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Integrated archaeological and archaeometric research in Hierapolis of Phrygia (Turkey): new light on ancient building sites

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***Abstract* – This paper concerns some results of the Marmora Phrygiae Project, carried out in the years 2013-2016 and aimed to reconstruct the building stone procurement strategies adopted in the city of Hierapolis in Phrygia (Turkey), across a broad chronological time span from the Hellenistic epoch to the Byzantine period. The research activities were based on a multidisciplinary approach, integrating the archaeological and art-historian study of the monuments of the city, the topographical investigation of the marble quarries in the territory of Hierapolis, and the archaeometric characterization both of extraction sites and marbles used in the Hierapolitan building sites. Specific lines of research have been also applied to the study of the chemical-physical mechanisms responsible for the decay of the marbles, the archaeometric investigation of the mortars, the study of the artificial materials used in ancient restoration works, and the analysis of colour traces on marble statues and sculptural reliefs.**

I. INTRODUCTION

This paper summarises the main results of the Marmora Phrygiae Project, financed by the Italian Ministry of Education, University and Research (MIUR) as part of the "*Futuro in Ricerca*" programme (FIRB 2012), which was carried out by CNR-IBAM-*Istituto per i Beni Archeologici e Monumentali* (lead partner), CNR-ICVBC-*Istituto per la Conservazione e la Valorizzazione dei Beni Culturali*, CNR-IGAG-*Istituto di Geologia Ambientale e Geo-ingegneria*, and University of the Salento (*Dipartimento di Beni Culturali*) [1]. The Marmora Phrygiae Project belongs to a line of research into ancient building sites, which, by means of new multidisciplinary approaches, not only studies the strictly art-historical aspects of the monuments, but also seeks to reconstruct the economic and social dynamics associated with the construction of great public complexes. In the period 2013-2016, the project sought to reconstruct the building stone procurement strategies adopted in the city of Hierapolis in Phrygia (Turkey), across a broad chronological time span, from the Hellenistic epoch to the Byzantine period. Extensive knowledge of the territory surrounding the city and detailed research into its monuments provided the basis for a painstaking historical reconstruction [2,3,4,5]. In particular, a systematic archaeological study has been conducted both in the marble quarries of the territories pertaining to the Phrygian city and the nearby Laodikeia and Aphrodisias, and in the public buildings of Hierapolis. This study has been integrated with the archaeometric characterization of the quarries and the marbles used in the building sites, thanks to the analyses of hundreds of samples collected from the quarry faces and the archaeological artefacts, to reconstruct the building stone procurement strategies adopted in Hierapolis with a diachronic perspective. In order to assign the sampled marbles to specific quarrying districts, the characterisation of the archaeological artefacts was based, as for the samples taken from the quarries, on the integration of minero-petrographic, isotopic and cathodoluminescence analyses.

Due to the specific hydrogeological and tectonic characteristics of the settlement area of Hierapolis, where highly damaging phenomena affect the building stones (such as the welling up of calcareous waters that coat the ancient remains in thick concretions, as well as the emission of gasses with high concentrations of carbon dioxide), a specific line of research has been developed in order to study the chemical-physical mechanisms responsible for the decay of the marbles and draw up protocols for restoration and conservation.

Moreover, in order to study other aspects of the ancient construction practices, an archaeometric investigation of the mortars used during the Imperial and Byzantine periods has been conducted, as well as the study of the artificial materials used in ancient restoration works and the analysis of colour traces on marble statues and sculptural reliefs.

Lastly, the Marmora Phrygiae Project supported the acquisition of many new data (both archaeological and archaeometric) about the ancient building sites of Hierapolis. Numerous data will be shortly available also thanks to an on-line geodatabase.

