Project no. 015245

MEDISTONE

Preservation of ancient MEDIterranean sites in terms of their ornamental and building STONE: from determining stone provenance to proposing conservation/restoration techniques

Instrument:	Specific Targeted REsearch Project
Thematic Priority:	PRIORITY [10] – [Specific measures in support of international cooperation – Mediterranean Partner Countries – FP6-2003-INCO-MPC-2]

Final Activity Report

Period covered:	from 01 January 2008	to 30 June 2009
Start date of project:	01 January 2006	Duration: 42 months

Project coordinator: Dr. David DESSANDIER

Project coordinator organisation: brgm (Géosciences pour une Terre durable)

Revision [1.0]

Table of contents

1. Project objectives & partnership

The MEDISTONE project proposes to contribute to the knowledge and the conservation of three of the most important ancient sites in North Africa (Volubilis in Morocco, Djemila in Algeria and Alexandria Lighthouse in Egypt) by the mean of three research axes and corresponding objectives:

- Identification of stones and determination of their provenance (objective 1 / work package WP1) in terms of geographic areas and, if possible, of the former quarry sites; till now, the region of origin of numerous stones used in constructions and ornamentations dating from antiquity, both in the west and the orient (and often reused in the Middle Ages) remained poorly defined or even unknown.

- Diagnosis of the conservation state of the stones (objective 2 / work package 2) at the sites; whilst the causes and mechanisms of the deterioration to stone are relatively well known for temperate European climates, the semi-arid continental climate of the selected sites, characterised by strong thermal amplitudes, high evaporation and strong wind action, together bring about specific weathering and alteration requiring more thorough investigations.

- Development of appropriate conservation / restoration techniques (objective 3 / work package 3) ; the objective is to provide answers to the main problems regarding stone conservation / restoration that are liable to be met at the selected sites ; it involves developing techniques for reassembling fractured and fissured stones ; this phase is based on European know-how and will take into account the climatic environment.

Moreover, data management of the obtained results includes circulation of the information between the non-European Mediterranean countries, and dissemination of the obtained results to partners but also to the whole scientific and technical community (objective 4 / work package 4).

MEDISTONE coordination is carried out by BRGM (French geological survey) represented by Dr. David DESSANDIER (d.dessandier@brgm.fr). Twelve organizations having experience in the field of ornamental and building stone studies and / or deterioration and conservation of cultural heritage stones are involved in the project. They represent both users and suppliers:

- Mediterranean Governmental institutions in charge of Cultural Heritage: Moroccan Culture Ministry (DPC, Morocco), Algerian Culture Ministry (MCA, Algeria), Supreme Council for Antiquities (CSASCA, Egypt).
- Universities and Research Organisations: Università IUAV di Venezia (IUAV, Italy), Moulay Ismail University of Meknès (MIUM, Morocco), University M'Bougara of Boumerdès (UNIB, Algeria).
- Scientific and Technical Institutes: BRGM (Co-ordinator of the project, French Geological Survey, France), Centre Interregional de Conservation et de Restauration du Patrimoine (CICRP, France), Institute of Geology and Mineral Exploration (IGME, Greece), Laboratoire de Recherche des Monuments Historiques (LRMH, France).
- Small and Medium Enterprises (SME): LITHOS SNC (Italy), PONS-ASINI GmbH (Germany).

2. Activities and results summary

The main and result of the project MEDISTONE are summarized here after per work package and corresponding objective.

2.1. IDENTIFICATION OF STONES AND DETERMINATION OF THEIR PROVENANCE

The activities and results of this first scientific objective are presented in the form of atlases (one per each of the three sites; delivrables D1) including maps of ancient quarries (delivrables D2) and collection of reference samples of the stones (delivrables D3). The delivrables of WP1 are already available in the form of reports downloadable on the web site of BRGM (www.brgm.fr) using the following references:

- D. Dessandier with the collaboration (in alphabetical order) of F. Antonelli, R. Bouzidi, M. El Rhoddani, S. Kamel, L. Lazzarini, L. Leroux and M. Varti-Matarangas (2008) – Atlas of the ornamental and building stones of Volubilis ancient site (Morocco). BRGM/RP-55539-FR, 166 p., 135 fig., 28 tab., 3 app.
- D. Dessandier with the collaboration (in alphabetical order) of A. Akarish, F. Antonelli, L. Lazzarini, L. Leroux, A. Nageh, A. Shoeib and M. Varti-Matarangas (2008) – Atlas of the stones of Alexandria Lighthouse (Egypt). BRGM/RP-56218-FR, 161 p., 109 fig., 9 tab., 6 app.
- D. Dessandier with the collaboration (in alphabetical order) of F. Antonelli, M. Hamiane, C. Khalfallah, L. Lazzarini, L. Leroux, C. Riache, H. Taoutaou and M. Varti-Matarangas (2008) – Atlas of the ornamental and building stones of Djemila ancient site (Algeria). BRGM/RP-56277-FR, 171 p., 141 fig., 5 tab., 4 app.

French versions of both atlas of Volubilis and Djemila are also available beside the Moroccan and Algerian Ministries of Culture to facilitate their appropriation by Moroccan and Algerian scientific and technical communities.

Atlas of the ornamental and building stones of Volubilis (Morocco):
The first part of the atlas introduces the history of Volubilis and gives an overview of excavations and restoration works. In a second part, the question of identification and area of provenance of the ornamental stones (local or imported) of the site is addressed based mainly on characterization of representative samples and comparison to available databases. The third and last part deals with the study of the building stones and the search of corresponding quarries relying on bibliographic data and in situ investigations (geological survey and sampling) and then on characterisation of collected samples and their comparison to those from Volubilis.
Concluding about ornamental stones, a quite very limited amount of decorative stones and marble *s.s species* was observed *in situ* or accumulated as roving materials. All of the *in situ* detected marbles and other decorative stones were located in five buildings: House of the Ephebe, Palace of Gordian, Bath of Gallienus, House of Venus and House of Orpheus. In most cases they are in the form of small tiles or slab-fragments embedded in the mortar of floors and walls used for fixing prefabricated marble/mosaic panels. Some other decorative stones and marbles objects are coming from the storeroom of Volubilis (erratic slab-fragments of white or colored marbles collected on the ground since the archaeological excavation until now by visitors and mainly by guardians) and the Archaeological Museum of Rabat (one column and a few statues of white marbles).
Although the imported stones and marbles in Volubilis are not present anymore in big quantities, the research revealed a significant relationship among this important Roman town

of North-West Africa and the most famous marbles source areas of the central and eastern Mediterranean basin (cf. Figure WP1.1).
Four colored marbles *s.l.* belonging to the classical *marmora* used by Romans in the whole Mediterranean Basin were identified: Cipollino verde *(marmor carystium*) from Karystos (island of Eubea), Rosso antico (*marmor taenarium*) from the Mani peninsula; Verde antico (*marmor thessalicum*) from Larisa, Breccia di settebasi (*marmor scyreticum*) from the island of Skyros. One other colored stone (a fossiliferous pinkish limestone), probably the most common decorative stone of the site, was found. Its provenance is still unknown, but a local-Moroccan origin is presumed since its use was observed in modern buildings.
Among the marbles *s.s.* identified in Volubilis, three categories were distinguished: white and pale grey marbles, grey striped and stained ones and a pinkish one:

- Concerning white and pale grey marbles, the statues studied are sculpted in two fine-grained classical white marbles very appreciated and largely distributed during the Roman age: the *lunense* marble from Carrara (Italy) and the *pentelic* marble from Mount Pentelikon (Athens – Greece). Among the white marbles used for slab and architectural elements of Volubilis, besides the *pentelic* marble, four other marbles were identified: the dolomitic variety of the *Thasian* marble from the district of Vathy (island of Thasos - Greece), the *Parian* marble from Lakkoi (island of Paros, Cyclades - Greece), the *Proconnesian* marble from the island of Marmara (Turkey) and one unknown white fine-grained marble (most probably having a local origin).
- About grey-striped or stained marbles quite abundant in the form of slabs, they macroscopically look like the type called "*greco scritto*" from Cap de Garde quarry (Annaba - Algeria), a graphitic medium-coarse grained marble with a white background drawn by thin grey-blackish veins or dark grey to bluish stains. Nevertheless, their petrographic parameters and isotopic compositions do not match with those measured for the classical Algerian *"greco scritto"* expressly sampled in the ancient quarry of Cap de Garde.
- Concerning pinkish marbles, a stele dedicated to Venus and slab fragments were identified corresponding to the so-called *Portuguese pink*, a Hercynian marble outcropping at Vilaviçosa in the Estremoz Anticline (Portugal).

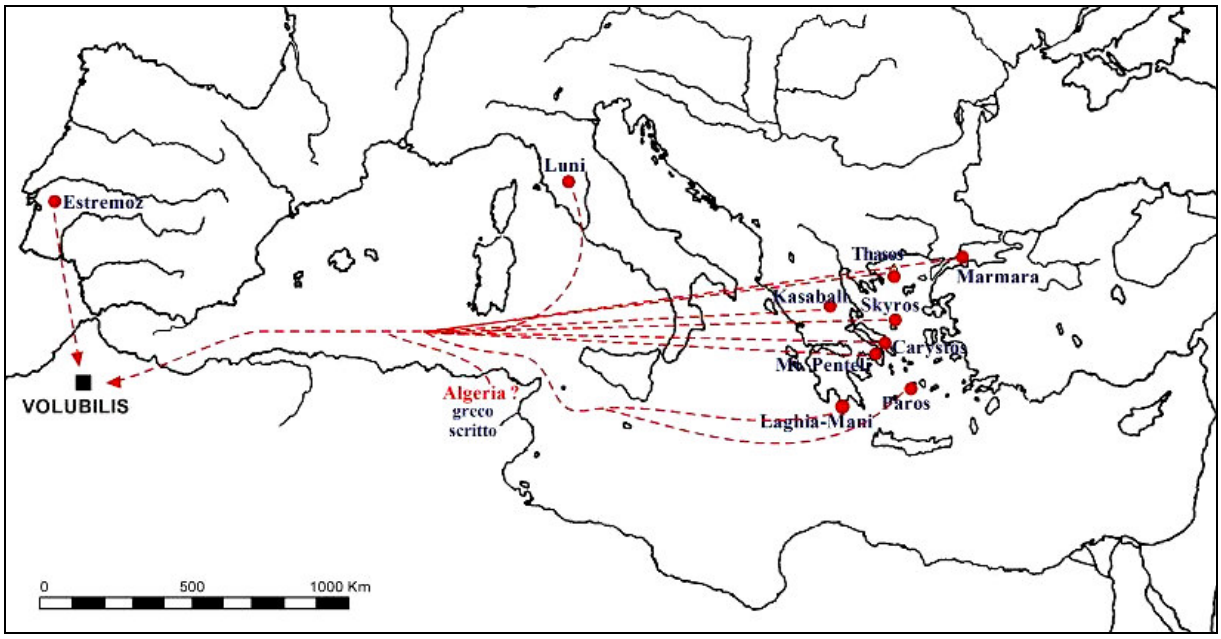

Figure WP1.1 - Provenance of the imported white and colored marbles of Volubilis.

Concluding about building stones (cf. Table WP1.1), the systematic survey of each monument completed by petrographic-mineralogical characterisation and chemical analyses permitted to identify and classify the building stones of Volubilis into six main categories

(referenced A to F). Therefore, the relative importance and the use of each of the six lithotypes was estimated and discussed.
After identifying the lithotypes of building stones of Volubilis, the search of their quarries of provenance was carried out, based on available bibliographic data and geological settings, then by sampling and in-laboratory characterisation of samples. Two main ancient quarries areas were located respectively near Aïn Schkor hill and on the upper part of Moulay Idriss Zerhoun city. Various outcrops were also investigated near Lakouar and Bou Assal villages, around Douar Ben Abdallah hill and also on the site of Volubilis itself. The considered quarries and outcrops are located in a five kilometres sector around Volubilis site. Their lithotypes were then compared to those (referenced A to F) from Volubilis ancient site.
This study globally succeeded in identifying the stones of Volubilis and determining their provenance areas. Besides the accomplishment of this objective, the whole of the gained data constitutes a knowledge improvement available for further investigations and studies dealing with archaeology and conservation of the ancient site. Not undertaken in the framework of this project, future archaeological studies for example could focus on the relationship between spatial distribution of the types of stones and periods of constructions.

