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E.Stone, an archive for the Sardinia monumental witnesses

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¹ Dept. Architettura: Disegno - Storia - Progetto, Facoltà di Architettura, Firenze
giorgio.verdiani@unifi.it

² Dept. Scienze della Terra, Facoltà di Scienze Matematiche Fisiche e Naturali
Università di Cagliari, Italy
columbus@unica.it

Abstract. The “E.Stone” project is based on the survey, documentation investigation and physical, geochemical and petrographic characterisation of the zoomorphic and phytomorphic stones of Sardinia. The name chosen to indicate this project means the full value of these stones, standing before the beginning of human history. The main task of this project is to survey and to document with an accurate laserscan survey, supported by topographical survey and integrated by GPS tracing and photographic and photogrammetric survey and supported by specific investigations on the rock characteristics. The further development of the collected data will be aimed to the definition of a digital “store of the knowledge” about the stone. This research will produce two main benefits: the creation of a clear and stable archive of these monuments and on the second hand will create the possibility to reply at any distance, a copy in digital material of the original item.

Keywords: Stones, Sardinia, Landscape, Laserscan, Survey, Geology, Documentation, Modelling, Documentation.

1 The E.Stone Archive

1.1 Background

In the world of humanity there are two kinds of processes which are always present: natural processes and the anthropic processes. These manifestations taken over time and conditions to evolve; some of these mutations are clearly visible in a lifetime, others take few instants, while certain requires millenniums or even millions of years to complete their cycle. In this way if we think to a stone on a seaside, shaped by the sea and by the wind, it comes immediately clear how long it will remain in its conditions if compared to a bare foot impression left by a man on the sand. A simple human sign will have a duration of some seconds or maybe of some minutes. The first wave will erase the trace. But even with this meaningful difference, in our daily life we are able to damage or even completely demolish the whole patrimony of monuments and rocks which is richly present in the Sardinia Island. Sardinia is the larger Island in the Mediterranean Sea and is the place where some meaningful natural masterpieces

very ancient rocks, with some formation coming from an age far more than 5000 years from our time, create a great emphasis about these stones, giving the viewer a great impression which goes far behind the simple surprise happening in front of some natural wonder.

The name chosen for this project is “E.Stone, an Archive for the Sardinian Cultural Witnesses”, the reason for this choice are first of all linked to the approach to the research, which is based on advanced digital tools, so that the word “Electronic” is placed in front of the word “Stone” written in English also in order to underline the intention to share and to disseminate the contents at an international level. The term “Witnesses” is used according to its often used in geology to refer to the rocks testifying a previous condition. The term “monuments” should be understood in its value described in the dictionary of the Treccani vocabulary: “[...] to indicate what, for its size, is giving an impression of grandeur and solemnity [...]”.

Fig. 1. The stone and the footprint, two different times

1.2 Documentation and Dissemination

To allow the preservation of these monuments the first step is knowledge, but not as a theoretical work ending in itself but as a passage of awareness based on a documentation process. The tools available today make it easier and more versatile than in the past. In this way, this particular monument will be treated like they deserve.

The digital survey tools and the advanced investigation solutions combined with high-tech multimedia presentation may find in three-dimensional modelling the right place to be focused, with the opportunity to realize different levels of detail. The creation of a repository of knowledge based on accessible criteria and multi-dimensional access, will in time allow to repair or even to rebuild, if necessary, when the monument should be seriously damaged.

Procedures based on a wide digital approach, from a massive use of laser scanning to the digital modelling aimed to produce multimedia contents, can surely be a process of effective disclosure of this environment, allowing users from all over the world to view, study, explore these monuments and learn more about their history that they have all around.

The possibility to use both the current prototyping techniques to produce physical models and the total reproduction of these items in different material can operate in three main ways: the creation of "spare parts" for the monument, the reconstruction of the monument in different materials for the easy and effective deployment in museums, exhibition areas or schools. In this way, the visitor will be able to touch the shapes of the monument. (and this will be a great advantage for the blind or visually impaired as well as for the people with normal vision). In this way, developing well oriented models, it will be possible to disassemble the models, to build innovative learning paths based on digital/physical models.