II. QUARRIES EXPLOITATION AND ANCIENT BUILDING SITES

Systematic archaeological and topographical surveys have reconstructed the ancient topography of the quarrying districts of marble, alabaster and breccia in the Hierapolis territory: the extension and characteristics of the extraction sectors, the techniques for extraction, the quantities of material extracted, the areas where the detritus was dumped and the presence of activities linked to the roughing out of specific artefacts have been determined [6,7,8]. The quarries and the ancient road network were georeferenced on large-scale topographical maps and high-resolution ortho-images, identifying the slipways and establishing the routes used for transporting the material to the city. Multitemporal satellite images were processed for the documentation of the quarries and their surrounding areas and for the identification of quarrying sectors that had been destroyed (due to the resumption of extraction activities) or filled in with detritus during last decades [9]. Even aerial filming of the quarries (faces and trenches) by means of a small remote-controlled drone was performed. In particular, about the marble quarries, four main extraction areas have been identified also in accordance with the geological study of the territory: two are very close to the city (Hierapolis-Gök Dere and Marmar Tepe), and other two lie further away (Thiounta and Gölemezli). Moreover, the marble quarries of Laodikeia (close to Denizli) and Aphrodisias were investigated.

Within the Marmora Phrygiae Project, some of the main Imperial and Byzantine monuments of the urban area of Hierapolis (such as the Sanctuary of Apollo [10,11], the North Agora [12], the Civil Agora [13], the Nymphaeum of Tritons [14], the Ploutonion [15,16] with the nearby Stoa of the Springs [17], the Marble Stoa and the Gymnasium [18], the Theatre [19], the so-called Bouleuterion, and the St. Philip Church [20,21]) and surrounding necropolises [22,23], which were characterised by extensive use of architectural elements in marble, were systematic studied. The investigations were conducted in accordance with a multidisciplinary approach that considered the floor plans, elevations and decorative schemes, as well as the design and construction processes, in order to reconstruct the organisation of the building sites and the division of the work among the various craftsmen [24]. Where the available data permitted, it also sought to calculate the work schedules, costs and requirement of manual labour [25]. In addition, special attention was paid to the ancient stone working and restoration techniques [26] (particularly significant in a seismic context such as Hierapolis), as well as the presence of demolition sites and the practice of reusing construction materials.

The study of the individual monumental complexes and their floor plans was integrated within the large-scale archaeological cartography of the city and the necropolises. Furthermore, in order to more accurately reconstruct the general site plans of certain large monumental complexes that have only partially been brought to light so far (such as the Civil Agora and the Gymnasium), various geophysical prospection systems (georadar, geomagnetic, geoelectric and seismic) were combined [27]. The aim was to verify and document the presence of buried walls, as well as to highlight, in specific sites (such as the Sanctuary of Apollo), the relationship between the buildings and their tectonic context (particularly the large seismic fissure that crosses the area), assessing the construction solutions adopted.

The reconstruction of the building stone procurement strategies adopted in Hierapolis between the Imperial and Byzantine periods was achieved thanks to the archaeometric characterization of the quarries and the marbles used in the building sites by mean of the analyses of hundreds of samples collected from the quarry faces (about 180 samples added to the existing databases) and the archaeological artefacts (about 270 samples from the urban area and 70 from the necropolises) [28,29]. For the archaeometric characterisation of the marbles, three different types of investigation were integrated: (i) minero-petrographic analyses, conducted in CNR-IBAM's Laboratory of Optical and Electronic Microscopy in Lecce (coord. by G. Quarta); (ii) isotopic analyses, carried out in CNR-IGAG's Laboratory of Mass Spectrometry in Rome (coord. by M. Brilli); (iii) cathodoluminescence analyses, conducted in laboratories of the UEA-ICAC (Unitat d'Estudis Arqueométrics of the Institut Català d'Arqueologia Clàssica) in Tarragona (coord. by M.P. Lapuente Mercadal).

The archaeometric analyses on samples taken from the archaeological artefacts of the urban area and necropolises of Hierapolis documented that 90% of the white, white veined and grey marbles used in the city between the Hellenistic and the Byzantine times came from the quarries located within the territory administered by the city: Marmar Tepe (53%), Hierapolis-Gök Dere (20%) and Thiounta (17%), which was believed to provide the more valuable marble among the local ones according to five funerary inscriptions from the Hierapolitan necropolises explicitly mentioning sarcophagi made of this marble [30]. An extremely limited quantity of material came from the Gölemezli quarries (1%), located 13 km north-west of the city and perhaps managed by Tripolis, and from the Denizli quarries (1%), situated 25 km to the south-east of Hierapolis, in the territory of Laodikeia. The material imported from the more distant and prestigious quarries of Dokimeion (6%) and Aphrodisias (1%) includes for the most part sarcophagi, while the quantity of these marbles used for the architectural and sculptural materials is limited to particular elements (especially column shafts). Finally, the provenance was not identified for only 1% of the sampled materials, which may also

include imported materials.