Atlas of the stones of Alexandria Lighthouse (Egypt):
The first part of the atlas introduces the Alexandria Lighthouse in terms of historical and topographical context, state of knowledge of building materials and history of underwater archaeological excavations. In a second part, the various archaeological monuments and artefacts considered (nowadays stored or exhibited in Alexandria or still underwater) are described and characterized in terms of their petrographic types of stone and physical-chemical properties. The third and last part deals with the search of potential provenance areas (reference quarries when possible) of the stones, relying on bibliographic data and in situ investigations (geological survey and sampling) and then on characterisation of collected samples and their comparison to those from Alexandria Lighthouse objects.
First of all, one should remember that the Alexandria Lighthouse was toppled into the sea. The archaeological site is nowadays essentially underwater just off the coast of Alexandria. Its ruins consist of about three-thousand architectonic blocks and statues lying on the seabed at depths between six to eight meters.
Until the beginning of modern underwater excavations only few and contradictory informations about the building materials of the Pharos were available. Some authors mentioned the lighthouse was build of white stone whereas others indicated the presence of marble, limestone and bronze for the decorated statues. Various theories followed one another talking about local limestone, nummulitic limestone, granite, alabaster, white marble…
According to new results following many underwater excavations from 1994, Jean-Yves Empereur (Centre d'Etude Alexandrine) first made a scientific and systematic investigation and review of the materials constitutive of the blocks, encountering granites essentially and sandstones as well as few graywacke, marble and limestones. The archaeologist explained the relative lack of limestone and marble blocks by three reasons: these softer stones are difficult to identify underwater after having been eroded over the centuries by marine flora and fauna, the need for chalk to manufacture cement for Alexandria city; these stones are more easily worked and therefore were taken to be re-employed in later constructions such the fortress itself and the adjacent Ottoman tower.
Till nowadays, the various undersea excavations in QaitBay extracted from under the sea about fifty blocks of different sizes (architectonic blocks and statues). Therefore, guided by Centre d'Etude Alexandrine (special acknowledgement to Mrs. Isabelle Hairy), an overall examination of the sites of exhibition and / or storage of these blocks reputed as coming from the collapsed Alexandria Lighthouse was undertaken. A detailed study of the blocks was performed to inventory megascopically the main types of stones related to the Pharos and a first series of thirty-two samples were collected. As most of the stones related to the lighthouse are still occurring underwater, a second series of thirty-five samples was collected, by diving, from still underwater architectonic blocks.

Lithotype observed on Volubilis		Use of the lithotype as building stone on the whole site			Reference quarries and outcrops of provenance of the lithotype	
Ref.	*Simplified designation*	*Proportion (%)*	*Types of use*	*Distribution in the monuments*	*Name*	*Geological formation and age*
A	**Beige-green marly limestones**	2,6	Medium-sized carved (and sometimes sculpted) architectonic elements Masonry stone-rubbles in very limited proportion	1-7% in almost all monuments	Aïn Schkor quarries area	Upper molassa, Miocene
B	**Beige-yellowish calcarenite limestones (so-called "molassa")**	60,2	Masonry stone-rubbles and various carved and sculpted elements (column, chapiters…)	60-80% in all monuments	Aïn Schkor quarries area, Douar Ben Abdallah and Bou Assal outcrops	Upper molassa, Miocene
C	**Grey massive limestones**	31,4	Architectonic elements (jamb, lintels, column, carved blocks of significant size). Masonry stone-rubbles in limited proportion	100% in Capitol, Basilica, Public Fountain, Triumphal Arch and Door of Tangier, 5-20% in other monuments	Moulay Idriss Zerhoun quarries area	Bedded limestones, Middle Lias (Domerian)
D	**Ochre-grey limestones rich in bivalves**	2,6	Masonry medium-sized stone-rubbles only	1-10% in almost all monuments More present in south and west parts	Lakouar outcrops	Grey marls and sandy limestones, Upper Lias (Bajocian)
E	**Coarse dolomites**	1,7	Masonry stone-rubbles mainly Many larger-sized blocks also used as basement elements	1-5% in all monuments	Indeterminate	Indeterminate
F	**Continental limestones**	1,5	Masonry stone-rubbles sometimes large-sized Basement elements.	80% in Mausoleum 1-5% in all other monuments	Volubilis bedrock	More or less conglomeratic limestones, undifferentiated Plio-Quaternary

Table WP1.1 - Synthetic restitution of the results of Volubilis building stones study.

The whole of the sixty-six archaeological samples were described megascopically and characterized in laboratory in terms of their petrographic types of stone and physical-chemical properties, classified as follows:

- Fifty samples are granitoïds (forty-two coarse pink granites and eight dark-grey granodiorites) mostly grouped together in monzogranite (± syenogranite) and tonalite (± granodiorite) fields (according to chemical classification of De la Roche et al., 1980).
- Nine are megascopically beige-yellowish to ochre-brownish siliceous sandstones made of fine-grained to coarse-grained (almost conglomeratic) more or less bedded materials and classified as orthoquartzites (according to Folk, 1954).
- Two samples are medium to coarse grained pure whitish crystalline marbles.
- Two megascopically look like greywackes of dark-grey color with a slightly oriented texture (foliation), classified under microscope as metasandstone and coarse-grained metasiltstone (according to Pettijohn et al., 1987).
- One sample is a fine dark grey-bluish limestone, corresponding to a lime-mudstone (micrite) containing a few silt-size grains of quartz and micaceous clays.
- Two samples looking like light-colored limestones megascopically are classified as fine sandstones with dolomitic cement to sandy dolostones. Contrarily to the others, both were not collected on underwater archaeological objects but on blocks constituting the basement of Qaitbay Fortress according to the hypothesis that the fortress was located in the same place than the Alexandria Lighthouse, using its ruins.

The search of reference quarries of the various petrographic types of stones constituting the archaeological samples was relied on bibliographic data and field investigations and sampling. Collected quarries representative samples were described megascopically and studied in laboratory before being compared to the archaeological samples:

- Concerning granitoïds, in accordance with bibliography, quarries were located in Aswan City area. A geological survey of modern and ancient ones was performed and thirty-two samples were collected. On the basis of their petrographic observations and chemical measurements (notably major elements contents), the granitoïds from Aswan quarries (Neoproterozoic age) are monzogranite (± syenogranite) and tonalite (± granodiorite) as the archaeological objects. Then Aswan granitoïd quarries are the provenance area of the stone of the whole studied archaeological objects made of coarse pink granite or dark-grey granodiorite from Alexandria Lighthouse.
- About siliceous sandstones, the bibliography focused the quarries investigations on quarries areas of Gebel Ahmar (from “Gebel Ahmar Formation”; Oligocene age) near Cairo and Gebel Gulab (from “Umm Barmil Formation” of the Nubia Group; Upper Cretaceous age) near Aswan. Based on petrographic observations on fourteen samples collected, the siliceous sandstones from Gebel Ahmar and Gebel Gulab areas are both orthoquartzites made of about 90% of coarse to medium-size quartz grains and resemble to those from Alexandria Lighthouse. Concerning chemical measurements (major and trace elements contents) the obtained values from both quarries samples are similar and compatible to those from the archaeological objects without nevertheless highlighting any discriminatory parameter of provenance. Only the presence of chert pebbles and the roundness (sub-rounded to rounded) of quartz grains in the nine archaeological samples as in Gebel Ahmar quarries ones seem to indicate in accordance with bibliography that Gebel Ahmar silicified sandstone quarries are the provenance area of the stone of these archaeological objects from Alexandria Lighthouse.
- Concerning white marbles, no search and study of local marbles was necessary. Indeed according to analytical results (specific mineralogical-petrographic methods and isotopic analysis), both samples (and their source archaeological objects) are made of two imported classical white marbles very appreciated and largely distributed during the Roman age: the Thasian marble from Vathy (Greece) and the Proconnesian marble from Turkey.

- For greywackes, in accordance with bibliography, quarries were located in Wadi Hammamat area (Precambrian basement age) in Eastern Desert. Fields controls were performed and six samples were collected. As the two archaeological ones, the quarries samples correspond petrographically to metasiltstone and greywacke metasandstone. According to this petrographic similarities and also concordant chemical measurements (major and trace elements contents) Wadi Hammamat quarries are confirmed as the provenance area of graywacke (s.l.) constituting the two sampled Alexandria lighthouse objects.
- About the fine dark-grey limestone provenance (one single sample of lime-mudstone – micrite - containing a few silt-size grains of quartz and micaceous clays), the only ancient quarry referred in bibliography as supplying dark grey and black limestones is located at Wadi Abu Mu'aymil (Eastern Desert). Belonging to the Mokattam Formation (late Middle Eocene age), theses stones are described as “silty/sandy, occasionally clayey mudstones” (Harrel et al., 1996). On the basis of the very few available data and without field control being worth to undertake for a single sample, it was not possible to conclude about the provenance of the archaeological sample even though Wadi Abu Mu'aymil quarry remains a possible provenance area.
- Finally, the search of provenance of fine sandstones with dolomitic cement to sandy dolostones (two blocks nowadays constituting the basement of Qaitbay Fortress and supposed to correspond to the ruins of the Alexandria Lighthouse; megascopically resembling to light-colored limestones”) focused on two quarries areas El Mex and Abu Sir (from the “Alexandria Formation”; pleistocene age) near Alexandria City. Based on petrographic observations on six samples collected, both areas supply calcarenite made of more than 90% of calcite clearly indicating that El Mex and Abu Sir quarries are not the provenance area of the current basement blocks of Qaitbay Fortress. By comparing with available data for other Egyptian limestone formations (Mokattam, Samalut, Minia, Drunka, Serai and Tarawan) used for quarrying, no lithological and mineralogical correlation was either found and the provenance of the fine sandstones with dolomitic cement to sandy dolostones remains still unknown.

This study globally succeeded in identifying the stones of the Alexandria Lighthouse and determining their provenance areas. Besides the accomplishment of this objective, the whole of the gained data constitutes a knowledge improvement available for further investigations and studies dealing with Egyptian stones.

Atlas of the ornamental and building stones of Djemila (Algeria):

The first part of the atlas introduces the history of Djemila (ancient *Cuicul*) and gives an overview of excavations and restoration works. In a second part, the question of identification and area of provenance of the ornamental stones (local or imported) of the site is addressed based mainly on characterization of representative samples and comparison to available databases. The third and last part deals with the study of the building stones and the search of corresponding quarries relying on bibliographic data and in situ investigations (geological survey and sampling) and then on characterisation of collected samples and their comparison to those from Djemila.

Concerning ornamental stones, a rather limited amount of decorative stones and marble *s.s species* was observed *in situ* or accumulated as roving materials. All of the *in situ* detected marbles and other decorative stones were located in seven buildings: House of the Bishop, House of Bacchus, Big Baths, Temple of Venus, Curia, Capitolium and Cosinius Market. They are in the form mainly of columns, sometimes of wall and floor slabs forming marble panels and more rarely of sculpted objects. A limited collection of some decorative stones and marble *s.s species* is also exhibited in the on-site Archaeological Museum. Finally, some other decorative stones and marbles objects (mainly erratic slab-fragments of white or colored marbles collected on the ground since the archaeological excavation until now by visitors and mainly by guardians) are coming from the storeroom of the Museum.

Although the imported stones and marbles in Djemila are not present in big quantities, the research revealed a significant relationship among this important Roman town of North Africa and the most celebrated marbles source areas of the central and eastern Mediterranean basin (cf. Figure WP1.2). Another alternative possibility is the import of these marbles from a unique source, the *statio marmorum* of Ostia, where all the marbles of the imperial provinces were stocked.