1.3 Decay Analysis for the Monumental Witness

Through the study of the geomaterials which are the natural constituents of the monuments of high historical and cultural significance examined here, it will be possible to evaluate the state of alteration and the causes that may have led the chemical and physical alteration. The intent will be to further investigate these issues, trying, on the basis of the results, to propose strategies for the conservation operating before then an environmental problem can take place. Operationally, all the monuments will be studied about their mineralogical and petrographic and physical characteristics, including various types of macroscopic alterations and their distribution in the same monuments.

1.4 The E.Stone Project

If adequate resources will be found, the project will develop a first program in the first year, at the starting phase of the project it will be immediately activated a working space to allow collaboration between the research teams. Within the first six months of activity the main campaigns of survey and documentation will start, including the sampling and study of geomaterials from the monuments, the archive will be formed immediately and simultaneously, together with the progress of the survey and study of the collected data.

A first task in the survey campaign will be the completion of the documentation about some of the main witnesses of Sardinia, including: Elephant Stone near Cagliari (surveyed in 2006), the Bear stone in Palau, the remains of the turtle shell in the other stones with zoomorphic or phytomorphic shapes around San Teodoro.

(Cuglieri), the monolith (also known as “the shaped cake”) on the Pulchiana hill in the Gallura area, the San Giorgio’s staircase in Osini. For each of the monuments it will be also catalogued and stored all the data on the characteristics, state of alteration and possible methods of restorative intervention in case of the presence of strong chemical and physical deterioration.

As told before, the survey will be operated with the use of laserscan technology, which will be chosen according to the survey condition, certain monuments will require long range scanner to be completely documented, other will require an high level of detail from the close range. The choice of the phase shift solution, which is capable to measure a range equal to a dome (320 vertical degree and 360 horizontal degree) with an accuracy of a few millimetres collecting up to 200.000 points for each operative second, makes the use of laserscan very interesting to reduce the operative time, but when the operator will need to operate from a meaningful distance, a slower, but more reliable time of flight solution will be used. The entire survey, conducted using even different solutions, will allow the full coverage of the investigated object. The survey will be linked to a specific topographic network, and then referenced on the national map, this will allow a solid archiving of the collected data and fully useful for all subsequent processing and analysis. The main steps of processing the data will be made through the development of traditional two-dimensional representations, views, elevations, sections, useful to present the object using representation solutions which will be easily understandable and communicable. After this phase, the survey data will be used to develop a three-dimensional digital surfaces model, with a procedure that will preserve the greatest correspondence between the collected points and the final model. These models will be useful for the analysis and the study about the surface shape of the object, they will be used to study specific functions and, when combined with photographs, to create images of graphics rendering.

Starting from these models, a complex process of treatment of the data will be used to produce a new series of three-dimensional digital models, designed for online consultation and implementation of multimedia products.

The stage of treatment completion will include the implementation of digital models for the 3D printing of physical models, produced with additive or subtractive processes with 3D printers which are becoming more common with time. In this way, the models allow users to access downloadable versions of the scaled digital models on specific machines, to print and create scaled versions of these monuments.

The models will allow reproducing a copy in resin, PVC or other economical materials, depending on the technology available. The production process of a physical model can be very simple, and in most cases it is very economical. In this way, it will be possible to envisage the possibility of reconstructing an entire remote corner of the monumental witness. Any school or association in the United States, South America, Australia or Japan, will be able to receive digital data as a start to build scaled or even real-sized models. This solution will allow also the access to the monument to blind and visually impaired people, they will be able to experience and understand the shapes of these stones thanks to tactile models.

with a common printer on paper to be transferred to appropriate thickness cut manually. So, starting from the digital model and following simple instructions, everybody will be able to get a scale models absolutely affordable and accessible to all.

E.Stone project, step 1: Setting up an Internet space for data sharing. At the beginning an Internet space will be activated on the network for sharing and collaboration between the research groups. In this way the data previously collected, bibliographic references, iconographic, photographic, geographic references manuals and information useful for the development of the project, will be kept continually updated in this collaborative space, based on classical protocols for remote sharing and virtual conferencing will be possible to solve the main participation trouble among the research groups. At this stage, only active members of research teams, will access to complete materials under development. However a small part of the whole research site as a "preview" of the site will be activated to facilitate the dissemination of information about the ongoing activities.

