158, 1.
230 Skylax *FGrHist* 709 = *BNJ* 709 with *Commentary* and *Biographical Essay* by Kaplan 2009; see also Bengtson 1954-1955, pp. 301-307; Mazzarino 1959, pp. 87-89; Peretti 1979; Marcotte 1986, pp. 166-182; Magnani 2003, pp. 117-120; Bianchetti 2008, p. 25; Shipley 2011; Squillace 2015, pp. 165; 175.
231 Hdt. 4, 44. Translation: Godley 1938.

Darius' policy was continued by his son and successor Xerxes I, who in 483 BC, at the beginning of the Second Persian War, tried to cut a canal across Mount Athos[232]. "When the bridges and the work at Athos were ready", Herodotus says, "and both the dikes at the canal's entrances, built to prevent the surf from silting up the entrances of the dug passage, and the canal itself were reported to be now completely finished, the army then wintered. At the beginning of spring the army made ready and set forth from Sardis to march to Abydos"[233].

In order to permit the passage of his army from Asia and Europa, Herodotus adds, Xerxes built also two pontoon bridges from Abydus and Sestus[234]. Both works, which Herodotus condemned as violations the places' nature, show Xerxes' desire to go beyond, to explore and conquer new lands, to exhibit the power of Persian kings.

As said, Ptolemy Philadelphus rebuilt the old canal. This king too, who prosecuted the power policy of his father by instituting or improving the Museum of Alexandria and by drawing the most illustrious Greek intellectuals to Egypt[235], used the cutting (or re-cutting) of the canal to stress the image of Egypt as the most opulent and dynamic reign in the Mediterranean. In that respect, we must recall the commerce of spices—in particular incense and myrrh, but also cinnamon, pepper, and nard—coming from Arabia and India, across the Red Sea, up to Alexandria, the 'city of perfumes' in the 3rd century BC[236]. The control of this important commercial road (already Alexander had promoted three missions from India to Susa and from Babylonia to the Red Sea[237]) was essential to give Ptolemy the prestige and wealth his reign needed.

In the 1st century BC, after Antony's defeat at Actium, Cleopatra, being no longer able to use the Pharaohs canal, undertook – as Plutarch attests – "to raise her fleet out of water and drag the ships across, and after launching them in the Arabian Gulf with much money and a large force, to settle in parts outside of Egypt, thus escaping war and servitude"[238]. Suetonius reports that Augustus, when conquered Egypt in 31 BC, commanded his army to clean all the canals of the Nile[239], but we do not know whether the ancient Pharaoh canal was among them. However, Ptolemy's *Geography* seems to attest that Trajan reopened the old canal or cut a new canal from Nile Delta to the Red Sea south of the first one[240], probably in concomitance with the conquest of Arabia (106 AD)[241]. In 111 AD the same emperor, according with Pliny the Younger (*legatus Augusti pro praetore* in Bithynia from that same year), planned to excavate a canal in Bithynia between the lake Sophon, at SE of Nicomedia,

[232] Hdt. 7, 22-24; see VASILEV 2015, p. 163. On Xerxes' canal see the archaeological investigations of ISSERLIN *et al.* 2003, pp. 369-385.
[233] Hdt. 7, 37, 1. Translation: GODLEY 1928.
[234] Hdt. 7, 36; see PERDRIZET 1912, pp. 357-369; ROCCHI 1980, pp. 417-429; BRIQUEL-DESNIER 1983, pp. 22-30. See Map (Fig. 3).
[235] See FRAZER 1972, I, pp. 320-335; ERSKINE 1995, pp. 38-48; BERTI-[COSTA] 2010, pp. 1-38.
[236] See SQUILLACE 2015, p. 191.
[237] See SQUILLACE 2015, pp. 166-169; SQUILLACE 2016, pp. 157-173.
[238] Plut. *Ant.* 69, 3. Translation: PERRIN 1950.
[239] Svet. *Aug.* 18.
[240] Ptol. *Geog.* 4, 5, 54; see AUBERT 2004, pp. 228; 233.
[241] Cass. Dio 68, 14, 5; *SEG* 7, 969; see SQUILLACE 2015, p. 172.

and the Gulf of Izmid/Nicomedia, on the Black Sea[242]; Trajan's goal – Pliny says – was to speed up trade[243].

Conclusion

To conclude, kings and emperors strived to open a canal between the Pelusiac mouth of Nile and the Red Sea since he could be benefit both their economic and propagandistic interests. Like the canal of Corinth, vainly planned and dreamed, according to Pliny the Elder[244], by prominent figures like Demetrius Poliorcetes, Caesar, Caligula, and Nero, the Nile canal ultimately proved very useful both to speed up trade between the East and Egypt and to extol the prestige of their makers.

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[242] See Map (Fig. 4).

[243] Plin. *Epist.* 10, 41-42; 61-62; see SHERWIN WHITE 1966, pp. 622-623; MOORE 1950, pp. 97-111; AUBERT 2004, p. 235.

[244] Plin. *N.H.* 4, 10. On Corinth canal: COOK 1979, pp. 152-155; MACDONALD 1986, pp. 191-195; DRIJVERS 1992, pp. 75-78; RAEPSAET 1993, pp. 233-256; WERNER 1997, pp. 98-119; PETTEGREW 2011, pp. 549-574.

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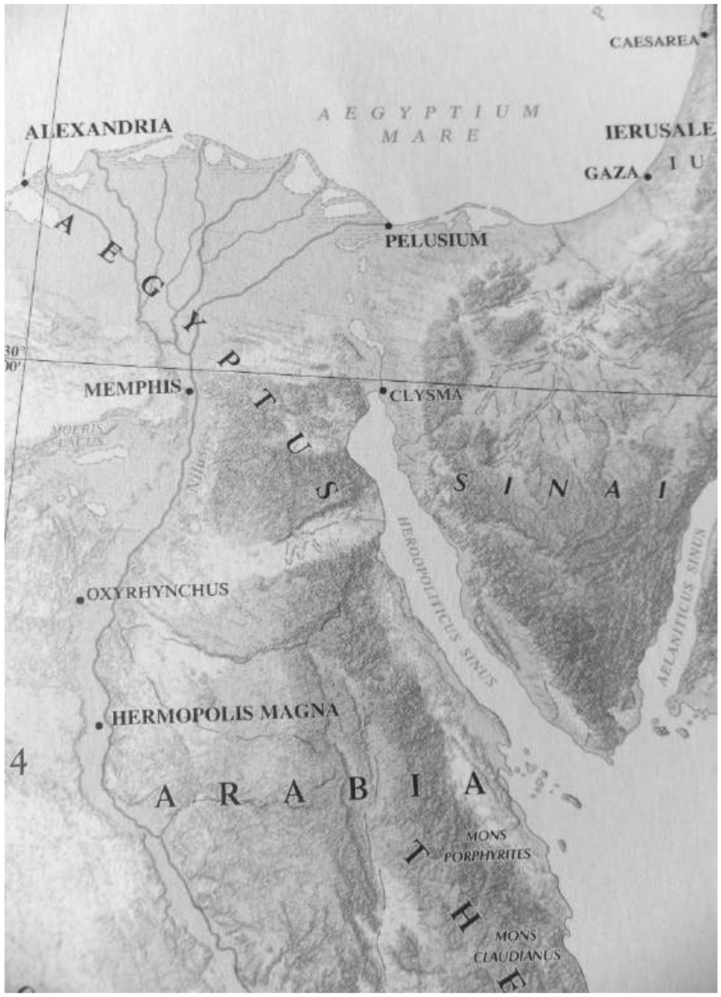

Fig. 1a - Nilus course. (Source: R.J. TALBERT (ed.), Barrington Atlas of the Greek and Roman World, Princeton 2000)

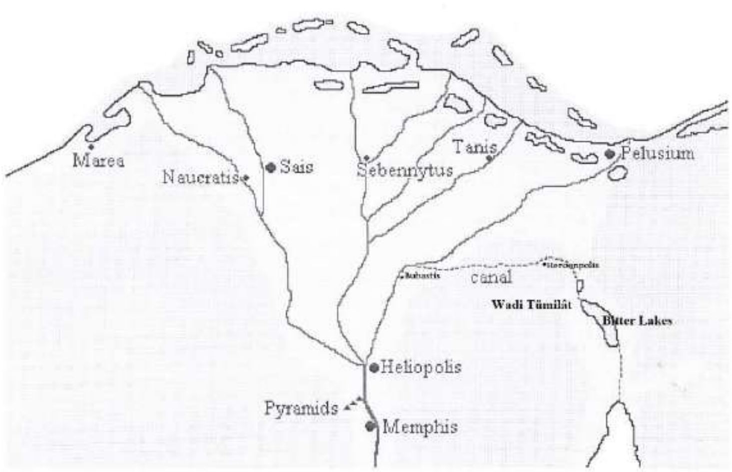

Fig. 1b - The ancient canal.