Seven colored marbles *s.l.* belonging to the classical *marmora* used by Romans in the whole Mediterranean Basin were identified:

- Four lithotypes imported from Greece: Cipollino verde (*marmor carystium*) from Karystos (island of Eubea), Verde antico (*marmor thessalicum*) from Larisa, Breccia di settebasi (*marmor scyreticum*) from the island of Skyros and Porfido verde antico (*lapis lacedaemonius*) from Stephania, near to Krokea (Sparta, Lakonia);
- Two lithotypes worked in North Africa: Alabastro a Pecorella from Bou Hanifia near Mascara (south of Oran), Algeria and Giallo antico (*marmor numidicum*) from Chemtou, Numidia, Tunisia;
- One lithotype imported from Minor Asia: *Marmor mysium* (Mysian granite) from Kosak, Pergamum, Turkey.

Besides these seven types of classical coloured marbles, four other coloured lithotypes were identified in the site of Djemila:

- A black limestone similar to the Tunisian Nero antico from Djebel Oust;
- Yellowish and reddish limestones very similar to the Giallo antico *(marmor numidicum* from Chemtou, Tunisia) but coming from the north-east of Kristel, Algeria, and locally denominated “Yellow of Kristel” and “Pink of Kristel”;
- A yellow-pinkish fossiliferous (including rudists) limestone of local Algerian origin supposed;
- White-honey and red calcareous travertines coming from Djebel Mahouna close to Guelma city or Kef El Amar near to Ain Smara village (south-East of Constantine city), Algeria.

Among the marbles *s.s.* identified in Djemila, two categories were distinguished:

- White and grey pure marbles: three lithotypes imported from Greece belonging to the classical *Marmora Romana* were identified: the *Pentelic* marble (from Mount Pentelikon, Athens), the dolomitic variety of the *Thasian* marble from the District of Vathy (north-eastern sector of the island of Thasos) and the *Parian* marble from Lakkoi (island of Paros, Cyclades); one local fine-grained marble coming from Filfila (north-East of Skikda) dated to Lias was also encountered;
- Grey-striped white crystalline marbles type “Greco Scritto” coming from Cap de Garde (Annaba, Algeria) for some archaeological objects and for others of still unknown provenance (other quarries in the region of Annaba? other region or country?).

Furthermore considering the ornamental stones, it is important to emphasize the use of the yellowish and pinkish limestones from Kristel – documented here for the first time in a Roman context – most probably as a local substitute of the famous and more expensive *marmor numidicum*. The same consideration has to be made for the use of the local whitish marble from Filfila (near Skikda), most likely employed as a substitute of the Lunense or Pentelic marbles.

Concerning building stones, the systematic survey of each monument completed by petrographic-mineralogical characterisation and chemical analyses permitted to identify and classify the building stones of Djemila into nine categories: one main lithotype (referred lithotype 1), three intermediate ones (referred lithotypes 2 to 4) and five minor ones (referred lithotypes 5 to 9) in terms of importance (total volume) of use (cf. Table WP1.2). After identifying the lithotypes of building stones of Djemila, the search of their quarries of provenance was carried out, based on the inspection of geological maps and focused fieldworks. Considering the few available data, investigations for determining a provenance area (or even quarry when possible) were undertaken for only the major (lithotype 1) and the

Lithotype observed on Djemila		Uses of the lithotype as building stone		Reference quarries and outcrops of provenance of the lithotype	
Ref.	***Simplified designation***	***Relative importance***	***Types of uses***	***Name***	***Geological formation and age***
1	Grey fine hard limestone	Major	Present on the whole site; in the form of stone-rubbles as well as dimension stones or other architectonic elements (lintels, jambs, columns, flagstones…).	Djebel Medjounès and Djemila mounts (Kef Ben Salah and Sidi Sadoun quarries).	Limestones of the Setifian Domes, Upper Senonian.
2	Greyish fine-grained bioclastic limestone	Intermediate	Concentrated in the primitive urban city (Capitolium and Cosinius Market) and around an area “temple of the Septimian Family – Square of the Severes”; in the form of sculpted elements such as many cornices, tables, columns and banisters.	Djemila mounts (Kef Ben Salah quarries).	Limestones of the Setifian Domes, Upper Senonian.
3	Beige cavernous tufa	Intermediate	Used mainly in the baths monuments as Stone-rubbles for walls; also as stone-rubbles in the remains of archways in the “Big Baths”, the Capitolium and the Temple of the Septimian Family; as dimension stones for one wall in the “Baths”.	El Hammam quarries on the south bank of Oued Ez Zatine.	Hydrothermal Tufas, Quaternary age.
4	Light-beige-grey limestone (with fragments of rudists and sparitic phenocrysts)	Intermediate	Distributed on the whole site but representing a limited overall volume; in the form of various architectonic elements (sometime sculpted) like steles, jambs of door, many columns, capitals and doorsteps.	South side of Djebel Halfa.	White massive limestones with debris of rudists (caprines) and crystalline cement, Cenomanian.
5	Reddish vermiculated travertine	Minor	Observed in the form of a few columns in the Basilica of Cresconius.	Unknown	
6	Beige hard coquinoid limestone	Minor	Observed in the form of a few columns for examples in the *frigidarium* of the Big Baths, and in the crypt of the Basilica of Cresconius.	Unknown	
7	Silty reddish and greyish bicolor dolomitic limestone	Minor	Observed in the form of debris of a few columns lying on the ground around the Theater.	Unknown	
8	Travertine with big lithoclasts surrounded by radiolitic concretions	Minor	Observed in the form of one column lying on the ground in the Theater.	Unknown	
9	Pinkish to purplish gypseus breccia with calcareo-dolomitic big lithoclasts	Minor	Observed in the form of very decayed fragments of one column lying on the ground in and around the Anonym Temple (east of the Temple of the Septimian Family).	Unknown	

Table WP1.2 - Synthetic restitution of the results of Djemila building stones study.

three intermediate (lithotypes 2, 3 and 4) types of building stones in terms of importance of use. The corresponding quarries and outcrops are located in a fifteen kilometres sector around Djemila. After identifying the lithotypes of building stones of Djemila, the search of their quarries of provenance was carried out, based on the inspection of geological maps and focused fieldworks. Considering the few available data, investigations for determining a provenance area (or even quarry when possible) were undertaken for only the major (lithotype 1) and the three intermediate (lithotypes 2, 3 and 4) types of building stones in terms of importance of use. The corresponding quarries and outcrops are located in a fifteen kilometres sector around Djemila.

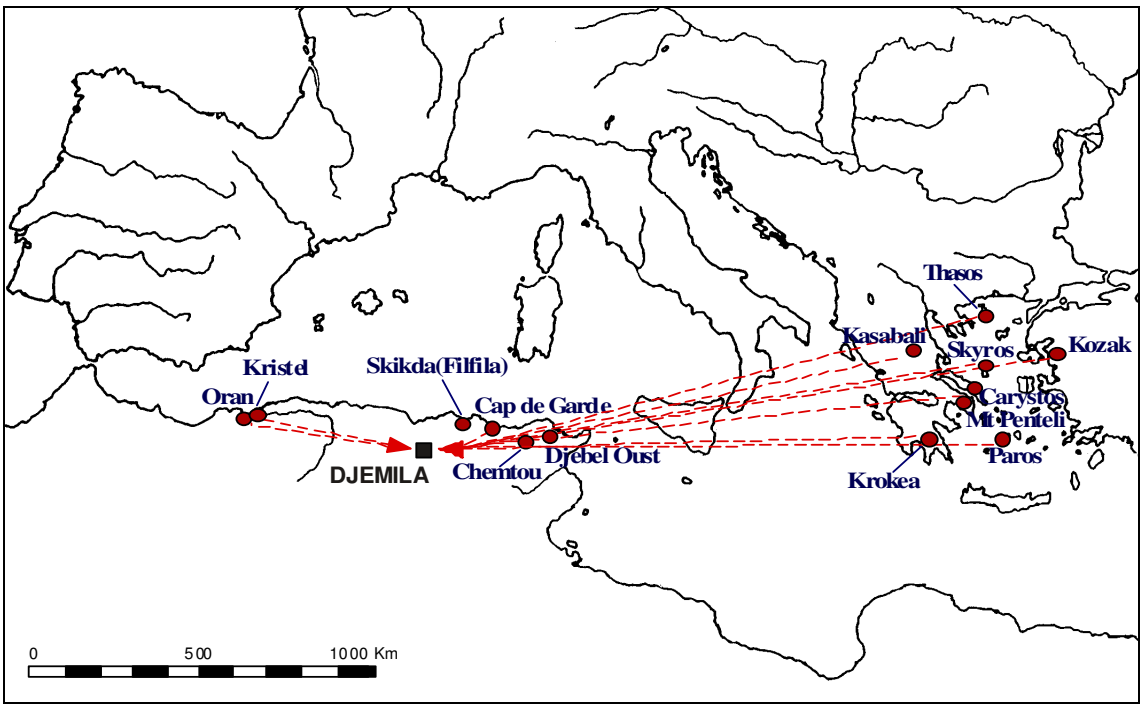

Figure WP1.2 - Provenance of the imported white and coloured marbles found at Djemila.

This study globally succeeded in identifying the ornamental and building stones of Djemila and determining their provenance areas. For building stones, future complementary fieldworks could permit to complete the results by validating the provenance of the lithotype 4 and determining the one of the minor lithotypes. For decorative stones, a more detailed survey of the Algerian various marble quarries could constitute a great challenge to complete the understanding of the Marmora Romana. First and foremost, the whole of the gained data constitutes a knowledge improvement available for further investigations and studies dealing with archaeology and conservation of the ancient site of Djemila.

2.2. DIAGNOSIS OF THE CONSERVATION STATE OF THE STONES

The activities and results of this second scientific objective are presented in the form of guides (one per each of the three sites; delivrables D4) containing a description of the main degradation features observed, a diagnosis concerning the causes of these degradations and some practical recommendations to improve the conservation of stones and sites. The delivrables of WP2 will be available from January 2010 in the form of reports downloadable on the web site of BRGM using the following references:

- J.-M Vallet and Ph. Bromblet with the collaboration (in alphabetical order) of R. Bouzidi, A. Daehne, D. Dessandier, M. El Rhoddani, S. Kamel, J. Linke, (2009) – Guide for the stones conservation of the ancient site of Volubilis (Morocco).
- A. Nageh with the collaboration (in alphabetical order) of A. Akarish, Ph. Bromblet, D. Dessandier, A. Shoeib, J.-M. Vallet (2009) – The deterioration phenomena, factors and mechanisms: Application to stones from Alexandria Lighthouse (Egypt).
- Ph. Bromblet and J.-M. Vallet with the collaboration (in alphabetical order) of A. Daehne, D. Dessandier, M. Hamiane, J. Linke, C. Riache (2009) – Guide for the stones conservation of the ancient site of Djemila (Algeria).

The three sites are quite different in terms of climate, location, kind of site, nature of stones:

- The site of Alexandria which concerns the famous Ptolemaic lighthouse is highly influenced by the proximity of the Mediterranean Sea which governs the climate of the region and gives a saline and wet environment. It is also very complex as the monument no longer exists as a building: some stones were re-used in the Turkish fortress of Qaitbay at the probable location of the Lighthouse; others have been lifted recently from underwater by dying as the lighthouse collapsed during the Middle Age. They are today exposed or stored as parts of the architectural structure or ornamentation of the lighthouse in different places in the town. The studied stones are mainly granite and granodiorites.
- The sites of Djemila (ancient Cuicul) and Volubilis are both antique Roman cities excavated during the first half of the 20th century and exposed to semi arid continental climate with strong thermal amplitudes and high evaporation rate. The investigations were mainly focussed on building stones due to the scarce traces of decoration stones on these sites. The building stones are limestones in both sites.

Two different approaches were undertaken, for respectively Alexandria Lighthouse and for the two roman sites (Volubilis, Djemila), even if the adopted study strategies were quite close:

- Overviewed observation of the stones alteration patterns which occur on each site in relationship with the stone lithotype (determined during WP1's actions)
- Choice on each site of selected areas which are representative of almost all the site
- Precise documentation in terms of an exhaustive study of the alteration patterns affecting these areas and their precise cartography; description of alteration patterns according to the "bilingual illustrated glossary on stone deterioration patterns" (collective, 2008).
- Sampling of the alteration patterns mainly focussed on these areas in order to understand the mechanisms which led to their formations and their causes by the way of in- laboratory studies.