E.Stone project, step 2: Defining a catalogue about the state of knowledge of the elements of the research. This important step will have a rapid development in the first phase of the project so it will be used to plan the survey and documentation campaign. This phase will be based on the development of an online database.

The creation of this catalogue will determine the complexity, scientific value, conservation status, risk status and accessibility of each monumental witness.

E.Stone project, step 3: Starting the survey and documentation campaign. The sampling and analysis of geomaterials. During this phase an intensive cartographic survey will start. The operations program will bring the survey units to collect data on various monumental witnesses. Regarding the study of geomaterials in the monumental witnesses, it is expected to develop individual campaigns, with duration of some days for each of the monumental witnesses; in this time the study of the macroscopic characteristics of lithological materials will be done, the material samples will be collected and the forms of alteration detection will be performed. One of the monuments of major importance will be the subject of the survey. A specific workshop / seminar will be organized, it will be opened to the local technicians, operators who handle land management (municipalities, provinces, Soprintendences), scholars, students of schools and the professionals who work in Cultural Heritage Landscape, as architects, engineers, geologists, archaeologists, surveyors, etc.

The operations of this phase will collect a huge volume of data and widen the knowledge of the ongoing works.

E.Stone project, step 4: First morphographic data processing, information management. Once the phase of collecting information will be completed and treated to be early accessible and "cleaned up" set of models, three-dimensional models, digital printouts, photographic and textual data will be made homogeneous according to common standards for the research groups, structured in accessible format. In this phase, data collection will enrich the catalogue database of monumental witnesses with a substantial increase in the state of knowledge about these elements.

broadcasting and public access through the project site. The production strategy for the models will be organized around three main lines of development: models for online viewing with photorealistic features; models for specific information (decay, thematic maps, etc ...); for 3D printing process solutions.

E.Stone project, step 6: Interpretation of data about geomaterials production change and proposals for the preservation of monumental witnesses. The analysis and analysis on the collected data going to store them into the database E.Stone. In detail, all geomaterials which are in the selected monuments will be analyzed in detail, the geochemical characteristics (fluorescence, spectrometry, mineral-petrographic (optical microscopy and X-ray diffraction) and physical characteristics. The analysis of materials will be mainly done on the outcropping parts which formed the area around and not directly on the witness. This will help to define the causes and processes of ongoing deterioration in the each monument. The proposal about intervention strategies for restoration and preservation will be based on the results of this phase.

E.Stone project, step 7: Dissemination of Information. A version for easy consultation catalogue of monumental testimony will be posted on the site of E. Stone. The site will be dedicated to access to three dimensional models and the section about multimedia materials will be inaugurated. The models will be set available for users of E.Stone with the ability to request access to the specimens and recording. The information about the progress of research will be disseminated through the traditional forms of publication and discovery of information from the Internet.

E.Stone project, step 8: Consolidation and management of the Internet space. At the end of the phase 7, the site of E.Stone will continue its growth by implementing a structure to make possible to access the Web geography (Google Earth and similar systems). The areas dedicated to individual monuments and witnesses will enrich the discussion forum with the participation of users of the project that this will contribute by adding their own images, reports, information about the "large stones of Sardinia" in this way users will be more involved and will also give the opportunity to ensure a continuous update about the state of the monuments, forming a sort of "public" monitoring.

E.Stone project, step 9: When the E.Stone website will arrive to complete its tasks and to present exhaustive set of information about the monuments and activities seminars and workshops in the area. Will take place, the techniques, procedures and technologies used for the E.Stone research will be shared with activities on Sardinia Island and with Internet based learning, the online seminars will be structured in such a way as to ensure maximum usability by different users (students, scholars, professionals, technicians). The double activity about learning, with direct visits and online seminars will be done to allow the better dissemination of the results.

1.5 Expected Results

- Creation of an online documentation centre about the "monumental witnesses of Sardinia" that will determine the methods and a reference for the management and processing of this data.