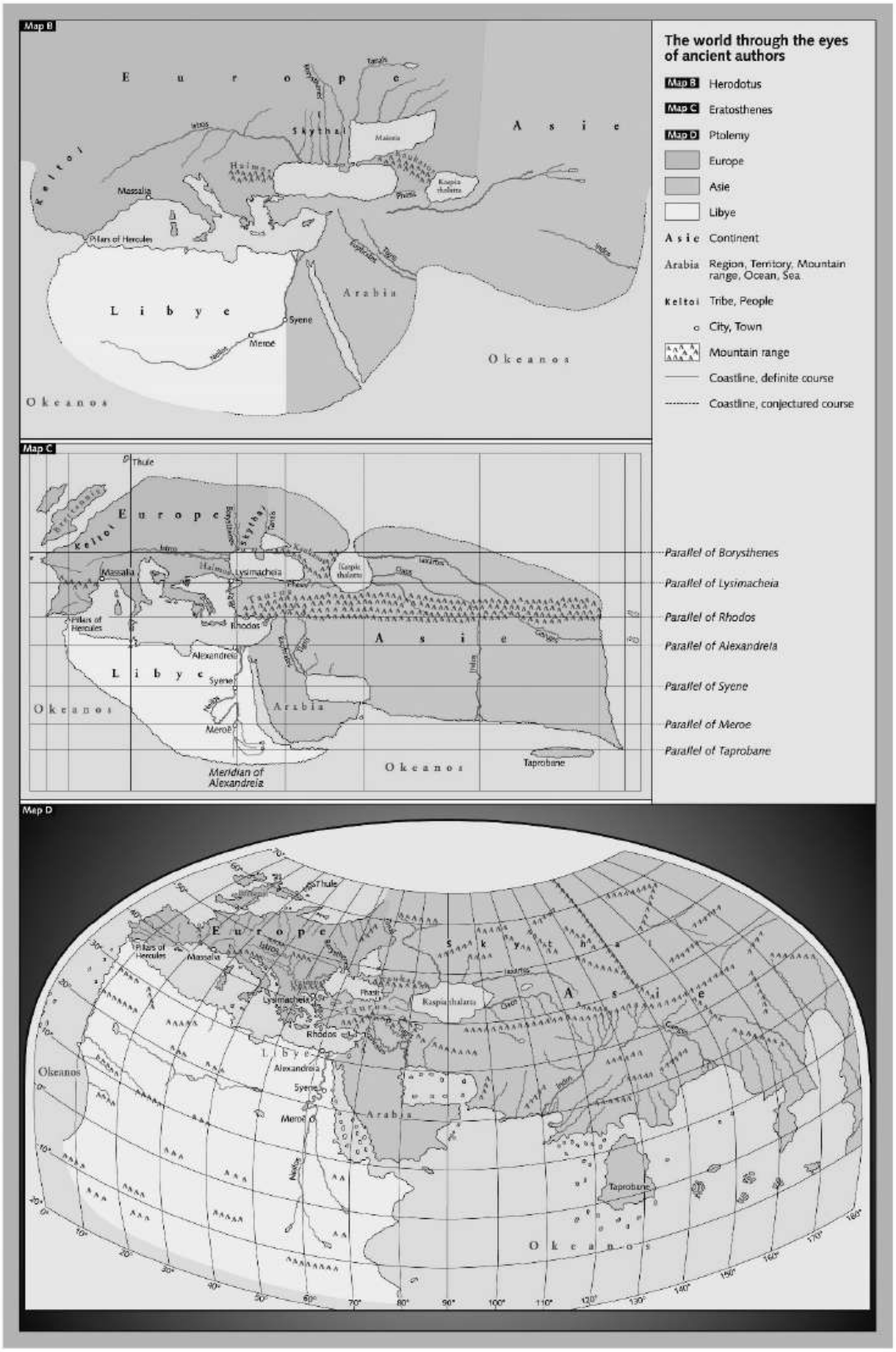

Fig. 2 - The World according to Herodotus, Eratosthenes and Ptolemy the Geographer. (Source: Brill's New Pauly. Supplements I – Vol. III: Historical Atlas of the Ancient World (http://referenceworks.brillonline.com/browse/brill-s-new-pauly-supplements-i-3).

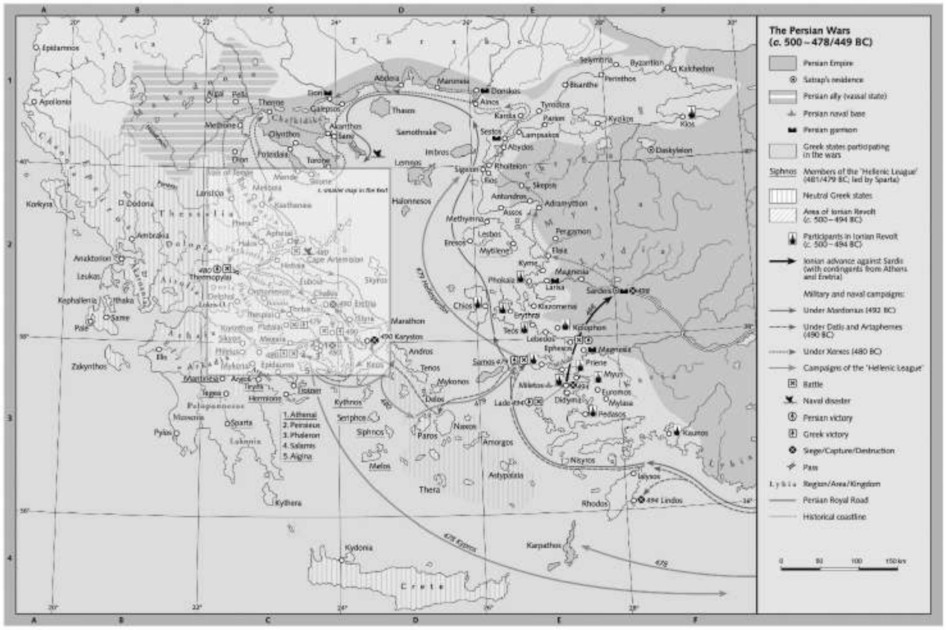

Fig. 3 - Xerxes' deeds (Source: Brill's New Pauly. Supplements I – Vol. III: Historical Atlas of the Ancient World (http://referenceworks.brillonline.com/browse/brill-s-new-pauly-supplements-i-3).

Fig. 4 - Bithynia and Nicomedia canal (Source: R.J. TALBERT (ed.), Atlas of Classical History, (1985), London – New York 2003, p. 158)

CONSERVATION OF THE WALL PAINTINGS IN KHONSU TEMPLE KARNAK, LUXOR, EGYPT

Cristina Vazio

Conservator, Rome

Abstract

The temple of Khonsu is located inside the monumental complex of Karnak at Luxor, Egypt. The temple was built in sandstone during the reign of Ramesses III (XIX Dyn). Several blocks derived from preexisting temples were reused in the interior. The rooms of the temples have polychrome decoration and relief wall decorations.
During the 2008, my team and I, carried out, for the American Research Center in Egypt (ARCE) and the Egyptian Antiquities Organization, a preliminary assessment of the state of preservation of six rooms in the temple. One year later, in 2009, we carried out and completed an intervention of restoration securing all the fragments that were at risk of collapse in various rooms and the complete restoration of paintings in Room XII.
In the paper, I summarise the results of the two projects carried out during the three years of study.
After an analysis of original techniques and materials, the present state of the decorated surfaces is examined. An analysis of the causes of decay is given, and a list of the decay effects visible on the surfaces. Trial conservation tests were carried out on a number of decorated surfaces considered representative for their original techniques and the decay phenomena to be observed, in order to ascertain the materials and methodologies suitable for the Tomb's future restoration.
At the end of 2008 Project, it was noticed that in most of the rooms studied, there were loose fragments at risk of falling off.
During the 2009 Project the consolidation of all these fragments was carried out, in order to prevent further losses of the pictorial layer; at the same time, we made the complete restoration of the wall paintings of Room XII.