The archaeological artefacts sampled are highly representative of the Hierapolitan situation in terms of the large number of items, the fact that they include all the types of architectural elements (decorated and not), and as they come from all the necropolises and urban monuments known today. The results of the archaeometric analyses, having been conducted on dated archaeological artefacts, also provide us with diachronic data on the choices made in the construction sites during the main monumentalization phases and how the Hierapolitan quarries were exploited. Moreover, they allow us to assess in which periods the importation of marbles was concentrated, i.e. the Hadrianic, Antonine and Severan periods.

III. STUDY OF THE DECAY OF THE MARBLES

As part of the Marmora Phrygiae Project a specific line of research was developed by CNR-ICVBC (coord. E. Cantisani) in collaboration with CNR-IBAM, in order to study the chemical-physical mechanisms responsible for the decay of the marbles and draw up protocols for restoration and conservation [31,32]. In fact, the specific hydrogeological and tectonic characteristics of the area of Hierapolis give rise to phenomena that are highly damaging for the conservation of the building stone, such as the welling up from the subsoil of calcareous waters that coat the ancient remains in thick concretions, as well as the emission of gasses with high concentrations of carbon dioxide. Furthermore, in Hierapolis the natural phenomena are accompanied by the often damaging effects of the presence of hundreds of thousands of tourists every year.

In this sense, extensive samplings were conducted to study the state of conservation of the investigated monuments. This research focused especially on the (i) monumental complexes built over the main fissures produced by the seismic fault (Sanctuary of Apollo, Ploutonion, Stoa of the Springs, Bouleuterion); (ii) monuments covered by calcareous formations that have been excavated in recent years using pneumatic drills (Nymphaeum of the Tritons, Marble Stoa and Gymnasium); and (iii) monuments whose remains are partially submerged in pools and lakes produced by spring water welling up through cracks in the subsoil, as is the case with the structures of the Civil Agora. The latter complex is also heavily affected by flows of tourists, who are responsible for damage and alteration of the architectural materials, caused both by physical actions and products such as suntan lotion that come into contact with the surfaces.

With the aim of determining the main decay phenomena for the individual monumental complexes, numerous samples were thus taken and subjected to laboratory analyses (optical and electronic microscopy, X-ray Diffraction, X-ray Fluorescence, FTIR-Fourier Transform Infrared Spectroscopy, Ionic Chromatography, biological analyses). The main decay phenomena identified in Hierapolis are: widespread granular decohesion, sulfation, corrosion and dissolution; reprecipitation of different carbonatic phases, travertine encrustations and earth deposits; thick crusts of Mn-oxides, entirely covering travertine and marble blocks excavated from Ploutonion; biodegradation and biological colonization.

Analyses were also conducted of the thermal spring waters present in various points of the archaeological area, both along the seismic fault (the lakes of the ex-Gendarmerie and Pamukkale Termal, the Ploutonion, the area of the Bouleuterion) and on the western edge of the terrace of Hierapolis, which is the starting point of the cascades that descend towards the village of Pamukkale, encrusting the slope with characteristic white calcareous formations. The analyses were conducted in situ (measuring various parameters: T, pH, O_2, C, Nitrates, Chlorides, CO_2) and in the laboratory (Ionic Chromatography, Gas Chromatography, ICP OES-Inductively Coupled Plasma Optical Emission Spectroscopy). In particular, the high presence of sulfate (thermal spring waters in the archaeological site are, in fact, calcium bicarbonate-sulfate), together with the fact that almost all of the dissolved gases were constituted by CO_2, make these waters able to deposit efflorescences and/or crust rich in gypsum, and make them very aggressive against carbonatic stones.

In addition, sensors were used to monitor thermo-hygrometric parameters and gases (CO_2, CO, H_2S, O_2), particularly in the Ploutonion and near Building A of the Sanctuary of Apollo, to evaluate their role in the conservation of the exposed material. The monitoring confirmed the high thermal stress on the surface, which was particularly significant on the marble artefacts, due to the strong solar radiation and to heat rising from the ground, as well as the presence of high concentrations of CO_2 in the Ploutonion area. Furthermore, in order to record the behaviour over time of surfaces located at varying distances from the seismic fault, the architectural materials of the Marble Stoa, the Sanctuary of Apollo and the Church of St. Philip were also monitored by means of colorimetric measurements (CIELAB system) and water absorption tests by the sponge contact method.