- Sharing and dissemination of knowledge; networking with other groups of experts, to promote and enhance the state of knowledge and the state of dealing with this category of heritage subject.
- Creating the conditions to allow a better approach to conservation and management of this particular stones.

Fig. 2. Schematic view of the E.Stone archive project

2 What Was Done Until Today

At the time for this project/work two stone monuments were examined: the **Monument of Castelsardo** (Anglona, north Sardinia) and the **Mushroom of Carloforte** (San Pietro Island, southwest Sardinia). For the first stone operations in the field activities were set up: 1) laserscan technology complete survey 2) study of the forms of macroscopic alterations and their distribution in the same stone; 3) collection of small sample from the stone monument; 4) experimental determination of geochemical and petrographic characteristics of geomaterials by laboratory analysis using many instruments: helium pycnometer, polarized microscope, electron microscope (SEM), X-ray diffractometer (XRD), X-ray fluorescence spectrometer, etc.; 5) interpretation of first data of laserscan survey and laboratory analysis to evaluate the grade decay and the causes of chemical and physical alteration of the materials. For the second stone, the work activities were limited only to the same points: 1), 2), 3) and 5). The end of this study, based of the results obtained, proposed strategies for the conservation of stone monuments.

of the Sardinian Cenozoic volcanism that forms a magmatic arc running along the western margin of Sardinia and southern Corse microplates (Lecca et al. 1995 and references therein). Volcanic activity, with a calcalkaline affinity *l.s.*, began in the Miocene (around 32.4 My ago; Beccaluva et al. 1985, Savelli 2002 and references therein) producing basaltic and andesitic lavas and ended about 13–11 My ago, reaching a climax between 23 and 17 My. From 23–22 My onwards (Beccaluva et al. 1985 and references therein), highly explosive ignimbritic fissural emissions with a rhyolitic composition occurred simultaneously and with alternating basaltic and andesitic lavas in various parts of the island, mainly along the western graben. This volcanism, whose products crop out in vast areas of Sardinia, is generally related to a subduction of oceanic lithosphere in a N-NW direction along the European–African continental paleomargin that produced the Oligocene rift between Sardinia and Corsica (Cherchi & Montadert, 1982). The volcanic activity preceded and partly accompanied the opening of the western Mediterranean sea through the formation of the Balearic and Algerian basins. This led to a 60° counterclockwise rotation of the Sardinia blocks around a pole located at 42.7° N and 9.6° E (Gueguen 1995).

2.1.1 Anglona Area

The crop out of Elephant ignimbrite is located in the northern part of the Oligocene Sardinian Rift, in Anglona (north Sardinia). In this area three extensional phases can be recognized in this area during a fifteen million year period which spanned the Sardinia continental microplate separation and Western Mediterranean back-arc opening (Sowerbutts, 2000). The first phase, initial late Oligocene extension, produced a half-graben geometry with syn-rift clastic deposits shed locally from fault scarps and highs, passing laterally to lacustrine marlstones. Calc-alkaline volcanic activity subsequently predominated as volcanic centres developed along one half-graben bounding fault, producing voluminous pyroclastic and epiclastic material. Second, mid-Aquitania–early Burdigalian extensional faulting, recognized from the clastic syn-rift stratal wedges, truncated and subdivided the half-graben. These sediments were sealed by a regionally correlated ignimbrite that in turn was affected by late second-phase faulting. Third phase extensional fault movement, which deviated the original fault trend then occurred. The pyroclastic rocks of Anglona show strong heterogeneity, as the result of different eruption conditions and emplacement temperatures (high- to medium- to low-grade ignimbrites). Scatter also depends on the different incidence of pumice, crystal and lithic fragments and matrix. Based on their volcanological characteristics the pyroclastic rocks were divided into two main types: 1) pyroclastic flow deposits with high- to medium-welded grade (including ignimbrites), from poorly to medium porous; 2) pyroclastic fall deposits with low-welded grade (e.g. cineritic products), from medium to strongly porous.