During the 2007-08 my team and I carried out a project for the American Research Center in Egypt (ARCE) and the Egyptian Antiquities Organization with the aim of developing a preliminary assessment of the state of preservation of six rooms of the total twelve rooms of the Khonsu temple in Karnak, Luxor[245].

The Project consisted of a brief historical outline of the Karnak area (Fig. 1) and the Khonsu temple (Fig. 2,3). After an analysis of the original techniques and materials we examined the

[245] 2007-08 Project: Egypt, Luxor, Karnak, Khonsu Temple, Project involving condition survey, examination of wall painting techniques and analysis of state of conservation with cleaning tests in six rooms of the Temple (XIX Dyn) by Cristina Vazio Company for ARCE (American Research Center in Egypt) and Egyptian Antiquities Organization.

present state of the decorated surfaces giving an analysis of the causes of decay with a description of their effects visible on the surfaces.

Trial conservation tests were carried out on a number of decorated surfaces considered for their original techniques and decay phenomena (Fig. 4). A proposal for the restoration of the rooms paintings, including time-frames and methods, concluded the first part of the Project.

The second part contained detailed reports on the state of conservation of every surface of the six rooms inside the Temple (Rooms III, VI, VII, X, XI and XII). An initial General Report specified the room and provided a number of useful observations about it. A Detailed Report, graphic diagram[246] (Fig. 5) and photographic documentation[247] then followed for every surface (entrance, walls, ceiling, etc.) with data on the state of conservation of the decorated layers and rock support (Fig. 6).

Within each Report there is a comparison with the corresponding photos taken by Chicago House. The Chicago House documentation[248] is a black and white photographic documentation carried out around 1960.

The comparison with the corresponding photo by Chicago House was particularly important for understanding the extent of degradation since that date.

By comparing the present state of the decorations with these photographs, it was possible to date certain decay phenomena or previous interventions. For example, it was possible to establish that most of the fillings and modern plaster layers and the soot phenomenon predate the Chicago House documentation.

In other cases, comparison reveals that certain decay phenomena have worsened over time. In fact various lacunae and cracks that were present were absent in the Chicago House photos while some mud drips had become much larger.

One year later, in 2009, we carried out and completed an intervention of restoration securing all the fragments that were at risk of collapse in various rooms and the complete restoration of paintings in Room XII[249].

Below we summarise the results of the two projects carried out during the three years of study.

The temple of Khonsu is situated inside the temple complex of Karnak in modern-day Luxor. Karnak consists of a vast complex of temples, rooms and other sacred buildings. The site developed gradually

[246] The digital graphic documentation was created by Associatimodus s.c.r.l. of Rome.
[247] The photographic documentation was made by Arce and C. Vazio.
[248] Chicago House is the permanent field mission in Egypt of the Oriental Institute of the University of Chicago. Since 1924, Chicago House teams have documented large portions of Karnak Temple, Luxor Temple, some private tombs, as well as all of the reliefs and inscriptions in the Temple of Ramesses III at Medinet Habu.
[249] 2009 Project: Egypt, Luxor, Karnak, Khonsu Temple, Complete restoration of the wall paintings of the Room XII and emergency treatment in six rooms of the temple (XIX Dyn), by Cristina Vazio Company for ARCE (American Research Center in Egypt) and Egyptian Antiquities Organization.

from an original nucleus, built at the start of the Middle Kingdom, although it is certain that there was some sort of constructions at Karnak even before this period.

The temple of Khonsu is located in the south-west corner of the precinct of Amun, between the temples of Amun and Mut. According to the legend, the moon god Khonsu was the son of these two divinities.

The temple of Khonsu was built almost entirely by Ramesses III although blocks of stone were taken from other pre-existing temples.

Most of the temple decorations were carried out under Ramesses III.

There is a First Hypostyle Hall with columns in the middle and on each side. This first hall then communicates with a Sanctuary of the Bark. The Sanctuary of the Bark in turn leads to the Second Hypostyle Hall which provides access to six rooms of the total twelve rooms of the temple (Fig. 7).

In ancient Egypt, quite frequently, several types of masonry were used in the same building, even in the same wall and especially in the core masonry behind the surface. Despite the monumentality of Egyptian building projects, another characteristic of Egyptian masonry is the apparent economy in the use of materials. The reuse of older building material was common, as was the preference for dressing blocks into odd shapes in order to avoid wasting material. Generally they used a poorer material for the core of a structure that was then cased with stone of higher quality. Probably the builders knew how to construct properly, but economic considerations often prevented them from doing so250.

The rooms seem to have a mixed masonry. In fact beneath the lacunae and cracks on the surface, we see that there are rectangular blocks with isodomic courses mixed with blocks of trapezoidal shape or stepped horizontal beds.

In Rooms III, VI, X and XI, a number of decorated blocks are visible which appear to have been taken from another site and then reused as foundation blocks or inside the structure of the wall (Fig. 8).

Stone is a sandstone, very soft, probably came from Gebel Silsila quarries.

The kind of dressing seems to be that of copper or bronze tools, generally used for soft stone (limestone, sandstone and alabaster), instead of stone tools for dressing hard stone (granite, quartzite and basalt)251. The regular, closely set longish lines, all hewn from the same direction, are typical from Ramesside to the end of Pharaonic times252.

Fillings of the joints between the stone blocks are in a rough mortar. They were made using gypsum, powder of stone, sand and silt from the Nile. The silt was known as kemet, black land, or hib. It is a

250 DIETER 1991.
251 ROCKWELL 1989.
252 DIETER 1991.

natural mixture of clay and fine sand which was regularly used as a rendering base since it made the mortar easier to work with, thus helping to avoid the formation of cracks253.

The following layer is a thick smooth plaster layer (4-5 millimetre) applied to the entire surface and composed of a big quantity of gypsum with powder of fine stone, fine sand and silt also used in the fillings, which helped the plaster's adherence to the surface.

On this layer the artists made the preliminary drawings.

Preliminary drawings were executed on the freshly prepared wall surfaces and this process was generally carried out in two stages.

The first stage involved the use of red ochre. Red preliminary drawings were sketched onto all the surfaces to be decorated. The second stage involved going over these drawings in black to give a better definition. Sometimes, horizontal and occasionally vertical red lines were used as a guide for defining the space for the figures and hieroglyphics to be represented. The lines were made by 'snapping' taut, stretched cords dipped in red pigment onto the plaster layer.

Relief carving was the next step. The outlines of the drawings were carved out and the surrounding surface chiselled away, leaving the plaster layer attached to the parts in relief only.

Most of the wall decorations are in relief (Fig. 9), except for the walls of Room III that are in bas-relief (Fig. 10). The ceilings of all the rooms were simply painted over, without relief (they were painted in black and then a thin layer of blue was applied on top to create a dark blue shade reminiscent of the night sky; as blue pigment was extremely laborious and costly to make, it was rarely applied alone to the ceiling surfaces).

Once the walls had been carved, a preparatory wash was applied to all the surfaces to provide a smooth, uniform background, generally of a white colour, for the next stage in the decorative process - that of painting.

The binding medium generally used for the pigments was Arabic gum, obtained from the local acacia tree. Arabic gum is composed of a mixture of potassium salts, calcium, magnesium and arabinose acid. Widely used in Egypt, Nubia and many other areas of Africa, Arabic gum was obtained by cutting the trunk and branches of the plant to obtain a resin to which water was then added.

Most of the decorations are executed on a white background and the white pigment, probably used in all six rooms, was huntite, that is a calcium and magnesium carbonate 254 (Fig. 11).

The other pigments used in the six rooms were:

[253] MORA - PHILIPPOT 1984.
[254] COLOMBO 1995.

Jarosite, a natural brown earth, it consists principally of sulphate iron, which probably was a product of sandstone alteration used for the Temple; in fact, it was found for the first time in Karnak[255]. Jarosite is similar to yellow ochre but more brilliant.