The deterioration phenomena, factors and mechanisms: Application to stones from Alexandria Lighthouse (Egypt):

The work focussed on the granitoid materials (granite and granodiorite) which represent the main part of the sculptures (22/27). Many stone degradation morphologies were observed and described on sculptures exposed in several places and coming from Alexandria lighthouse. Sculptures show very different alteration features which reflect a multiphase history and successive alterations. Many sculptures are re-used material and come from Egyptian antique towns like Heliopolis. After a visit of the six different sites of storage / exposure / exhibition of the lifted out blocks in Alexandria, three of them have been chosen:

- The Eastern Harbour platform of Qaitbay where lies a granite made lintel, precisely mapped in terms of its alteration patterns
- The Marine Museum Garden where two pieces of a monumental female statue and one base of statue precisely mapped in terms of their alteration patterns, are stored

- The Kom El Dikka open-air Museum where nineteen masterpieces are nowadays exhibited. These objects have been raised, desalinated and exposed by CEAlex (French archaeological laboratory dedicated to researches); the sphinx A13 in granite and the part of a sphinx (A14) in granodiorite have been precisely mapped in terms of their alteration patterns.

Documentation and various information concerning the excavations, the restoration work (desalination, repair, cleaning), the state of conservation undersea and the history of each sculpture were collected (thanks to Mr Empereur and Mrs Hairy from CEAlex).
Among the samples collected on desalinated or not desalinated pieces, thirty were selected for deeper investigations about:

- Chemical, biological and physical alteration due to the seawater on the different stones.
- Mechanisms involved in the scaling of the Aswan granite (weathering during antique times, sea-water interaction, modern weathering, comparison with fresh granite coming from the antique quarries).
- Impact of marine concretions and their removal on the preservation of the surface of stones.
- Efficiency of the desalinisation process by determining the soluble salt content of samples.

As the rock material in the quarries shows typical weathering features, a survey of the alteration affecting the granitic material in the quarries was also conducted and some weathered rock materials were sampled to characterize the alteration of the rock material that ancient Egyptians used for monuments.
Many various kinds of degradation feature were observed with different possible origins and mechanisms (weathering of the stone before its extraction in quarry, weathering during Antiquity, undersea alteration, current weathering).
The first alteration features are already present in the granite sampled in Aswan quarries and occurred before the extraction of stones. Different deterioration features of these oriented granites were observed as:

- Contour scaling on cutting faces, degradation of plagioclases and deferriferrous biotites in the granitic site from the unfinished obelisk,
- Intra and inter granular fracturing of granitic blocks,
- Gradient of deferrification of ferro-magnesian minerals from the surface to the depth (first centimetres) in the South Mahmoudia area quarry (cf. Fig. WP2.1).

Figure WP2.1 - Different alteration patterns affecting the surface of a modern granite block in the South Mahmoudia quarry: - the scaling pattern is visible on the surface of the block - inter and intra granular cracks affect the block mainly in its subsurface - the iron oxide content coming from the alteration of ferromagnesian primary minerals seems to decrease from the surface to depth

On thin sections, we put the focus on the alteration features that could be observed under optical microscope. Near the surface, intergranular and intragranular cracking networks (cf. Fig WP2.2, left) were noticed and correlated with the scaling of the stone. Feldspars and especially plagioclases are partially sericitised. Biotites are partially exfoliated (cf. Fig. WP2.2, right) and iron oxides have precipitated in their boundary (cf. Fig. WP2.3.). These alterations seem to be mainly due to the weathering of the stone before its carving.

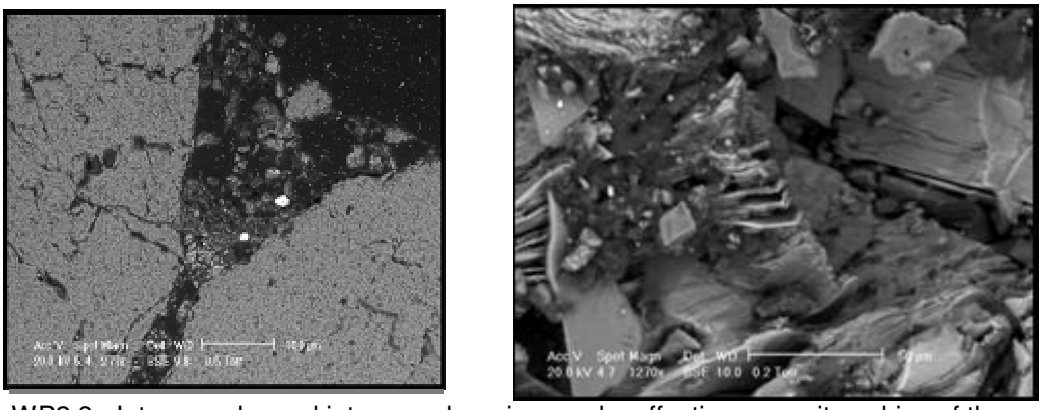

Figure WP2.2 - Intragranular and intergranular microcracks affecting a granite sphinx of the opening museum in left, and exfoliated biotite in the sample 30 (granite lintel on a dockside near the site of lighthouse) in right, observed under SEM (secondary electronic beam (BSE) mode)

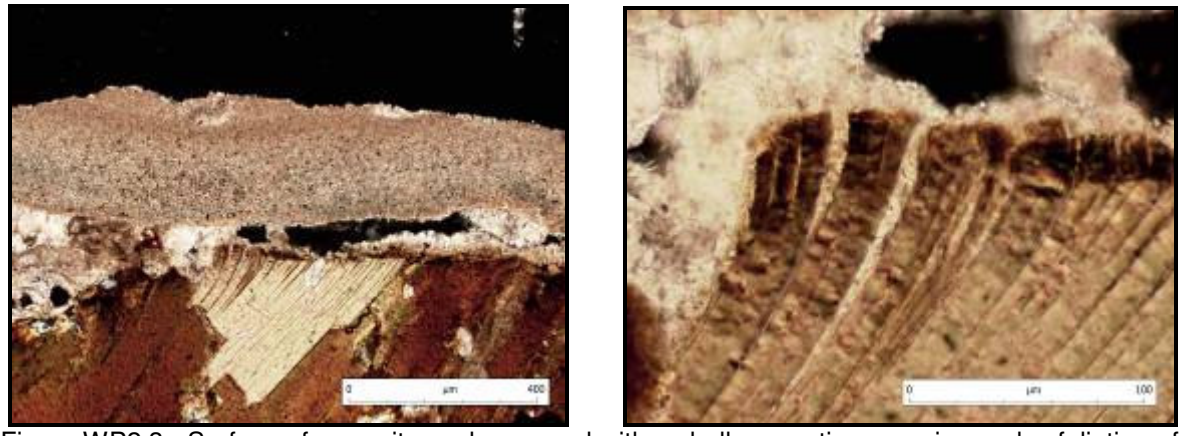

Figure WP2.3 - Surface of a granite scale covered with a shell concretion covering and exfoliation of biotite with calcite filling underneath (detailed view on the right photography) – thin section, crossed Nicols.

Apart from the biogenic calcite of the shells covering the stone, two generations of calcite have at least crystallised in the porosity. The first one made of large monocrystalline grains can have a hydrothermal origin. The second one, more abundant, is microcrystalline and fills the cracks. Its origin is currently not yet determined. The macroscopic and microscopic observations reveal that the biotite is more weathered than the other minerals as feldspars and quartz in any case and more particularly in case of masterpieces included in the first group. This leads to the increase of the roughness of the surface, the granular disintegration and the development of weakness planes scales and exfoliation.
In comparison with the polished and shining sculptures which have never been immerged that we have seen in Alexandria (Pompei column) and in Aswan (basins…), various kinds of degradation were observed on the sculptures and the stones lifted from the sea in the place where the lighthouse collapsed. Using the terminology of ICOMOS glossary written by the International scientific committee for stone (collective, 2008), the main encountered degradations are:

- *rounding*, *missing parts*, *scratch*, *cut*, *roughening;*
- *scaling*, *contour scaling*, *crumbling*, *granular disintegration*, *chipping*;
- *staining*, *concretion*, *colouration;*
- *cracks.*

Scaling, contour scaling, staining were also observed on the granite material from the quarries and are probably inherited alteration features already present on the rock that ancient Egyptians extracted or which occurred during antiquity. As it was already related for ancient granite quarries in other cases, the quarries were digged in the very superficial and weathered granite formation (clayed paleoalterite layers), sometimes in rounded blocks of typical granite chaos where the granite material shows alterations such as discoloration due to deferrification of biotite and contour scaling. In fact, the granite outcrops had been weathered for a long time under climatic conditions different from the current ones before they were exploited as building and sculpture materials. Physical, chemical, physical and biological factors are usually involved in the weathering process. There are several mechanisms of weathering including physical (frost, salt crystallization, expansion due to water and temperature variation…) and chemical ones (hydrolysis, hydration, and oxidation…). The macroscopic and microscopic observations reveal that the biotite is as expected more weathered than other minerals such as feldspars and quartz. This leads to the increase of the roughness of the surface, the granular disintegration and the development of weakness planes scales and exfoliation.

Alteration patterns affecting the most damaged sculpture, a red sphinx (A 13) of the open-air museum, were precisely described in order to perform the alteration mapping (cf. Fig. WP2.4). Degradation patterns such as the contour scaling affecting the flank of the sphinx should be inherited from the quarry.

The blocks have been found in shallow waters, at a depth where waves are active. Rounding, roughening, concretions and some rusty colourations are typical undersea marine alteration features. Rounding (cf. Fig. WP2.5) and roughening affect the edges and salient parts of the sculptures. They may be due on one hand to the abrasive effect of seawater bearing micro-size grains and on the other hand to the moving and the scraping of blocks caused by waves. Shell concretions take place in sheltered areas of the sculpture. Some rust colorations may be due to the corrosion of iron contained in the reinforced concrete of the immerged blocks (built dike).

Missing parts and cracks could be mainly due to the falling of the lighthouse. Scratches and cut may have been made by tools during the preliminary cleaning of the sculpture before lifting up them from the sea. Granular disintegration and crumbling affect few sculptures which were lifted earlier and which have yet not been desalinated. It concerns also few sculptures put on the ground and reached by rising damp and garden watering. Soluble salt contents were measured on desalinated items and on stone material sampled directly on sculpture remaining underwater. The measurements show that the desalination procedure is efficient and results to very low and acceptable salt contents in the pieces exhibited in the museum or stored in different places in Alexandria. Desalination is thus recommended for all the pieces lifted from the sea. Consolidation is only required for the few most damaged sculptures, carved in badly weathered rock materials. Recommendations have been done for the maintenance of sculptures (periodic cleaning…).