Lastly, IR thermographic surveys for the identification of thermal anomalies affecting structures built over the seismic fissures were conducted in the Sanctuary of Apollo, the Ploutonion and the Stoa of the Springs, both on the ground and from a low-flying aerial platform (tethered balloon) [33].

IV. STUDY OF OTHER ASPECTS OF ANCIENT CONSTRUCTION PRACTICES

In order to study other aspects of the ancient construction practices, further specific lines of research

were developed by CNR-ICVBC in collaboration with CNR-IBAM. First of all, an archaeometric investigation of the mortars used in Hierapolis (both for bedding and plasters) during the Imperial and Byzantine periods was conducted [34]. Numerous samples were taken from various monuments held to be representative of the different ways of using mortar (bedding mortar for ashlars, grouting, filling, wall cladding mortars, plaster and stucco work) and the main phases of construction of Hierapolis. Minero-petrographic characterisation of the mortars, designed to reveal their micro-structure and composition (in terms of binder and aggregate), was thus conducted on the Sanctuary of Apollo (Buildings A and C, Nymphaeum), the Ploutonion, the Stoa of the Springs, the Great Building, the Theatre, the Nymphaeum of the Tritons and the Church of St. Philip. In the latter context, and in the Byzantine domus of Insula 104, the plasters and pigments of the mural paintings were archaeometrically characterised by non-invasive techniques (optical microscopy and imaging techniques) and micro-sampling. Regarding the fragments of Byzantine plaster discovered in the Church of St. Philip, the research was integrated with the art-historical study of the materials, in order to reconstruct the techniques adopted and the pictorial motifs [35].

Another specific line of research concerned the study of the artificial materials used in ancient restoration works thanks to the sampling of fragments of ancient bonding mortars from the marble blocks belonging to the Sanctuary of Apollo, Theatre and Ploutonion [36]. The analytical methodologies applied to identify the organic and inorganic components were: XRD, FTIR, Optical Microscopy (OM) in polarized transmitted light, Pyrolisis (PY) analysis and GCMS-Gas Chromatography Mass Spectrometry. In particular, the mortars of Hierapolis showed the presence of animal glue and a Pinacae resin, in agreement with the recipes described in the historical sources.

Lastly, another research entailed the analysis and study of the traces of colour present on marble statues and sculptural reliefs in the North Agora, the Sanctuary of Apollo and the Theatre [37]. The investigations involved analyses both in situ, using non-invasive and portable techniques (Ultraviolet Fluorescence; Visible Induced Luminescence), and in the laboratory (XRD, FTIR and GCMS on the patinas, and FTIR and Raman Spectroscopy, SEM-EDS-Scanning Electron Microscope Energy Dispersive Spectroscopy, HPLC-DAD-High-Performance Liquid Chromatography with Diode-Array Detection and GCMS on the traces of pigment). In particular, Egyptian blue, red and yellow ochre were detected, together with traces of ancient surface treatments.

V. THE MARMORA PHRYGIAE GEODATABASE

Within the project was developed and implemented a digital archive based on an open-source database server, which shortly will be made available free online via the Marmora Phrygiae web portal [38]. It contains a large part of the archaeological and archaeometric data gathered in the course of the project, always precisely geolocalised. This positioning is implemented on the platform's cartographic component, structured on a number of levels that provide progressively greater detail: (i) high-resolution satellite images available on the WMS servers of Google Earth; (ii) the official cartography of the Republic of Turkey on a scale of 1:25,000; (iii) a satellite ortho-image acquired by QuickBird-2 in 2002; (iv) the archaeological cartography of Hierapolis on a scale of 1:1,000.