Red ochre. Deposits of this naturally occurring red earth were to be found in Upper Egypt, in the region of Abu Simbel, along the Red Sea and on the Sinai Peninsula. It consists principally of iron oxide and was found in a pure form or mixed with varying amounts of clay or chalk depending on the deposit location.

Egyptian blue is a synthetic pigment obtained from the fusion of silica, calcium carbonate, basic copper carbonate and sodium carbonate. The final result is a double silicate of copper and calcium. The resulting pigment was composed of large grains which possessed the characteristic of reflecting direct light and hence was extremely brilliant[256].

Egyptian green, a synthetic pigment which has the same chemical formula as Egyptian blue and is obtained in the same way, except that its colouring is probably due to the different oxidation process undergone by the mixture around the edges of the mass contained in the mortar. In fact, it is possible to find ancient Egyptian mortars containing a blue mass in their bases and a green mass around the upper edges[257].

Black carbon is the commonest colouring ingredient of black pigments, their consistency and minor constituents depending on the method of manufacture; vine black contains carbon in a more or less pure state and the ancient Egyptians obtained it by burning grapevine twigs[258].

A final layer of varnish or coating was applied to the yellows and reds only, and hence these colours have a shiny appearance. Sometimes the varnish used was Arabic gum, which was used as a binding agent, or in other cases tree resin or egg white[259].

It is clear from the evidence collected during the examination of the rooms in the Temple of Khonsu that one of the main causes of damage to the decorated surfaces was the outbreak of fires inside the temple.

Many of the rooms, including parts of the Sanctuary and the Second Hypostyle Hall, were subject to extensive blackening which in some places only affected the pictorial layer but in others all the various layers of the decoration including the stone support.

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255 COLOMBO 1995.
COLINART 1998.

256 SCHIPPA - TORRACA 1965.
DELAMARE 1998.
The sodium carbonate, while fundamental to the chemical reaction, doesn't appear in the final result. The fusion was obtained by heating the mixture to a temperature of 850°C for up to 15 days. The quality of the pigment depended on the length of time the mixture was heated. A long cooling process then followed, while the liquid turned into a solid mass. This mass was subsequently crushed in a mortar, washed and sieved.

257 SCHIPPA - TORRACA 1965.

258 MORA - PHILIPPOT 1984.

259 RICKERBY 1993.

Whatever the nature or origin of the decay phenomena, once the chemical-physical integrity of the support or the overlying layers has been damaged, this damage is to be considered irreversible. The structure or the surface can never be returned to their original intact state, even with restoration interventions. Obviously, where the original structure has collapsed or the decorated layer detached from its support, the losses can be considered permanent. The contact of the decorated surfaces with very high temperatures can unfortunately cause this type of irreversible damage (Fig. 12).

Of the six rooms examined, Room X shows a type of damage that is completely irreversible. The stone shows decohesion, with extensive scaling and chromatic alteration to yellow, red and black. The preparatory layers and the pictorial layer, where they survived, have completely turned in to red and black (Fig. 13).

Tests on the other rooms covered in a uniform layer of black soot (Rooms III, VI and VII) appear to show even if damage has been done, the situation could at least be remedied (Fig. 14).

Where black soot was present to a lesser extent (Rooms XI and XII), it was probably due to fires that have been lit for 'domestic' purposes or torches that have been used to illuminate the rooms. Fortunately, in these cases no irreversible damage appears to have been done.

Structural problems were another main cause of the deterioration of the wall paintings. Many of the rooms had a large number of cracks and lacunae which ran along the joints between the blocks of stone (Fig. 15).

Many of the cracks were relatively recent, as shown by comparison with the Chicago House photos taken around 1960. Some of the rooms had lost part of their ceilings (Rooms X and XI) while in others, blocks of stone had moved out of alignment (Room XII). The plaster and pictorial layers consequently showed a great lack of adhesion and had many loose fragments (Fig. 16). These phenomena indicated structural problems, either past or present, which needed to be monitored. Monitoring devices can be applied to establish whether structural movement is still under way or are stable, in order to prevent further collapses.

Water, whether in the form of rain or damp, was another major cause of the damage observed to the decorated surfaces. In nearly all the rooms examined, there were large lacunae in the plaster and pictorial layers up to a height of 1-2 metres and in some cases even higher. Rock scaling and decohesion were also observed together with losses of the pictorial layer (Fig. 17). These damage phenomena indicated rising damp. The mud drips also revealed the action of rain water in the past which had damaged the walls, particularly where the ceiling was missing (Fig. 18). Saline efflorescences and carbonatic crystallisations subsequently formed once the walls dried.

Another factor of decay was the wind. A large quantity of dust on the walls and the erosion of the rocks indicated exposure to the wind, which contributed to the damage of the surface decorations.

Another phenomenon of degradation was the presence of guano of bats. During the centuries the small and cramped rooms have been a refuge for this type of animals, especially during the night. In fact, one of the first interventions made on our arrival was to close the rooms with doors equipped with nets, which guaranteed the passage of the air but not that of animals and birds.

Moreover, previous interventions of restoration have often been made inaccurately.

As an example, the extensive abrasions of the pictorial layer in Room III, indicated inappropriate previous cleaning. Here, attempts were made in the past to remove the layer of black soot still present on the wall surfaces which caused the almost total loss of the pictorial layer. Fortunately, there were no signs of inappropriate cleaning interventions in other rooms.

In some cases, the presence of different types of fillings indicated that more interventions were carried out in the course of the time. This kind of interventions are reversible. In fact, the old fillings can be removed and re-filled in a more appropriate way.

After the analysis and studies of 2007-08, in the following year 2009, a programme was conceived and implemented for the consolidation of all the surfaces in order to avoid the fall of the detached fragments in the six rooms and for the complete restoration of the wall paintings in Room XII.

The consolidation and cleaning stages are extremely important because they are irreversible and therefore require the greatest care and attention in any restoration intervention.

This is even more so in the case of ancient Egyptian decorations which, painted on a layer of gypsum-based plaster using Arabic gum as a binding medium, are very sensitive to polar substances, especially water, which can dissolve the original plaster and pictorial layers. But not only does the original technique render these type of decorations very fragile. Over the years, an accumulation of various decay phenomena has contributed to the deterioration of the decorated layer. These characteristics were taken into consideration when choosing which substances to use and the most suitable methodologies.

The consolidation process consisted of strengthening the cohesion of the rock, the plaster and the pictorial layer; reattachment of raised paint flakes and of areas where the plaster layer detached from the rock support (Fig. 19, 20).

For these various stages of the process, substances were chosen which had already been tested in the laboratory and experimented with over a number of years in the conservation sector. These substances carried out their function without interfering with the original decorated surface.

At the same time, we completed the restoration of Room XII.

We started the process of cleaning, using adequate solvents that remove the uppermost layers of undesirable deposits and respecting and preserving the original patina, i.e. the layer of natural aging 260 (Fig. 21).

For the operation of cleaning some considerations must be made.

The wall paintings were created by artists at a particular period in time. Some transformations of the original materials are inevitable over the course of time and, furthermore, some real irreversible alterations result in disfiguration of the image. Consequently, the removal by cleaning of all non-

[260] TORRACA 1984.

original materials does not restore the artwork to its original state, i.e. the state in which it was left by the artist on completing the original work. It simply reveals the present state of the original materials

What is termed ‘patina’ is the result of this normal effect of time on matter261. The patina is the layer of natural aging which occurs on the surfaces of all objects and works of art. This extremely fine layer forms as a result of natural deposits and microclimatic factors, such as light. It is part of the normal aging process of any work which begins as soon as it is exposed to atmospheric agents and is therefore inevitable and irreversible. Obviously, with the passage of time, natural deposits accumulate to the extent of creating an actual layer of dirt on the top of which other substances are sometimes added.

Thus one must distinguish between the desirable ‘original patina’, that is natural aging, and additional layers of undesirable deposits.

While the original patina should always be respected and conserved in any restoration intervention, the other uppermost layers should be removed because they inevitably damage the work of art and in most cases interfere with its legibility and visual clarity (Fig. 22,23,24).

The wall paintings of the six rooms in the Khonsu Temple, besides showing various other types of damage, also showed the natural aging of the top layer, i.e. the original patina, natural deposits and an undesirable layer of soot.