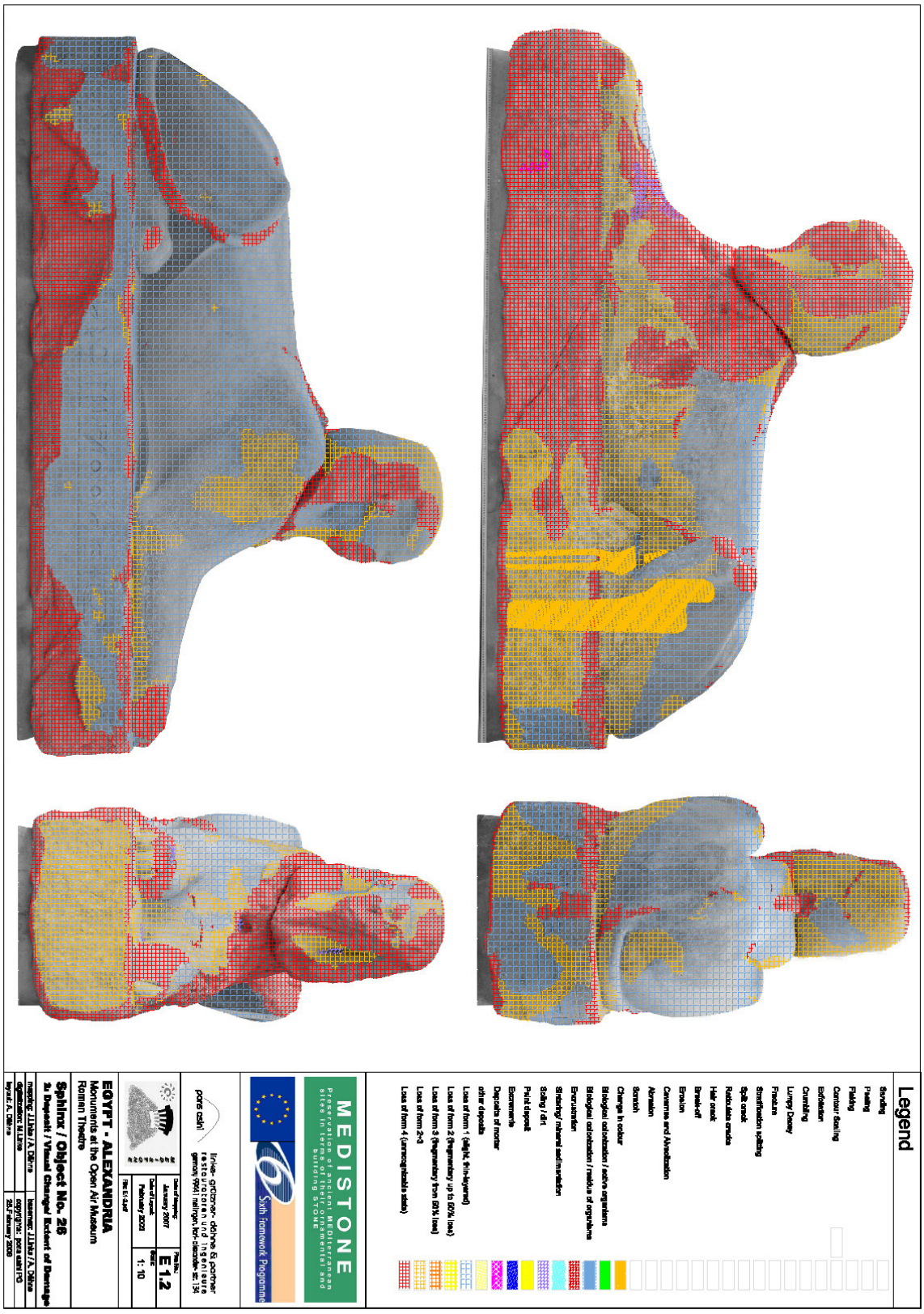

Figure WP2.4 - Example of an alteration mapping of the front face of the red sphinx from the Opened Air Museum of Alexandria

Figure WP2.5 - Marine shells in left and rounding affecting granite masterpieces from the Alexandrian lighthouse which are now presented in the opening museum

Guides for the stones conservation of the ancient sites of Djemila (Algeria) and Volubilis (Morocco):

Concerning Djemila and Volubilis which are located on marly highlands, a detail survey of the site was undertaken during the missions to list the alteration patterns affecting the different kinds of building stones. Views were taken at different scales in order to make the guide of main degradation features. Detailed mapping of selected walls and two stones showing characteristic alteration patterns were done. Ultrasonic velocities were measured on the different lithotypes of the building. These measures were also undertaken for each site on the two selected stones before any attempt to re-assemble them.

Deeper investigations were done on the site in order to describe more precisely the degradation features and to collect samples (powder, scales, lichen):

- Lichens were mainly collected in the Theatre of Djemila and the Basilica of Volubilis which present different species in order to determine them;
- An orange patina observed on both sites was also studied and sampled in the Theatre of Djemila and the Basilica of Volubilis ; the aim was to determine its origin;
- Two zones of about 20m^2 in Djemila (an arch that threatens to collapse and a West wall along the rebuilt temple of Septimus Severe) representative of the fracturing affecting limestones were also selected, documented and sampled;
- In Volubilis, soluble salts were quantified on samples collected on stones showing scaling on the Basilica and a pillar of a gate in the baths of Capitol near the Basilica.

Thin sections were made and then observed using photonic and scanning electronic microscopy. Mineral and chemical contents were analysed with spectroscopic techniques (SEM-EDX, Raman) and X Ray Diffraction.

Guides for the conservation of both sites were writing, describing stone alteration patterns, enumerating the main degradation factors and advising few interventions, and some recommendations about the improvement of maintenance and restoration / conservation strategy were proposed.

Djemila (Cuicul) Guide

A. Stone degradation features

The site shows a high biological activity: *lichens*, *algae*, *plants* and even *trees* are growing on the stones and within the masonries, producing specific stone alterations (*pitting*) (cf. Fig. WP2.6), enlarging the joints, the *cracks* and threatening the stability of walls. The microorganisms have induced the development of various coloured *patina* according the exposure and the stone. Saline alteration is limited. It produces *alveolization*, *peeling* that occur only at the contact with restoration works which had been done with cement and

concrete, materials able to supply the site with soluble salts. The main stone lithotypes are hard and compact, fine grained and tectonised limestones. These building stones present very important problems of *fracturation* and *detachment* linked to different causes: the hardness and rigidity of the stone materials, the presence of internal plans of orientation such veins, faults filled with calcite or iron oxides, that can be considered as plans of weakness, and local overloading phenomena allowing various phenomena such as *chipping*, *splitting*, scaling, *missing part* (cf. Fig. WP2.7). Water (rain, snow, run-off, infiltration…) is the other main factor responsible for the degradation of the stone. Water causes directly *differential erosion* and *microkarst* formation, *encrustation*, *biological colonization*, *patina* formation and local salt weathering. It is also involved in the *detachment* and *crack* appearance (*peeling*, *scaling*, *splitting* and *chipping*). Because of the lack of any roof, water is able to decay joint mortars and renders which protected the stone masonry from infiltration and gave stability to the masonries. Several masonry damages have been also reported. Djemila is an archaeological site with many remains of buildings. More than eighty percents of the masonries have been rebuilt during the discovering and excavation period from 1907 to 1954. The ancient restorations made with cements or hydraulic lime base repair mortars do not show the required durability and compatibility with the original materials. Ancient restoration works have been also examined in terms of durability and compatibility with the stone materials.

Figure WP2.6 - Pitting occurring on the surface of a limestone due to the endolithic lichen growth

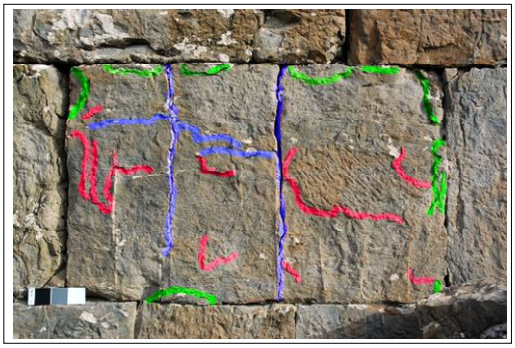

Figure WP2.7: Cracks (splitting) and detachment features (chipping, scaling) on a dimension block of fine hard grey limestone (lithotype 1). The tool marks are no longer visible excepted in one limited place on the right side of the stone - *unstable wall along the temple of the septimian family.*
Chipping : green lines - Splitting : blue lines - Scaling : red lines

Tourism which is rising has right now few negative impacts on the conservation of the site (*graffitis*). A database of all the degradation features has been made, including the description and the illustration of tens of degradation. A mapping has been done in a selected antique wall which is considered to be a reference for the survey of the evolution of the conservation state of the site in the future. Both these documents are given in Annexe. Two stones showing cracks were selected for detailed mapping at the scale 1/2 and as a

support for WP3 restoration work (reassembling). Ultrasonic velocities measures on these two stones before any attempt to re-assemble them were also undertaken.

B. Degradation factors

The site is located in the open country, without any industrial or urban pollution and far from the sea and sea salt sprays. The salt weathering is very limited due to a good drainage through the marly substratum and efficient leaching by rain and run-off waters. On the opposite, very important problems of fracturation and detachment linked to different causes, internal (veins, faults, microcracks…) and external (instability, seismic activity, overloading…) to the building materials have been observed. The main stone building materials are tectonised limestones with calcitic veins network that one can considered as defects for a building material. These structural damages are enhanced by the fact that the main stone materials are hard to very hard limestones, not able to deform themselves but with a rigid behaviour leading to rupture under mechanical stresses. Moreover, the assembling of the dimensional stones, without mortars (dry masonry) increases the stress transmission from one stone to the others without any possibility to deaden it in more elastic, flexible materials. The role of earthquakes is difficult to measure on the site but should have played an important part in the structural damages observed. Water (rain, snow, run-off, infiltration…) is the other main factor responsible for the degradation of the stone. Water causes directly dissolution features, erosion and microkarst formation, encrustation, vegetal growth, patina formation and local salt weathering. It is also involved in the detachment and crack appearance (peeling, scaling, splitting and chipping). Because of the lack of any roof, water is able to decay joint mortars and renders which protected the stone masonry from infiltration and gave stability to the masonries. Due to its rural environment, Djemila suffers also from biological activity at different levels : Lichens, algae and may be bacteria have induced the development of various coloured deposits according to the exposure and the stone material and some kinds of lichens have produced specific degradation such as pitting. Vegetals (weed) and even trees grow on the masonry and participate to the general degradation process, enlarging the joints, cracks and threatening the stability of walls. Although more and more visitors come to the site, actually only few degradations could be attributed to tourism (graffitis, may be some fires and some local stone breaking down). But one can think that the impact of those visitors is not immediate and will progressively increase until a point where degradations will be much more apparent.

C. Recommendations

Because of the increasing number of visitors which are expected in Djemila, problems of masonry stability are probably the most urgent cases that should be taken into account. These few instability problems need a quick intervention to prevent dramatic accident such as collapse and people injuries. For conservation purpose, some interventions are advised to remove:

- Soluble materials from outside and shelter them from rain.
- Carved architectural elements from the ground and put them on special support in order to prevent rising damp, salt contamination and access to visitors who may climb on them.

The improvement of the maintenance would be very profitable to the conservation of the site. Maintenance works should be focussed on few objectives, such as regular removal of trees and vegetal from masonry, reappointing of walls, realization of glacis and mortar protection upon remains of walls, reassemble fractured stones taking into account the methodology and the product set up during the project (see work package 3 delivrables) and strengthening of unstable or already collapsed masonries. This maintenance should be associated to a careful survey of the site and its evolution over time with the assistance of mapping or photos to make possible interventions without delay in case of new alteration features. Training should be planned for people who should be dedicated to the maintenance and conservation of the site. Concerning the deposits and their cleaning, it is not an urgent matter. The orange patina is a very thin layer that could result both from the deposition of aeolian fine particles

and the production of some mineral phases (calcium oxalates) during microbiologic activity. Its formation requires a very long time. It should be considered as the noble ageing patina of the stone and give its character to the archaeological site. Lichens and algae grow all over the site because they have found profitable environmental conditions. Apart their look that one can consider as anaesthetic, they are responsible for very limited degradation, mainly pitting, which concerns not more than 1mm under the stone surface. If they were removed, new ones will grow immediately soon after. They should be considered as another natural patina which participates to the character of the site. Only very punctual removal should be considered on steles covered with inscriptions and some ornamental stones that could display a nicer decorative aspect after cleaning…This cleaning would have to be renewed every 2 or 3 years as the available biocide treatments (quaternary ammonium base products) have not any preventive action. Many restorations and reassembling made of ochre to pinkish mortars during the first half of the 20th century are now decayed and unsightly. The more damaged ones should be removed and replaced by a more suitable lime base mortar. Others could be restored by a superficial repair with lime mortar.

Volubilis Guide

A. Stone degradation features

In Volubilis**,** the main observed alteration patterns are scaling phenomena affecting the grey massive building limestone (31 % of all the stones blocks present, according to the results that WP1 team obtained on this site), a *granular disintegration* affecting the beige-yellowish calcarenite limestone (60 % of all the stones blocks present, according to the results that WP1 team obtained on this site), a *biological colonization* and an *orange patina* visible on many walls and sculptures of the site. Around 20m² of the West wall of the Basilica were selected as representative area for the mapping and the description of the alteration patterns. More particularly, two grey massive limestone stones of this wall showing *scaling* were selected for both WP3 restoration work (reassembling) and mapping of the alteration patterns at the scale 1/2. A pillar of a gate in the baths of Capitol which had been built with the soft yellow limestone, showing *scaling*, *granular disintegration* and *fissures* was also selected and mapped (1/5) for deeper investigations in relation with the work of the WP3 (reassembling).