The alphanumeric data are structured within the geodatabase in three interconnected records, of which the first two contain archaeological data and the third archaeometric information: (i) "context", concerning an accurate description of the contexts investigated, i.e. the marble quarries and the urban and funerary monuments of Hierapolis; (ii) "object", concerning the artefacts within the contexts of investigation that were subject to sampling (quarry faces and roughed-out blocks; architectural elements, statues and sarcophagi); and (iii) "sample", concerning the results of the archaeometric analyses conducted on the individual samples taken from the investigated objects, both in the quarries and in the city and necropolises, subdivided into two sub-records, one for the analyses designed to characterise the quarries and determine the provenance of the archaeological artefacts, and one for the analyses performed to determine the state of conservation.

In the course of the project, the geodatabase was implemented online by the various research teams by means of a web application, proving to be an effective tool for managing, sharing and integrating data. The geodatabase will be published online via two consultation interfaces, one geographical and the other alphanumeric. The former consists of a webGIS that makes it possible to consult the archaeological and archaeometric data by means of geospatial queries, starting from the position of the data in space, navigating on the maps and satellite images. The alphanumeric data are consulted via a web application that interfaces with the geodatabase, presenting the data organised in the three records described above. In this way the scientific community will have access to a considerable quantity of information on the Roman Imperial and Byzantine architecture of Hierapolis and the marble quarries of south-western Phrygia, with a detailed characterisation of the stones extracted. This information will be of particular interest in studies of the provenance of the marbles used in the other cities situated at a short distance from Hierapolis (such as Laodikeia and Tripolis) and in south-western Anatolia more generally. In addition, restorers working on the site of Hierapolis in particular or in the nearby

ancient cities of the Denizli basin will be able to find important information in the geodatabase, for example on the deterioration of the stones or the various marbles to be used in the course of the restoration and repair of archaeological artefacts.

The Marmora Phrygiae Geodatabase therefore constitutes an important development in the panorama of archaeological and archaeometric open-data resources on the white marble quarries of south-western Anatolia. In fact, it makes available both the numerical values of the quantitative analyses (such as those of the stable isotopes of carbon and oxygen) and the descriptive assessments of petrographic and cathodoluminescence analyses. Furthermore, all the photomicrographs of thin sections and the cathodoluminescence images will be also available online, thereby enabling verification by the users themselves.

VI. CONCLUSIONS AND RESEARCH PROSPECTS

The scientific results obtained in the course of the Marmora Phrygiae Project will certainly be of great interest to the various research groups, archaeologists and restorers working in Turkey. The multidisciplinary research has made it possible to build a solid base of knowledge on many aspects of the history of Hierapolis, such as the exploitation of the natural resources of the territory, the archaeometric characterisation of the marbles of the city and the nearby quarrying districts, the building stone procurement strategies adopted during the city's long life and the organisation of the building sites. In addition, it has made available a large quantity of information on the forms of deterioration of the building materials, which future restoration programmes aimed at the city's monumental complexes must necessarily take into account. More generally, data on the archaeometric characterisation of the quarries of south-western Phrygia will enrich the reference databases used for determining the provenance of marbles used in Antiquity. In addition, the detailed georeferencing of ancient quarrying districts can be used by local authorities to implement suitable safeguard and conservation policies, which must also consider the constant threat to these quarries from the resumption of extraction activities.

In conclusion, the Marmora Phrygiae Project has opened up a series of avenues for research that can be taken up in the coming years. Among these, concerning the quarries, one of the most important is the detailed archaeometric characterisation (by means of minero-petrographic and geochemical analyses) of the alabasters of Hierapolis, in order to clearly distinguish them from the other calcite alabasters used in Antiquity in the Mediterranean basin (first results in [39]). These data will also make it possible to determine the true extent of the export of this high-value stone and will enrich the Marmora Phrygiae Geodatabase, whose modular architecture enables successive implementations and developments. Lastly, regarding the city's building sites, the research conducted in the course of the project has convincingly shown the knowledge potential of an approach that strongly integrates archaeological, art-historical and archaeometric research. The samplings of the various monuments of Hierapolis have been more or less extensive, depending on their state of conservation and the level of knowledge on each case, but they have all made it possible to acquire important information on the choices and strategies adopted inside the different building sites. In order to shed more light on the economic and organisational aspects of the construction of the city's various building complexes, the next stage of the research could be to conduct, for specific contexts, sampling and archaeometric analysis of all the conserved materials. The same approach could also be applied to specific classes of artefact, such as certain types of sarcophagi in the necropolises.

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