During the cleaning operation of the trial conservation test areas, it was evident that some room decorations still had a very well conserved original pictorial layer and patina and only a layer of natural deposits above. Other room decorations had an original pictorial layer that was extremely damaged plus a covering of very dark, thick soot on top, while others had an original pictorial layer irreversibly transformed and a very dark, thick layer of soot above it.

After the cleaning we carried on the restoration of Room XII with the filling of all the lacunae and cracks also removing the old fillings, because they had an appearance and texture which was too different from the original materials.

This treatment should not be undertaken until the adherence of the paint, especially along the edges of the lacunae, has been verified and until the necessary consolidation has been undertaken in order to avoid the risk of crumbling when ensuring a perfect bond at the edges. The mortar must have the level and texture of the original rendering and the materials (medium and inert fillers) must be identical or at least similar to those of the original ones, including its granular composition262.

The small lacunae and cracks, deeper than about 1cm, that created dark marks interfering excessively with the uniformity of the decorative cycle, were filled with a mortar, level and texture similar to those of the original ones, including its granular composition. The big modern fillings were removed and in their place was applied a new mortar using local sand (Fig. 25,26).

At the end of the cleaning and filling interventions, the many abrasions and losses were more evident and greatly disrupted and confused the legibility of the work. Their very pale tones interfered to such

[261] MORA - PHILIPPOT 1984.
[262] MORA - PHILIPPOT 1984.

an extent with the visual clarity of the scenes that they distracted and in some cases, monopolised the eye of the observer.

It was therefore necessary to harmonise the tones of these abrasions and small lacunae with a light glaze similar to the patina present on the decorations263. This was done using natural earth and Arabic gum as a binding medium.

Natural earths, which are easily acquired, are sold in powder form and contain no binding agents, unlike colours sold in tubes, the precise make-up of which is never clearly stated.

The natural earths that we used were Burnt Umber and Raw Umber, mixed with a trace of Vine Black. The binding medium was Arabic gum made from the seeds of the local acacia tree, the same binding agent used in all Egyptian paintings.

It thus well integrated with the original decorations, with no signs of incompatibility between the different materials. Moreover, Arabic gum always remains a completely reversible but chromatically stablesubstance.

This type of re-integration was only applied to the abrasions and small losses of the pictorial layer. The process did not involve the application of colours to the reliefs, either temporarily or permanently. The glaze served to re-establish the uniformity of the surface without the risk of altering the remaining pictorial layer beneath (Fig. 27, 28, 29, 30).

The large number of visitors entering the tight, narrow spaces of the Room XII and of all other rooms of the Temple, put the decorated surfaces at risk. In fact, there are a lot of lacunae of the plaster layer and losses and abrasions of the pictorial layer on the middle sections of most surfaces, especially at the entrances.

It would be advisable to limit the number of people visiting the rooms and prevent them from touching the surfaces not only in the Khonsu temple but also in many other temples and tombs in Egypt.

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[263] MORA - PHILIPPOT 1984.

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Fig.1 - Karnak, Luxor, Egypt

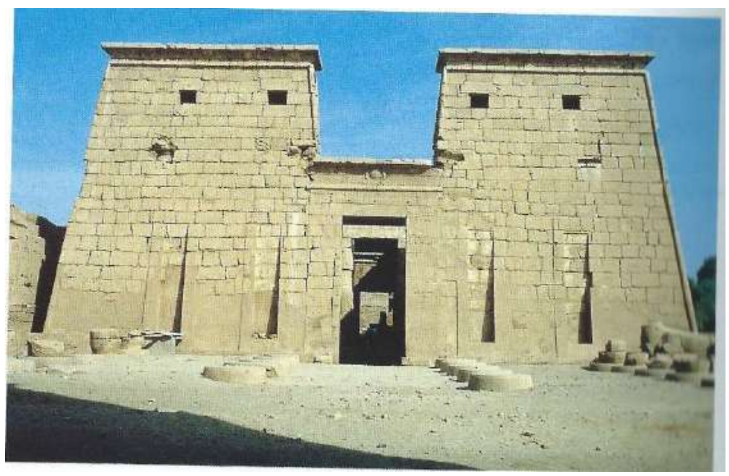
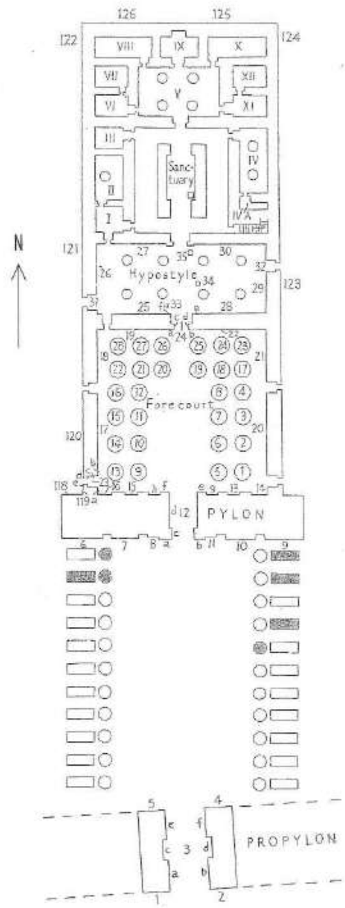


Fig.2 - Temple of Khonsu, Karnak, Luxor, Egypt

Study of the State of Preservation of the Decoration at the Khonsu Temple
Subproject 2008



KHONSU TEMPLE - Plan 1:1000

Fig.3 - Plan of Khonsu Temple

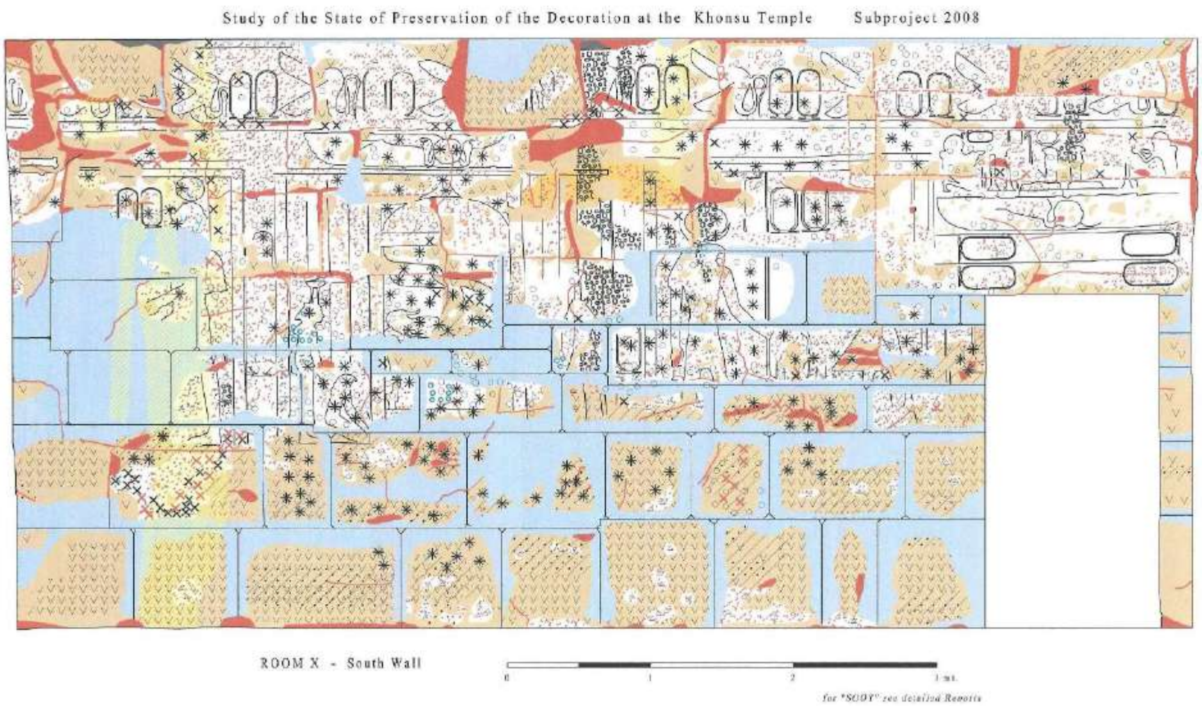


Fig.4 - Room X, graphic diagram of south wall

Fig.5 - Room VI, trial conservation test, 2008 - photo by C. Vazio

Fig.6 - Room XII, documentation, 2008 - photo by C. Vazio

Fig.7 - Entrance of Second Hypostyle Hall, Temple of Khonsu

Fig.8 - Room X, reused block - photo by C. Vazio	Fig.9 - Room XII, wall paintings in relief - photo by C. Vazio