B. Degradation factors

The study of the alteration causes of the stones in Volubilis showed that both human (in terms of non-adapted past restorations, anthropogenic behaviour and or lack of maintenance) and natural factors (because of water, soluble salts, high climatic variations, biological colonizations, soils movements) are responsible for the alterations which occur in Volubilis. As in Djemila, *orange patina* (cf. Fig. WP2.8), biopatina and *lichen* largely affect the stones.

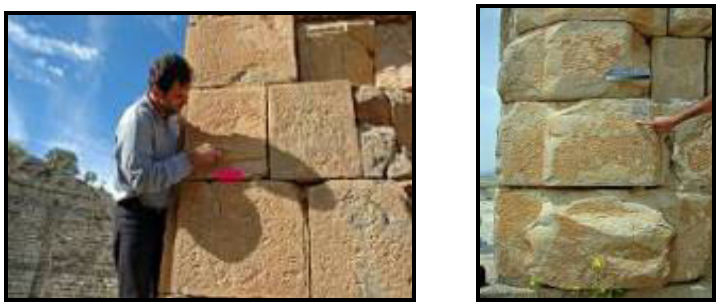

Figure WP2.8 - Orange patina on the surface of the limestone building stones in Djemila (left) and Volubilis (right)

The soluble salts (including gypsum ($CaSO_4$, $2H_2O$) and halite (NaCl)) especially are present in stones of re- assembled structures (use of non adapted mortars for their restoration). The grey massive limestone is quite weakly affected by the alteration. The alteration patterns are

generally quite severe on the beige-yellowish calcarenite limestone especially when the stone blocks suffered to past re- assembling acts (anastylosis) because of the combined action of soluble salts and swelling clays. The alteration is in progress, especially when soluble salts are present (cf. Fig. WP2.9) and leads to the loss of stone materials.
Since the neglect of the city, human presence because of traditional agricultural practices, tourisms behaviour or vandalism which produced scratches and graffiti has slowly and strongly affected the site.

May 2006

October 2007:
Loss of material (see the orange arrow on the previous image)

March 2008:
Contour scaling is detaching Erosion and discolouration are in progress (see the red arrows)

June 2008

Figure WP2.9 - Evolution of the alteration of the surface of a stone (lithofacies C according to WP1 determination: grey massive limestone) on the West wall of Volubilis Basilica (Volubilis Morocco) in presence of soluble salts from 2006 to 2008.

C. Recommendations

The resulting recommendations which end the guide for the stones conservation of the archaeological site of Volubilis (Morocco), concern the optimization of the strategy of conservation- restoration to adopt. This strategy is typically based for an archaeological site on different orientations which concern maintenance actions, the organisation of the surveillance and the watch of the site, the development of an adapted and accessible documentation using if it is possible modern media and the planning of conservation-restoration acts. It ids also based on the periodic modification of tourists ways, and the recognition of all the human activities which occur on a sites. Thanks to the study of different kind of stones and the knowledge of their conservation state it is now possible to focus more accurately the actions on important buildings, and stones which are to better conserve, paying attention on their environment and taking into account all the important existing conservation work as well as the available financial means of the conservation team.

For both sites, Djemila (Cuicul) and Volubilis, it is clear that something should be done to improve the valorisation of the sites and to organize the visit of tourists in a better way, giving to them more up-to-date information concerning the history but also the materials and the conservation. These informations could be presented in a leaflet as well as on panels all over the site. It would be necessary to give them also some recommendations on how to visit an archaeological site without damaging its elements, at least the most fragile or unstable ones, taking care to this fragile testimony of our common past. Some pathways should be drawn for the visitors, preventing them to climb to the walls when walking within the site**.** The redaction of these documentations requires the collaboration of scientists, restorers, conservators, archaeologists at least those involved in the project.

In conclusion, the three previous studies globally succeed in the diagnosis pf alteration and conservation of the stones on the three focussed sites. Besides the accomplishment of this objective, theses work are an implement to the management of the conservation of the sites and give new possible orientations in order to preserve their global vision and also to increase the safeguard of parts of them which need to pay attention without a to much important development of budget.

2.3. DEVELOPMENT AND TESTING OF TECHNIQUES IN THE REASSEMBLING OF FRACTURED AND FISSURED STONES

The activities and results of this third scientific objective are presented in the form of four reports (delivrables D5 and D6) available from January 2010 in the form of reports downloadable on the web site of BRGM using the following references:

- M. Nasraoui with the collaboration (in alphabetical order) of D. Dessandier, J.D. Mertz and P. Pagnin (2009) - Reassembling of fractured and fissured stones: Technical protocols adapted to three Mediterranean ancient sites. *This deliverable (D5) is a common report to the three sites because the scientific approach (dilatation, conductivity) performed in the lab is the same for all stone and products used*.
- M. Nasraoui with the collaboration (in alphabetical order) of D. Dessandier, J.D. Mertz and P. Pagnin (2009) – In situ restoration of fissured stones and broken pieces of Volubilis ancient site (Morocco): Long-term monitoring procedure of the in situ test.
- J.D. Mertz with the collaboration (in alphabetical order) of D. Dessandier, M. Nasraoui and P. Pagnin (2009) - In situ restoration of the statue of King Ptolemy from the Alexandria Lighthouse (Egypt): Long term monitoring procedure of the in situ test-zone.
- J.D. Mertz with the collaboration (in alphabetical order) of D. Dessandier, M. Nasraoui and P. Pagnin (2009) – In situ restoration of fissured stones and broken pieces of Djemila ancient site (Algeria): Long-term monitoring procedure of the in situ test zone.

Even the problematic of reassembling and used lime products are the same in the sites of Volubilis and Djemila, origin of damage, fracture and studied limestones are quit different and justify separate reports. In Alexandria, the tested product in the lab and used in the field have specific properties.
Within this general frame, the lack of information on the dilation behaviour of the mix stone/gluing product, as well as the poor availability of experimental strategies recording the thermal conductivity at the interface of such composed material, have been in the past significant factor of failure to long-term stone reassembling under high T and RH variation conditions. The WP3 of the project proposes, after the set-up of relevant laboratory instrument capable of performing accurate dilations, reassembling protocols specific of each lithology to gain improvement in:

- diagnosis, analysis and assessment of fractured materials of three cultural heritage sites;
- identification of traditional techniques of reassembling;
- in laboratory characterisation of thermal and hygric dilations of the involved materials in order to provide technical protocols for reassembling fractured stones that are liable to be met both the stones lithology and climatic conditions of the three selected sites. This phase is based on European know-how, and take into account the climatic and environmental specificity (thermal amplitude of semi-arid continental climate at the Mediterranean located sites), as well as the social-economic context in each Mediterranean partner country. Indeed, technical solutions commonly in-use in Europe as temperate climate, may be less durable or even completely ineffective and will need to be adapted and validated in each case study;
- selection of significant fissured stones or broken archaeological pieces available for practical restoration and training ;
- in-situ application and monitoring of conservation processes after reassembling procedure.

Technical developments
The detailed knowledge of thermal and hygric dilations of stones is a prerequisite condition for any reassembling action of broken or fissured stones. After previous test and evaluation of a new set-up of relevant laboratory instrument capable of performing accurate dilations, it is crucial for decisions on proper reassembling actions to assess the dilations of the gluing product in order to reach compatible ‘dilation’ behaviour of the mix stone/product.
Due to their origin and ageing, stones are generally mixtures of mineral phases with different swelling/shrinking abilities. Dilation of some minerals as clays is more relative humidity-sensitive, when dilation of other phases, as quartz, is more temperature-dependant. Obviously a single dilatation condition cannot provide complete information on the long-term behaviour of reassembled stones and complementary methods of dilation examination and analysis have to be associated.
All thermal and hygric measurements have carried out with the same dilatometric system.
The calibration of each sensor was carried out in a small displacement range +/-50 mV using a thickness-standardised wedge Mitutoyo SD-45B of 100 µm according to the National Institute Standard Technology (NIST). Deviation of output current in the considered displacement range allows improving the real precision of each sensor (cf. Tab. WP3.1).

Sensor	104	105	106	107	108	109	110	111
Precision (µm)	0.38	0.37	0.30	0.38	0.34	0.35	0.30	0.33
Shift (during 5 successive cycles)	0.001	0.007	0.002	0.021	0.021	0.024	0.008	0.004
Resolution (µm)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table WP3.1 - Nominal precision specific for each sensor.

During the whole project, the dilatometric system has been optimised and finalised to perform representative measurements and both dilation data induced by RH change and thermal cycling (cf. Fig. WP3.1). Additional tests about thermal conductivity approach were performed for the study of heat transfer at the stone - product interface, using a System (cf. Fig. WP3.2) of Analysis of Thin Materials by Infra-red (SAMMIR) developed in the Laboratory of Energy and Optics of the University of the city of Reims (France).

Figure WP3.1 - Hygric and thermal dilatometric system developed during the project.

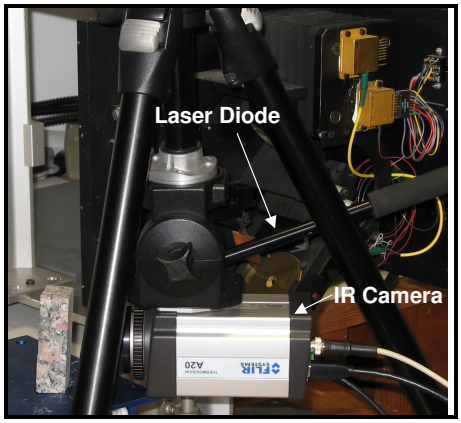

Figure WP3.2 - Experimental device used for heat transfer into the compound stone-product composed by an optic of excitation, an optic of detection and finally an electronic for data acquisition and processing.

Tested resins and injection mortars for reassembling

The three world heritage sites have been losing their broken stones at an alarming rate. Thus, the main objective of the present work is the use of dilatometric approach in order to suggest the most effective and compatible product dealing with the reassembling of fractured stones. Reassembling techniques common in Europe make use of either injection of mineral-based gluing product which show a good degree of chemical compatibility with the stone (ultra-thin hydraulic paste), or more generally, organic compounds developed form polymer chemistry such as acrylic resins, PU or epoxies (cf. Tab. WP3.2).

	Resins				**Injection Mortars**		**Homemade mortars**	
Trade name	Hilti RE 500	SIKA Power Fix	Kema pox RL 215*	Eurostac EP-In 2501	PLM M	LEDAN TA1	CL	HL
Product type	Epoxy + cement	Esther methacrylic	Epoxy	Epoxy	Hydraulic mortar	Hydraulic mortar	Calcic Lime	Hydraulic Lime
Manufacturer	Hilti			Brescianisr	CTS	Tecnoedile, Toscana	-	-

Table WP3.2 - Tested gluing products.

These organic products show undeniable advantages related to their intrinsic qualities such as adhesive properties and mechanical resistance along with there ease of use related to rheological and hardening properties. But, the applicability and the transposition of these solutions, already proven in Europe, need to be tested in the contrasted climatic conditions, especially with regard to temperature variations which have an influence on the dilation behaviour of the material, and ultimately on their additional years of service. In parallel, it is considered important to examine and suggest specific formulations which make the use of

cheaper local products like lime, that unlike polymers, are readily available in local market places. Then, the specimens tested were selected covering a large range of different gluing products in use for the preservation of failing artefacts of sandstone, limestone, marble, and other building stones, but also a special attention has been paid to formulate and evaluate the performance some home-made injection mortars.
This summary presents the field work and the testing undertaken in partnership with the partner 5 (Lithos) in order to make injection mortar recipes based on local materials. Indeed, the main objective target is promoting local raw materials, in Morocco and Algeria, in hopes of applying low-cost lime-injection mortar for stone-reassembling interventions. Additional compounds have been added to improve the natural characteristics of a traditional mortar. The preliminary recipes were made using local quick-lime, pozzolana and calcareous stone powder (in Morocco lime can be found only as massive quick-lime, while in Algeria lime is partially slaked and carbonated and in a powdery form). The basic tested formulation was as follow: Base home-made mortar is:

- 1.5 parts quick lime slaked into a paste;
- 2 parts sifted pozzolana;
- 1 part stone powder.