2.1.2 Volcanic Island of San Pietro

The crop out of Mushroom pyroclastic rocks is located on the San Pietro Island (southwestern of Sardinia), completely formed by volcanic rocks belonging to the Cenozoic Sulcis complex (Garbarino et al. 1985; Garbarino et al. 1990). It

gionally extended calc-alkaline activity. In a first, has a calc-alkaline volcanism (less than 15 My) with a character fissural and led to the formation of lavas and ignimbrites deposits to regional extension. In the second phase, there is a type of comagmatic volcanism, with the formation of lavas and peralkaline ignimbrites. The last phase has a calc-alkaline volcanism, with the emplacement of products with textures typical of pyroclastic flow.

The volcanic outcrops in the 'Punta delle Oche' (north island), where the Elephant Stone is located, are ignimbritic rocks (with a calc-alkaline affinity) typical of the latter phase.

2.2 The Elephant Stone

Until laserscan technology, this monument was not really surveyable, the shape, the huge massive structure was a real problem for anyone who would like to realize a serious survey of the whole stone. Thanks to the laserscan technology, the work became as easy as a complete photographic campaign. The older survey, published years before, was about the tombs and was a good work, but it was a classical bidimensional set of drawings, moreover it was aimed to document the ancient graves, and gave no information about the stone in itself. To face this problem, we choose to use a Leica HDS 3000 panoramic scanner, based on the time of flight technology. This was done for two reasons: for first this scanner is capable to gather a very accurate set of points from a very short distance and this was a very important feature to allow the survey of the inner parts of the graves. Secondly this scanner is also capable to gather a very accurate result from a long distance, so it was possible to place the scanner in the upper parts of the hill in front of the stone and take the survey of the upper parts with the same quality of the all the rest of the monument. To obtain a high quality result in the overall operation the laserscan survey was supported by a complete topographical survey, aimed to build a specific network of all the points and targets placed on the monument and absolutely necessary for a clean reconstruction of the single scans. It is important to remember that the use of a topographical survey is not only fundamental because of the high level of accuracy in the registration of the scans and for the better and easier scanning planning; it is important because when a topographical network is planned, a series of permanent points are placed on the ground around the monument. Those special points can remain placed in the site for many years; so if there is the need for a new survey, for example if it happens that the monument is damaged, or for simple monitoring needs, it is possible to have a really accurate comparing of the two surveys according to points which are common to the monument. In facts it would be possible to reply a new survey from any part of the monument. In fact of the laserscan and there will be no need to have a complete new survey, also a single part of the monument can be measured again.

The new survey can be placed exactly on the old one according to the topographical survey, based on some of the old points left on the area during the first survey. In this way, having a reference system based on the general environment, it is possible to monitor any change not only in the shape of the stone but also in its position.

the system of the lower tombs. In this way a good, almost complete coverage of the stone was produced and a large amount of the landscape around the monument was also taken. The overall pointcloud is made of almost twenty five millions of points. The accuracy obtained was around six millimetres for each scan. For the scanner was placed inside the graves the use of a wireless access point was useful to have a remote control of the scanner from the outside.

The topographical network was based on six topographical stations and a survey of the almost forty targets applied on the stone and completely removed at the end of the whole scanning session.

2.2.1 First Data Treatments (Digital Survey Dataset)

The first step in the treatment of the collected data was, as usual, the registration of the single scans in a unique digital model. This was done following two criteria for this kind of survey: for first the single pointclouds were registered in a topographical survey, then they are geometrically compared (using the “close strain” function in Leica Cyclone) to improve the alignment of each pointcloud with the other.

After the registration, the first operation taken on the resulting pointcloud was aimed to produce some simple sections all around the monument and a first simplified, surface model with almost all the occlusion holes fixed.

The whole first treatment was aimed to produce a massive, basic model of the monument. This was a first surface model useful to verify the quality of the data. On the surface digital model a first texturing treatment was applied to allow a better evaluation of the result.

Bringing this model to generic rendering software like Maxon Cinema 4D allowed testing how versatile the obtained model was. Inside this software it was possible to produce a series of rendering views of the digital model and it was possible to create an environment to develop some 3D interactive simulations to allow a better understanding of the first result without the need to share the heavy and hard to manage surface model. The 3D interactive simulations were developed using the Quicktime VR format, a pre-compiled system of visualization capable to bring the perception of a virtual space, with a visualization based on a pre-calculated series of frames. The overall effect is quite good, allowing a good sight on the whole model and a better exploration of the shape of the monument without any need of complex navigation systems. Obviously this was just a simple, first test to verify the quality of the model while the whole project is planned to achieve a more complex structure.