Fig.10 - Room III, wall paintings in bas-relief - photo by C. Vazio

Fig.11 - Room XII, south wall, 2009 - photo by C. Vazio	Fig.12 - Room X, irreversible alteration - photo by C. Vazio

Fig.13 - Room X, irreversible alteration - photo by C. Vazio	Fig.14 - Room VII, black soot over paint layer - photo by C. Vazio

Fig.15 - Room X, structural problems - photo by C. Vazio

Fig.16 - Room VII, loose fragments - photo by C. Vazio

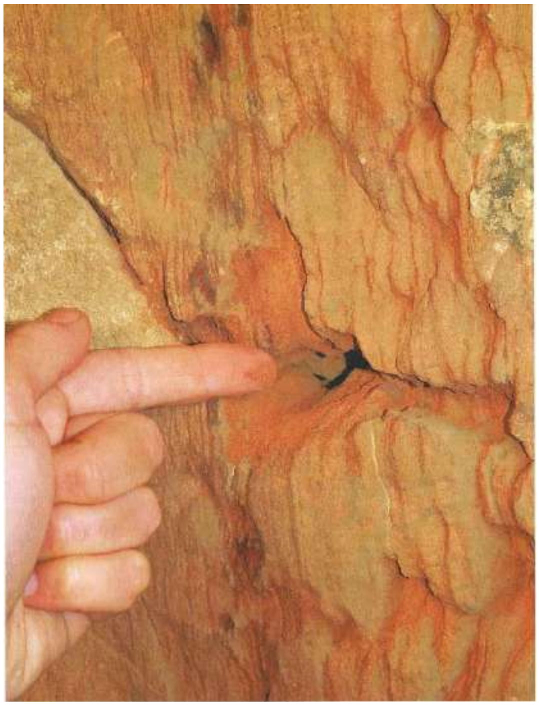


Fig.17 - Room X, rock decoesion - photo by C. Vazio	Fig.18 - Room VI, mud drips - photo by C. Vazio

Fig.19 - Room XII, consolidation of the rock - photo by ARCE

Fig.20 - Room XII, consolidation of the paint layer - photo by ARCE

Fig.21 - Room XII, cleaning of paint layer - photo by ARCE

Fig.22 - Room XII, cleaning of paint layer - photo by ARCE

Fig.23 - Room XII, cleaning of paint layer - photo by ARCE

Fig.24 - Room XII, cleaning of paint layer - photo by ARCE

Fig.25 - Room XII, filling of the lacunae - photo by C. Vazio

Fig.26 - Room XII, filling of the lacunae - photo by C. Vazio

Fig.27 - Room XII, north wall before restoration - photo by ARCE

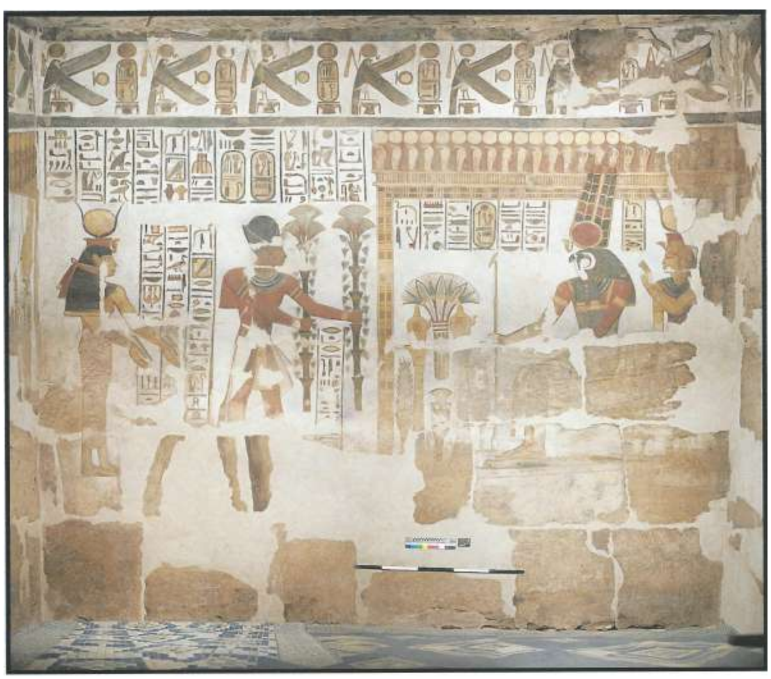


Fig.28 - Room XII, north wall after restoration - photo by ARCE

Fig.29 - Room XII, south wall before restoration - photo by ARCE

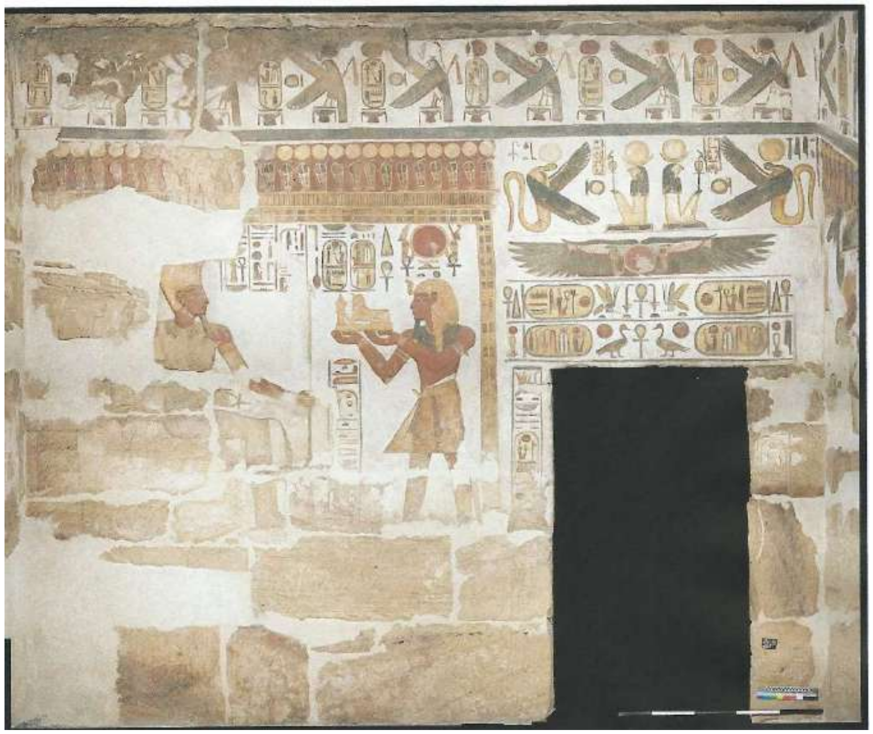


Fig.30 - Room XII, south wall after restoration - photo by ARCE

The Geological Evolution of Some Archaeological Sites in the Nile Delta Region, Egypt

El-Sayed Abbas Zaghloul

National Authority for Remote Sensing and Space Sciences (NARSS), Cairo

E-mail: eazaghloul@narss.sci.eg

Abstract

The geographic distribution and the geological sequences of the archaeological sites on the Nile Delta of Egypt reveal that the origin of these sites was controlled by the geological evolution of the Delta and the well-known ancient Nile Delta Branches at the Holocene and recent times.

The general slope of the delta is towards the northwest direction; it means that the north-western delta is lower than the eastern one. This may explain the presence of north-western sand dune fields while the north-eastern region is characterized by the presence of the coastal sand bars which runs parallel to the coastal shore line.

Field observations, topographic, geomorphic and the geological successions clearly show that the location of the archaeological sites in the Nile Delta were clearly controlled by the locations of the Turtle Back mounds in southern and central Delta regions for people to live on top of these mounds to be safe from the hazards of the Nile floods, and at the top of the Sand Dunes (Barchans and Longitudinal dunes) in the north-western region. While in the north-eastern region, they make their settlements on the top of the coastal sand bars to be safe from the high tide of the Mediterranean Sea and nearby to the outlet of the ancient Nile Delta branches mainly during the Roman times.