In order to improve the performance and prevent water retention and cracking, small content of additive (acrylic) was introduced in the paste mortar. Dilation behaviours of the products (2 home-made mortars, 2 ready-to-use lime products, 5 different epoxies resins) and the stones (3 limestones, 2 plutonic rocks) subjected to humidity and heat gradients were carried out (cf. Fig. WP3.3 and 4).

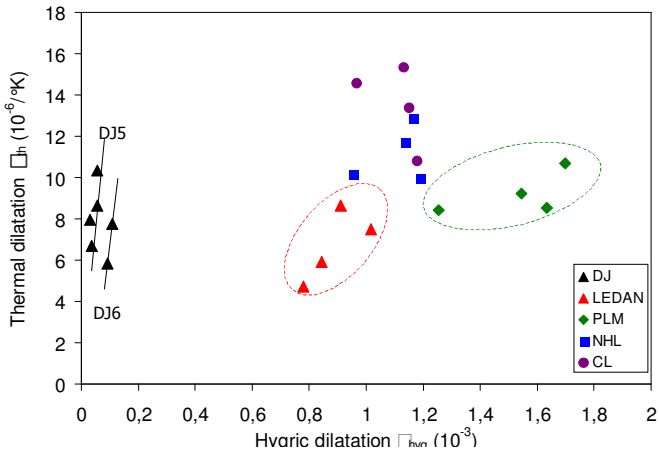

Figure WP3.3 - Thermal and hygric behaviour of the lime products with the hard limestone in Djemila.

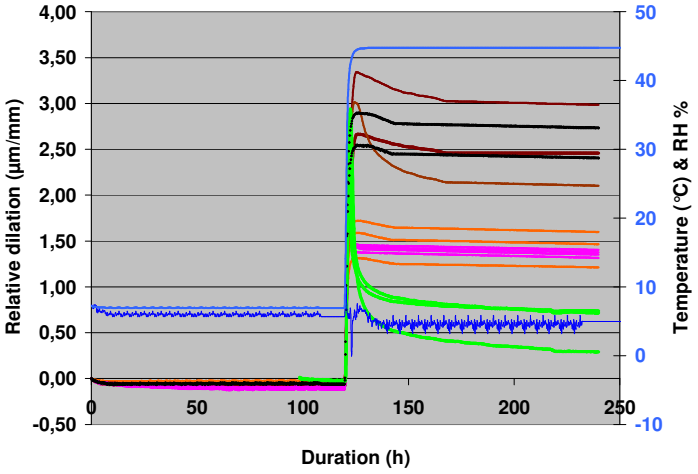

Figure WP3.4 - Thermal dilation behaviour of the tested epoxy resins.

In Egypt / Alexandria, the involved partners decided to select the right hand of the colossal statue of Ptolemy exhibited in front of the Bibliotheca Alexandrina as the most pedagogic in situ restoration to do. The right hand has been fixed and re-assembled using steel pins and Hit-RE500 epoxy resin, which presents the best thermal behaviour close to the granit.

Field-works, training and in-situ restoration in the three archaeological sites

- Site of Volubilis (Morocco) = injection of fissured soft limestones in front of the Therms of Gallian and of desquamated hard limestones in the Basilica.

The selected fractured stones are located in the Gallian Therms which is built with a soft limestone. This lithotype is a beige-green marly limestone (type A according to WP1 results), distributed on almost the whole monuments in a small proportion. A second place close to the west side of the wall of the Basilica was also investigated (cf. Fig. WP3.5) because of the hardness of the limestone used (grey massive limestone, type C according to WP1 results) and its relevant thin contour scaling less than 1mm width. In situ restoration was achieved by injection grouts and mortars (home-made mortar, PLM and Ledan products).

Figure WP3.5 - West wall of the Basilica decayed by scaling (Volubilis, Morocco)

Figure WP3.6 - Reinforcement of small scales by injection of home-made mortar using a syringe (Septimian temple Djemila, Algeria).

- Site of Djemila (Algeria) = injection of the fissured hard grey limestones in the west wall of the Septimian Temple.

The two studied particular blocks in the west enclosure of Septimian temple correspond to the grey fine hard limestone (lithotype 1 according to WP1 results). These blocks are both located in the middle of the wall exposed to the same environmental exposure conditions. The blocks in the lower part are posed traditionally and the other ones are positioned perpendicularly to the stratigraphic bedding. They contain both thin calcitic veins developed in the vertical and horizontal planes and some of them are underlined by cracks. Lastly, cracks have variable size between less than 1mm to several millimetres in width. These characteristics allow many possibilities of treatment of the cracks and check current practical possibilities for the smallest ones. This close zone has been selected for further investigation and injection test (cf. Fig. WP3.6) of adapted lime products (home-made mortar and Ledan product).

- Site of Alexandria Lighthouse (Egypt) = reassembling of the right hand of the colossal statue of Ptolemy coming from the Lighthouse and nowadays exhibited in front of the Bibliotheca.

Previous mission in quarries around Aswan area has confirmed the origin of the pink granite used for decorative statues of the Lighthouse (Alexandria). The right hand of the colossus showed all the characteristics to conclude to the reassembling process according to the current practices in the field of conservation-restoration. The practical reassembling work was carried out in close cooperation with partner n°5 using pin system and Hit-Re 500 epoxy resin tested in the lab (cf. Fig. WP3.7).

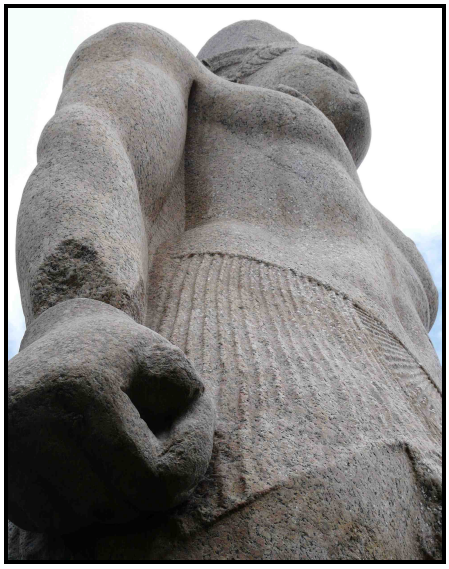

Figure WP3.7 – Colossal statue of Ptolemy after re-fixing of its right hand using steel pin and It-RE 500 epoxy resin.

Parallel to reassembling technique development, during in-situ application, a great importance was put on the long-term applications by training the local staff in charge of the conservation of the site. In situ restoration transfer technology and training of young scientists have been applied in the archaeological sites as the result of the research works in the lab. They have been kept involved in the whole reassembling procedure in order to gain practical experience and to become autonomous for future interventions. For example, an experimental restoration was carried out during the in situ workshop in Djemila. It was followed by the Algerian partners of the project and with enthusiasm by six students in Master grade of the Institute of Archaeology (Algiers university, Algeria) In addition of the treatment of the selected cracks in the wall, three broken masterpieces found in the archaeological site were restored (a Corinthian capital, a frieze and a votive stele) The present restoration was carried out using STAC EP 2501 epoxy resin which is frequently used by partner 5 (Lithos Snc).

Long term monitoring and recommendations

All characteristics or properties mentioned above could be consigned in a document which will be filed and perfectly indexed. This form document (data sheet) will be used for a systematic description of the following headings:

- MORTARS AND INJECTION GROUTS IN THE RESTORED STONES
  - Change of colour within natural stresses
  - Assessment by touching of the surface granularity and texture
  - Granular disintegration
  - Cracks formation and material continuity
  - Loss of material
- PHYSICAL AND CHEMICAL COMPATIBILITY OF RESTORATION PROCESS
  - Visual diagnosis of the surfaces during raining or drying phases
  - Assessment of differential hygric behaviour

- DURABILITY AND EFFECTIVENESS OF THE INJECTION TREATMENT
  - Ultrasonic velocity measurements (in Volubilis and Djemila sites)
  - Control of displacement and mechanical stability

A new output periodic form would be emitted at each site fellow-up. Observations will be precisely described and completed with significant photographs in order to allow a direct visual comparison of the treated zones. The realistic periodicity for such follow-up and recording is once per year or every two years.

2.4. DISSEMINATION OF RESULTS

With the objective to disseminate the scientific and technical results of the project and to promote its methodological aspects, two workshops (delivrables D7 and D8) and several scientific publications (see paragraph "published results") were undertaken during the project.

The first workshop of MEDISTONE took place at the "Maison de la Culture" of Moulay Idriss Zerhoun City (Morocco) the 20 and 21 March 2008 with the kind organisation of Partners 10 and 11. As a part of MEDISTONE ongoing dissemination activities (Work package WP4 of the project – Foreseen delivrable D7), the workshop focused on the first scientific objective (work package WP1 - Identification of stones and determination of their origin) of the project. Besides the whole of MEDISTONE partners (European and African ones), the event gathered about 50 researchers and students mainly from Morocco, Algeria and Egypt. The presence of high authorities of Morocco (President ("Wali") of the Meknès-Tafilalet Region, General Secretary and Cultural Heritage Manager of the Culture Ministry, President of the Meknès University) for Opening Speeches testified the high interest and involvement levels of MEDISTONE project of Morocco.

Kindly organized by the Supreme Council of Antiquities (SCA), the second and Final Workshop of MEDISTONE project took place in Egypt at Cairo University (May 25th – 26th, 2009) and in Alexandria (May 27th, 2009, morning). As a part of MEDISTONE ongoing dissemination activities (Work package WP4 of the project – Foreseen delivrable D8), the workshop dealt with the Final scientific results of the project. Besides the MEDISTONE partners (European and African ones), the event gathered about 50 researchers. To facilitate communication between researchers, an English / French / Arabic simultaneous translation of each oral presentation was available. This event was introduced in Cairo, May the 25th by Dr. Ibrahim DARWISH, General Director of Alexandria Museums and representing Dr. Zahi HAWASS, General Secretary of Suprem Council of Antiquities, and followed by speeches by Dr. David DESSANDIER, Co-ordinator of the project (BRGM, France), Mr. Michele GENOVESE, Scientific Officer (European Commission, Research Directorate, Belgium) and Prof. Dr. Ahmed SHOIEB, head of the project for Egypt (Cairo University, Egypt). A conference mediated by Prof. Lorenzo LAZZARINI, University IUAV of Venice, and titled A METHODOLOGY FOR THE DETERMINATION OF THE ORIGIN OF DECORATIVE STONES USED IN CLASSICAL ANTIQUITY opened the scientific works. Two other conferences titled DECIPHERING THE BUILDING STONES OF MONUMENTS: DIAGNOSIS, DECAY AND PROVENANCE. CASE STUDIES FROM GREEK MONUMENTS (by Dr. Myrsini Varti-Matarangas, Institute of Geology and Mineral Exploration, Greece) and ALEXANDRIA LIGHTHOUSE: THE ARCHEOLOGICAL EVIDENCE (by Prof. Jean-Yves EMPEREUR, Centre d'Etudes Alexandrine, Egypt) were also presented the 25th and 26th of May. The results of MEDISTONE were presented in the form of three consecutive sessions focused on Volubilis (Morocco), Djemila (Algeria) and Alexandria Lighthouse (Egypt) each one dealing with the results of the three scientific work packages WP1, WP2 and WP3. Each session or conference was followed up with many questions and fruitful discussions.

3. Final plan for using and disseminating the knowledge

3.1. DELIVRABLES

Delivrables of WP1 (three atlas of the stones, one by site) are already available in the form of reports downloadable on the web site of BRGM (www.brgm.fr) using the following references:

- D. Dessandier with the collaboration (in alphabetical order) of F. Antonelli, R. Bouzidi, M. El Rhoddani, S. Kamel, L. Lazzarini, L. Leroux and M. Varti-Matarangas (2008) – Atlas of the ornamental and building stones of Volubilis ancient site (Morocco). BRGM/RP-55539-FR, 166 p., 135 fig., 28 tab., 3 app.

- D. Dessandier with the collaboration (in alphabetical order) of A. Akarish, F. Antonelli, L. Lazzarini, L. Leroux, A. Nageh, A. Shoeib and M. Varti-Matarangas (2008) – Atlas of the stones of Alexandria Lighthouse (Egypt). BRGM/RP-56218-FR, 161 p., 109 fig., 9 tab., 6 app.