All the process is aimed to produce three main results, each result intended for a different purpose:

- The first result is to have a very high quality survey of the monument and a precious documentation of the conditions of the stone in the November 2011.
- The second result is to produce a set of popular and interpretative models to enhance the possibility of using and sharing of the knowledge about this monument.

2.2.2 Final Data Treatments (Digital Survey Dataset)

The first part of the work over the data treatments clearly showed that an approach developed in a small simplification of the model can give a good looking result. This is interesting only for shape analysis and monitoring purposes.

The time consuming rendering and the impossibility to use the high resolution model for real time access creates the need to face the modelling process in a specific way. So a different approach was chosen, no more direct modelling of the pointcloud, but a process starting from a new rebuilt and optimized polygonal model and then a reconstruction based on the subdivision surface modelling.

The following steps in modelling produced a variable resolution model, allowing to switch gradually from a full resolution representation to a lower polygon count representation, crossing all the intermediate steps of the representation.

The keywords for this process of variable simplification were: edge length, Re-Topology modelling. To greatly enhance the representation two specific digital modelling and texturing solutions were adopted, the classical texture mapping procedure based on the photographic documentation campaign of the site and a specific Normal Mapping procedure based on the information coming from the high resolution model in itself. In this way a whole new model was produced, not only for monitoring or accurate information extraction, but greatly suitable for multimedia representation.

The software workflow for the developing of this new multimedia oriented model was based on Pixlogic Zbrush and Maxon Cinema 4D.

A The whole process was aimed to develop a specific solution for the needs of the items, to produce a method to face and develop high performance models of elephant shaped stones and natural monument, the case study operated on the Elephant Rock demonstrate the full opportunity offered by the method, capable to produce

Fig. 3. Rendering view of the three dimensional digital model of the elephant s

strength that link the procedure to the monuments the stone of the elephant are the natural shape, the human artefacts producing smooth parts in the surveying, the impossible task to define a regular geometric pattern as real solution, the description of the monument; the real need to have a continuous variation of details while changing the representation scale.

2.2.3 The Volcanic Rocks of Elephant Stone

On the geological front of the analysis for this monument the sample collection is just completed and the geological research unit is working on a materials study. All the collected and treated information will be then linked to a pointcloud model to create specific visualizations of the decay conditions of this particular and unique stone.

The Elephant stone are pyroclastic rocks with welded from high- to medium- and a strong heterogeneity, due to variable presence of lithic fragments, (with various size, until to decimetre) and pumice into the matrix of stone. These rocks have an open porosity ranging about from eight to 25% (in litho-clasts and fragments of lava-like ignimbrites with strongly welded); the matrix of the pyroclastic rocks, characterized from low- to medium-welded grade, the open porosity varies about from 15% (in unaltered matrix) to 45% (in altered matrix). In the sample strongly altered, the porosity comes to 50%.

What happens inside the vitreous matrices, already characterized by porosity in the original (Macciotta et al. 2001). Microscopic analysis indicated that the ignimbrites of Elephant stone have a porphyritic structure (with porphyritic index between 1 and 2) with phenocrysts of opaque minerals (magnetite and/or titanomagnetite), plagioclase $\pm$ clinopyroxene and rare quartz. Actually, further analyses are in progress.

2.3 The Mushroom Stone

About the Carloforte Mushroom Stone it is possible to say “we just arrived to see a large part of the stone remembering the “umbrella” of the mushroom stone” in March 2010, while a survey was planned for the end of May 2010. The mushroom is an ancient stone completely developed by the action of the atmosphere (e.g. wind with marine aerosol, meteoric water, thermoclastism, etc.; see section 2.4 Decay of stone witnesses) over a very articulated volcanic stone.

A particular alteration process has produced a kind of “umbrella” over a mushroom rock. The reasons of the fall are probably due to a natural issue, but this simply outlines how urgent is a survey of these fragile system. So, even if in its hardly shape, the survey was done in June 2010.