Introduction

In the northern part and along the Nile delta coast, aeolian processes are demonstrated by repeated occurrence of drift sands and diverse types of aeolian landforms. Waves, currents and tides dredge sands from the sea floor and the nearby-eroded areas and deposit them on the beach in the form of sand dunes (longitudinal and barchans) sand bars, where they are subjected to aeolian processes. This may be attributed to natural micro-relief, such as shrubs and rock debris, or macro-relief, such as rising cliffs and depressions.

On the contrary, in the central and southern part of the delta, the ancient Nile Delta Branches were characterized by the presence of sand islands (Oxbow Lakes) which form the Turtle back mounds[264].

Nile Delta Landforms

The surface slopes gently northwards in the central part while in the east it slopes to the northeast and in the west it slopes to the north/west. The difference in elevation between its apex in the south

[264] Embabi 2004.

and the Mediterranean coast is 18 m. The contour map shows that the surface of the eastern Delta surface is higher than the western surface, leading to the formation of many depressions and lakes (Fig. 1). Some geomorphic features[265] point out in the Delta such as:

- Nile Delta Ancient Branches,
- Turtle Back Mounds,
- Coastal Land Forms, Sand Dune Field, Coastal Sand Bars (Fig. 2),
- Wetland (Barari, Salt Marshes).

Origin of the Archaeological sites

The field observations, topographic, geomorphic and the geological successions clearly show that the location of the archaeological sites in the Nile Delta were clearly controlled by the locations of the Turtle Back mounds (Fig.1) in southern and central Delta regions[266] for human settlements on the top of these mounds to be safe from the hazards of the Nile floods, and at the top of the Sand Dunes (Barchans and Longitudinal dunes) in the north-western region while in the north-eastern region they make their settlements on the top of the coastal sand bars to be safe from the high tide of the Mediterranean Sea and nearby to the outlet of the ancient Nile Delta branches mainly during the Roman times.

The origin of the archaeological sites in the Nile Delta can be classified into three classes according to their geomorphic and the geologic setting. These classes are:

The Turtle – Back Mounds

The Turtle – Back Mound is a small low-lying yellow sandy hillock with rounded crests within the recent silt dark brown color. Its height varies between 10-11 m in the southern part of the Delta and 2-6 m in the north whereas the area is covered by several square kilometers to few hundred meters. Historically, as far as that Turtle – Back mounds (Kom or Tall) stood high above the level of the recent flood plain; it was inhabited and now remained as archeological sites as Tall Basta – San El-Hagar, Kom Ferein and others during the Hellenistic and Roman periods. Most of these Turtles were recently exposed to major changes and modifications due to quarrying of their sands as building materials. The ancient Tanitic Branch of the Nile (Fig. 3) bifurcated at the head of the Delta and took an easterly route, passing by a number of towns and settlements until it reached the town of San El-Hagar (Djane) and the harbor of Tannis.

San El-Hagar archaeological site

San El-Hagar (Djane) is considered to be the most important archaeological site in north-eastern part of the Nile Delta (Fig. 3), it is almost certainly one of the largest and most impressive fishing and fowling preserve. San al-Hagar is actually the largest Tall in Egypt, encompassing some 177 hectares

[265] EMBABI 2004.
[266] EMBABI 2004.

of land, and rising about 32 meters and mainly consists of fluviatile sands (Fig. 4). The earliest mention of the town is known from a 19th Dynasty building block of Ramesses II (Fig. 5) discovered at Memphis.

It became the northern capital of Egypt during the 21st Dynasty. There were seven temples located in the area of San El-Hagar. The chief deities worshiped here were Amun, his consort, Mut and their child Khonsu, who formed the Tanite Triad. The Radar image (Fig. 6) clearly showing the buried structures and streets underneath the surface.

The Sand Dune

Sand dunes are spread along the northern plain of the Nile Delta at disconnected localities[267]; it forms the "North Delta Dune Field". The dune types vary between simple barchans, complex and deformed barchans, and small linear dunes. The maximum height is 20m but the most prevailing height is 2-3m. There are two generations of dunes. The first is the older stabilized dune and the recent movable dunes at the top.

The sands of the Nile Delta Coastal Dune Field originated from the Nile Deposits that were deposited along the northern margins of the Delta[268] and rich with heavy minerals (Black Sands). They appear to the west, north and south of Lake Idku and Burullus at some of the islands on the lagoon, and in mid – Delta area between Rosetta and Damietta Branches. It runs parallel to the shoreline for about 30 km and a maximum width of about 8 km in the area facing El Bouseily Village. They have vegetated surface crust of variable thickness, ranging from a few cm to more than 30 cm. Loose friable and cross bedded sand occurs below the indurated crust. Linear dunes are represented in the western segment and are aligned sub-parallel to the dominant NW–SE winds. Simple linear dunes occur as straight and irregularly sinuous with sharp crests. They vary in length from a few meters to about 0.9 km and in height up to 12 m.

Some archaeological sites are located at the top of the sand dunes to be above level of the flood in the Canopic and Bolbitic Nile Delta Branches. The most important one is Kom El-Debaa North (El-Bahari) and Kom El-Debaa South (El-Qibli).

Kom El-Debaa archaeological areas

Two sites, Kom Debaa El-Qebli and El-Bahari, located near to the shores of Lake Maryut. Kom Debaa El-Bahari (North) is small, narrow tall with an ancient cemetery upon its (Figs. 7, 8). The surface, covered with pottery fragments and a number of graves are visible on the eastern side.

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[267] EMBABI 2004.
[268] SESTINI 1976.

The maximum dimensions of the site of Kom Debaa El-Qebli are approximately 450 m. from north to south and 300 m from east to west. The site is a low hillock, approximately 8 m high at its highest point above the surrounding fields.

The contact between the cross bedded sands (Fig. 9) and the overlaying silt was marked by the presence of about 20 cm. of charcoal remains (Fig. 10). The preliminary findings from the pottery study suggest that the south site is earlier, with occupation shifting to the north. Before the Ptolemaic settlement there may have been a river channel to the west, flowing through a swampy area. The silt deposits from such channel created the levee upon which the Kom Debaa sites were founded and existed until the silting up of the channel in the Late Antique period.

Traces of house plans (Fig. 11) can be seen on the north-eastern side of the mound slope near the top. The material could be dated to the Imperial Roman period (that is, Early to Middle Roman), with only a few examples of Late Ptolemaic and Late Roman pottery.

Tall Abu-Mandour archaeological area

Tall Abu Mandour is located along the western bank of Rosetta Branch. It has an elongated shape trending in NW-SE direction parallel to the river banks (Fig. 12). The site is located at the top of a small linear dune which stood high about 10m. above the ground level.

The Coastal Sand Bars

Lake Manzala is located at the north-eastern corner of the Nile Delta. Within the Manzala lagoon, there are many archaeological sites, the most important being Tall Tannis, located 6 Km south of Port Said (Fig. 13) and covers an area of about 8 Km². It was a seaport and center of commerce. The site is located on the top of the coastal sand bar[269] which runs parallel to the ancient shore line of the Mediterranean Sea during the Pleistocene time (Fig. 14). The elevation is little more than 5 m. above the present water level in the north-eastern sector of El- Manzala Lake (Fig. 13).

The Tannis archaeological area was located on the north-eastern edge of the Nile Delta, opposite to, and protected by; relatively large coastal sand bars (Fig. 14) which had made the area suitable for being utilized as a harbor since the pre-Hellenistic period. The island was a prominent trading port. It was also a bishopric and important Christian center, and the site of a battle during the Arab conquest of Egypt in 642[270]. The town was attacked and damaged on several occasions in the eleventh and early twelfth centuries, and finally evacuated by order of the Ayyubiy Sultan Al-Malik M. Al-Kamil in 1227, though the island nonetheless continued in use as a trading base until at least the fifteenth century.

[269] ZAGHLOUL 2015.
[270] MUNIER 1943; BALL 1942; BUTLER 1902; HUSSEINI 2014.

Summary and conclusion

It is obviously clear that the ancient settlements from pharaonic to Islamic periods are located above the dune sands and the coastal sand bar to be safe from the threats of the high Nile floods through the former Nile Delta Branches while the historical sites in the central Nile Delta located at the top of the turtle back mound.