- D. Dessandier with the collaboration (in alphabetical order) of F. Antonelli, M. Hamiane, C. Khalfallah, L. Lazzarini, L. Leroux, C. Riache, H. Taoutaou and M. Varti-Matarangas (2008) – Atlas of the ornamental and building stones of Djemila ancient site (Algeria). BRGM/RP-56277-FR, 171 p., 141 fig., 5 tab., 4 app.

A French version of both atlas of Volubilis and Djemila are also available beside the Moroccan and Algerian Ministries of Culture to facilitate their appropriation by Moroccan and Algerian scientific and technical communities.

Delivrables of WP2 (three guides, one by site) will be available from January 2010 in the form of reports downloadable on the web site of BRGM using the following references:

- J.-M Vallet and Ph. Bromblet with the collaboration (in alphabetical order) of R. Bouzidi, A. Daehne, D. Dessandier, M. El Rhoddani, S. Kamel, J. Linke, (2009) – Guide for the stones conservation of the ancient site of Volubilis (Morocco).

- A. Nageh with the collaboration (in alphabetical order) of A. Akarish, Ph. Bromblet, D. Dessandier, A. Shoeib, J.-M. Vallet (2009) – The deterioration phenomena, factors and mechanisms: Application to stones from Alexandria Lighthouse (Egypt).

- Ph. Bromblet and J.-M. Vallet with the collaboration (in alphabetical order) of A. Daehne, D. Dessandier, M. Hamiane, J. Linke, C. Riache (2009) – Guide for the stones conservation of the ancient site of Djemila (Algeria).

A French version of both guides of Volubilis and Djemila are also available beside the Moroccan and Algerian Ministries of Culture, of to facilitate their appropriation by Moroccan and Algerian scientific and technical communities.

Delivrables of WP3 (four reports, one by site) will be available from January 2010 in the form of reports downloadable on the web site of BRGM using the following references:

- M. Nasraoui with the collaboration (in alphabetical order) of D. Dessandier, J.D. Mertz and P. Pagnin (2009) - Reassembling of fractured and fissured stones: Technical protocols adapted to three Mediterranean ancient sites.

- M. Nasraoui with the collaboration (in alphabetical order) of D. Dessandier, J.D. Mertz and P. Pagnin (2009) – In situ restoration of fissured stones and broken pieces of Volubilis ancient site (Morocco): Long-term monitoring procedure of the in situ test.

- J.D. Mertz with the collaboration (in alphabetical order) of D. Dessandier, M. Nasraoui and P. Pagnin (2009) - In situ restoration of the statue of King Ptolemy from the Alexandria Lighthouse (Egypt): Long term monitoring procedure of the in situ test-zone.

- J.D. Mertz with the collaboration (in alphabetical order) of D. Dessandier, M. Nasraoui and P. Pagnin (2009) – In situ restoration of fissured stones and broken pieces of Djemila ancient site (Algeria): Long-term monitoring procedure of the in situ test zone.

3.2. PUBLICATIONS AND CONGRESSES COMMUNICATIONS

About twenty publications communications and publications were undertaken during the project as described in the tables here after. One other paper has been submitted and three others are still in progress (one about the stones of Alexandria Lighthouse, one about the compatibility between stone and products by using the dilation method, and another about the technical work and restoration in the three archaeological sites).

Planned / Actual Dates	Type	Type of audience	Countries addressed	Size of audience	Partner responsible /involved
June 06	Dessandier D., Vallet J.M., Bromblet P., Leroux L., Mertz J.D., Delorme F. (2006) Medistone: A new research program on the preservation of ancient mediterranean sites in terms of their ornamental and buildinig stone., in SAUVEUR 7 - Safeguarded cultural heritage. Understanding and viability for the enlarged Europe - Prague - République Tchèque - 31/05-03/06/2006 [Published]	*Research*	*Europe*	*~ 300*	*BRGM CICRP LRMH*
June 06	Dessandier D., Vallet J.M., Bromblet P., Leroux L., Mertz J.D., DELORME F. (2006) Presentation of a new research program on the preservation of ancient Mediterranean sites in terms of their ornamental and building stone., in ASMOSIA VIII - Association for the Study of Marble & Other Stones used In Antiquity - Aix en Provence - France - 12-18/06/2006 [Published]	*Research*	*World wide*	*~ 200*	*BRGM CICRP LRMH*
Autumn 2006	Mertz J.D., Vallet JM., Bromblet Ph. (2006) - MEDISTONE : Préservation des pierres ornementales et de construction des sites archéologiques antiques du pourtour méditerranéen. Culture et Recherche, n°110, automne 2006, pp. 14-15.	*Research*	*France*		*LRMH*
June 07	Varti-Matarangas M., Dessandier D., Leroux L., Kamel S. (2007) Volubilis archaeological site (Morocco) : identification of building stones and determination of their provenance., in 7th International Symposium on the Conservation of Monuments in the Mediterranean Basin - Orléans - France - 06-08/06/2007 [Published]	*Research*	*Mediterranean Basin*	*~ 200*	*BRGM LRMH IGME Meknès University*
October 2007	El Rhoddani M., Kamel S., Dessandier D., Varti-Matarangas M., Leroux L., Mahjoubi R. (2007) - Données préliminaires sur les anciennes carrières du site antique de Volubilis (Maroc)., in RIPAM 2007 – 2èmes Rencontres Internationales sur le Patrimoine Architectural Méditerranéen -Marrakech - Maroc - 24-26/10/2007 [Published]	*Research*	*Mediterranean Basin*	*~ 200*	*All partners*

Planned /actual Dates	Type	Type of audience	Countries addressed	Size of audience	Partner responsible /involved
October 2007	Dessandier D., Leroux L., Lazzarini L., Antonelli F., Varti-Matarangas M., Kamel S., Shoeib A. Akarish A., Hamiane M., El Hajraoui A., Bouzidi R., Zadem R., Riache C. (2007) - Résultats préliminaires concernant l'identification et la détermination de la provenance des pierres ornementales et de construction de trois sites antiques africains (Volubilis au Maroc, Djemila en Algérie et Phare d'Alexandrie en Egypte) – 2èmes Rencontres Internationales sur le Patrimoine Architectural Méditerranéen - Marrakech - Maroc - 24-26/10/2007 [Published]	*Research*	*Mediterranean Basin*	*~ 200*	*All partners*
October 2007	Vallet J.M, Bromblet Ph., Dähne A., Linke J., El Rhoddani M., Kamel S., Bouzidi R. (2007) - Mapping and field study of stone degradation patterns: a preliminary step for the optimization of the conservation of the roman city of Volubilis (Morocco) – 2èmes Rencontres Internationales sur le Patrimoine Architectural Méditerranéen - Marrakech - Maroc - 24-26/10/2007 [Published]	*Research*	*Mediterranean Basin*	*~ 200*	*All partners*
October 2007	Nasraoui M. and J-D. Mertz (2007) - Thermal and hygric stone dilatation: a key step in the path of reassembling fractured stones of Volubilis archaeological site - – 2èmes Rencontres Internationales sur le Patrimoine Architectural Méditerranéen - Marrakech - Maroc - 24-26/10/2007 [Published]	*Research*	*Mediterranean Basin*	*~ 200*	*All partners*
September 2008	Dessandier D., Bromblet Ph., Vallet J-M., Leroux L., Akarish A., Nageh A., Shoieb A. (2008) -Contribution of the study of the building stones and monumental sculptures of Alexandria lighthouse (Egypt)., in Proceedings of the 11th international congress on deterioration and conservation of stone : 15-20/09/2008 - Torun - Poland [Published]	*Research*	*World wide*	*300*	*BRGM, CPP-LRMH, CICRP, SCA*

Planned /actual Dates	**Type**	***Type of audience***	***Countries addressed***	***Size of audience***	***Partner responsible /involved***
September 2008	Dessandier D., Antonelli F., Varti-Matarangas M., Leroux L., Lazzarini L., El Rhoddani M., Kamel S. (2008) - Atlas of ornamental and building stones of Volubilis ancient site (Morocco)., in Proceedings of the 11th international congress on deterioration and conservation of stone : 15-20/09/2008 - Torun - Poland, J.W. Ludaszewicz and P. Niemcewicz, pp 1197-1204 [Published]	*Research*	*World wide*	*300*	*BRGM, CPP-LRMH, IUAV, MIUM, IGME,*
June 2009	Varti-Matarangas M., Dessandier D. (2009) - Lithofacies study of the building stones of Volubilis monuments (Morocco) and their provenance - In ASMOSIA IX - Association for the Study of Marble & Other Stones used In Antiquity – Tarragona -Spain - 08-13/06/2009 [in press]	*Research*	*World wide*	*200*	*BRGM, IGME*
June 2009	Dessandier D., Antonelli F., Lazzarini L., Varti-Matarangas M., Leroux L., Hamiane M., Riache C., Khalfallah C. (2009) - Atlas of ornamental and building stones of Djemila ancient site (Algeria) - In ASMOSIA IX - Association for the Study of Marble & Other Stones used In Antiquity – Tarragona -Spain - 08-13/06/2009 [in press]	*Research*	*World wide*	*200*	*BRGM, CPP-LRMH, IUAV, IGME, MCA, UNIB,*
January 2009	Antonelli F., Lazzarini L., Cancelliere S., Dessandier D. (2009) - Minero-petrographic and geochemical characterisation of “greco scritto” marble from Cap de Garde near Hippo Regius (Annaba, Algeria). In Archaeometry 51, 3, pp. 351-365, Blackwell, Oxford [Published]	*Research*	*World wide*	*500*	*IUAV, BRGM*
Mars 2009	Antonelli F., Lazzarini L., Cancelliere S., Dessandier D. (2009) - Volubilis (Meknes, Morocco): archaeometric study of the white and coloured marbles imported in the Roman age. In Journal of Cultural Heritage 10, pp 116-123, Elsevier [Published]	*Research*	*World wide*	*500*	*IUAV, BRGM*

Planned /actual Dates	**Type**	***Type of audience***	***Countries addressed***	***Size of audience***	***Partner responsible /involved***
October 2009	Dessandier D., Antonelli F., Lazzarini L., Leroux L., Varti-Matarangas M., Leroux L. - Méthodologie d'identification & détermination de la provenance des pierres décoratives et des pierres de construction – Application au site antique de Volubilis (Maroc) – Mines & Carrières, hors-série à paraître en octobre 2009, Revue de la Société de l'Industrie Minérale [In press]	*Research*	*France*	*1000*	*BRGM, IUAV, CPP-LRMH, IGME*
October 2009	Bromblet Ph. Dähne A., Hamiane M., Linke J., Riache C., Vallet J-M. (2009) – Diagnosis of the conservation state of the stone in the roman city of Cuicul (Djemila, Algeria) – 3rd international meeting on the Mediterranean architectural heritage, 15-17 October 2009 [Accepted]	*Research*	*Mediterranean Basin*	*200*	*CICRP, PONS ASINI, UNIB, MCA*
October 2009	Dessandier D., Kamel S., Leroux L., El Rhoddani M., Varti-Matarangas M. – Les anciennes carrières d'approvisionnement en pierre de construction du site antique de Volubilis (Maroc) - 3rd international meeting on the Mediterranean architectural heritage, Lisbon, 15-17/10/2009 [Accepted]	*Research*	*Mediterranean Basin*	*200*	*MIUM, BRGM, CPP-LRMH, IGME*
January 2010	Antonelli F., Lazzarini L., Cancelliere S., Dessandier D. – The white and coloured marbles of the Roman town of Cuicul (Djemila, Algeria) – [Submitted in March 2009 to the Journal of Cultural Heritage , Elsevier]	*Research*	*World wide*	*500*	*IUAV, BRGM*

Scientific and Technical Center
3, avenue Claude-Guillemin
BP 6009
45060 – Orléans Cedex 2 – France
Tel: +33 2 38 64 34 34

Service Géologique Régional
Provence Alpes Côte-d'Azur
117 avenue de Luminy
BP 168
13276 – Marseille Cedex 9, France
Tel: +33 4 91 17 74 76