Recently, major parts of these dunes have been subjected to reclamation. Consequently, agricultural resources, tourism, impact of climatic changes and human settlements would be seriously affected by the remaining of these archaeological sites.

Acknowledgement

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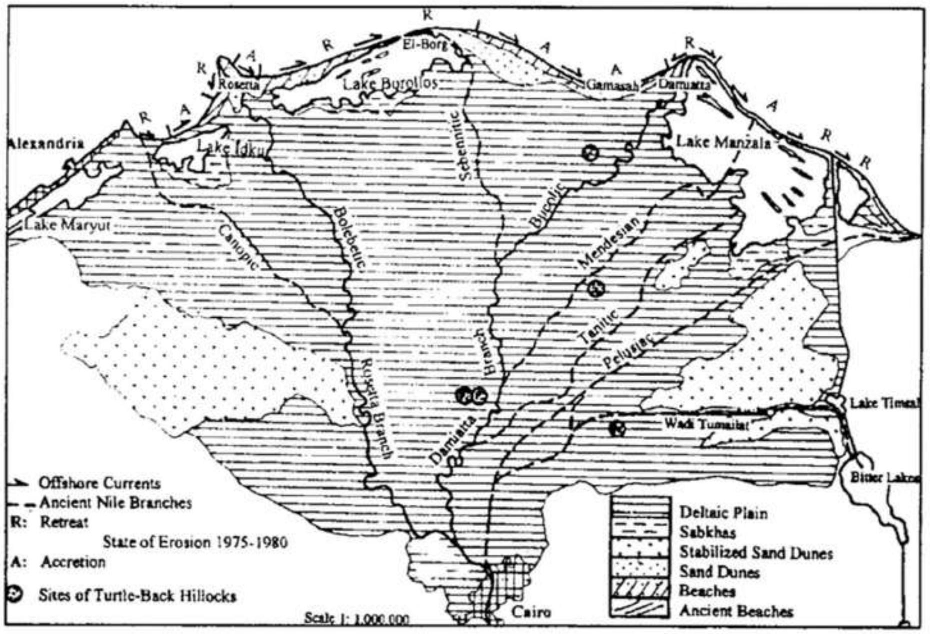

Fig. 1 - The main geomorphic features in the Nile Delta (After Embabi, 2004)

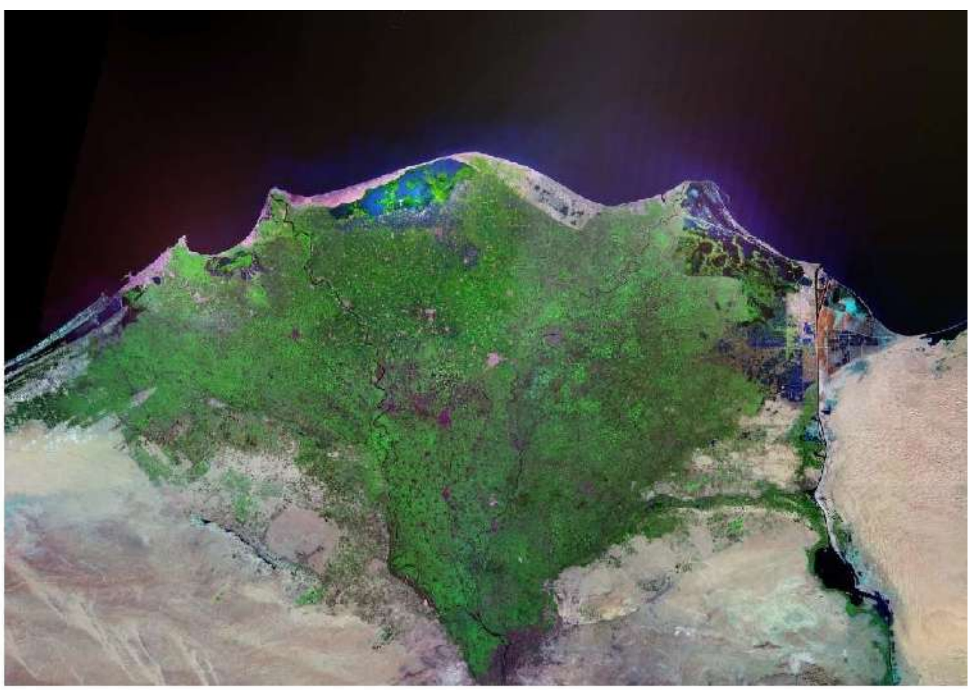

Fig.2 - Satellite Image showing the North Nile Delta Sand Dune Belt

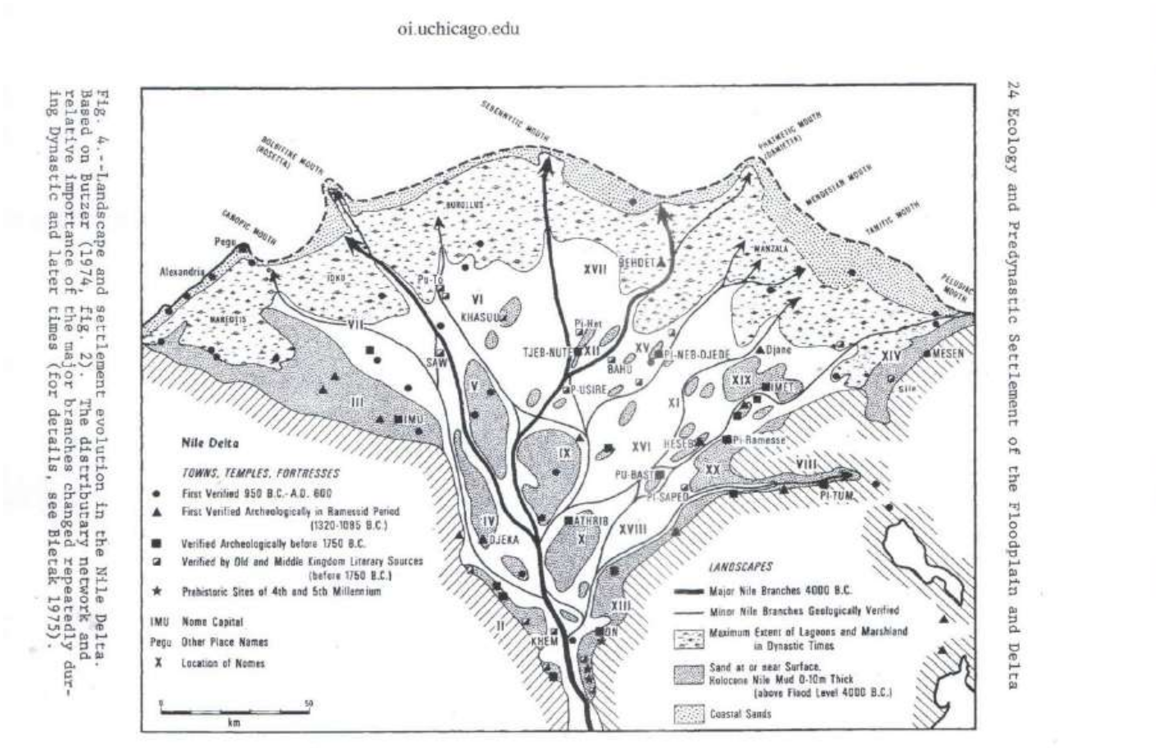

Fig. 3 - Landscape and settlement evolution in the Nile Delta (Based on Butzer, 1976)

Fig. 4 - The fluviatile sand deposits of the Turtle back mound

Fig. 5 - An obelisk clearly connected with Ramesses II, from the cartouche

Fig. 6 - Satellite Radar Image showing the buried structures in San El-Hagar

Fig. 7 - Kom El-Debaa El-Qibly

Fig. 8 - Kom El-Debaa El-Bahari

Fig. 9 - Cross-bedded Aeolian sands exposed at Kom El-Debaa El-Bahary

Fig. 10 - Charcoal remnant at the contact between the sand and the silt

Fig. 11 - Section in the southern side of Kom Debaa El-Bahri, showing a red brick construction.

Fig. 12 - Tall Abu-Mandour archaeological area

Fig. 13 - Satellite image showing the location of the Tannis archaeological site (Google earth)

Fig. 14 - Pleistocene Coastal Sand Bar with marine shell fragments

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