The complex shape of this stone and the demanding walk needed to reach it with all the instruments, made us prefer to operate with a light phase-shift scanner Cam2 Faro Photon 80. The survey was based on spherical target system, to reconstruct each single scan into a unique model.

Fig. 4. The digital survey of the mushroom stone

The scans were taken in three series, a first series with the scanner placed on the ground, a second series with the scanner on the tripod at medium elevation, and a third series with the scanner on the tripod at the maximum elevation.

In this way it was obtained a very good coverage of the whole stone and of the fallen fragment, mainly too large and heavy to try to turn them on the other side. For a scan of the opposite side, it was preferred to avoid this fearing to produce further damage. A complete collection of sample and a first geological documentation of the whole stone and of the area around it was made.

A study about the various forms of macroscopic alterations was made on the gathering of small samples from monument stone.

All the digital survey data and all the geological data (physical, geochemical, petrographic characteristics of geomaterials) are now under development and in the next months it is planned to investigate what is effectively happened to the collapse of the umbrella and to define a clear picture of the state of decay of the

2.4 Decay of Stone Witnesses

Aside from the late-stage syngenetic alteration processes, the pyroclastic Elephant and Mushroom stones are greatly affected by epigenetic alteration.

tion. In the first case (a), late-stage chemical alteration processes transform the original paragenesis to a greater or lesser extent, altering the mineral associations of the glass (with incipient devitrification) with the formation of new secondary minerals. In the second case (b), the mechanisms of physical degradation are probably related by: 1) presence of soluble salts (from soil or atmosphere) that exert crystallization pressure into open pores of stone; 2) differential thermal dilatation in the normal day range of temperature and solar radiation; 3) absorption/desorption of meteoric water (Columbu et al. 2008) or water from soil or air moisture. Water hydration/dehydration of hygroscopic mineral (e.g. salts). Nevertheless, the decay mechanisms of these two stone witnesses are different.

This depends, on the one hand, by different microclimatic conditions and exposure of stone surface to atmospheric agents and, on the other hand, by different mineralogical and mineral-petrographic characteristics of geomaterials.

In fact, the Mushroom stone is located near to the sea (about 200 metres), while Elephant stone is located about 3.3 kilometres from the sea. Moreover, the petrographic rocks of Elephant have different petrographic features and then are more heterogeneous, due to the greater presence of lithic fragments, lithoclasts into the matrix. Elephant and Mushroom monuments have diverse macroscopic forms of decay (decohesion, exfoliation, alveolation, differential degradation) and present different crypto- and epi-florescence.

These macroscopic forms are distributed differently in the external surface of the stone. In the Elephant the decay processes are mainly concentrated: 1) in the lower part of the big block of stone (that rests directly on the soil and is characterized by the presence of circulating water solution by capillarity), with strong backward exfoliation profile of stone; in this zone differential degradation, with enucleation of lithoclasts and lithoclasts, and exfoliation are the principal alteration macroscopic forms. On the top and median parts of Elephant stone that exposure to the SE-S-SW where there is more frequent the solar radiation; in these zones strong alveolation processes and physical degradation are more present, due to the differential thermal dilatation and diurnal cycles of moisture absorption/desorption; the alveolation is present mainly under the 'proboscis' of Elephant and into the outer room of 'Elephant's jaws'. In the other outer parts of the monument with exposure to the NE-NW, biological deterioration agents (e.g. moss, lichens, etc.). In the Elephant stone, similar processes were observed. XRD analysis performed on the collected samples from the external surface of parts of monument exposed to south and to west, indicated the presence of hematite, consequently to alteration of Fe-Mg minerals.

Diffraction analysis on other samples taken on the outer crust of the monument indicated considerable amounts of gypsum.

It is planned to investigate which is the origin of this phase; probably partially from meteoric precipitations because these have often a small quantity of gypsum; this is formed by interaction of sulphur dioxide, acidic rainwater and atmospheric particles of CaCO_3 .

Fig. 5. Macroscopic alteration form of alveolation on the surface under the proboscis of phant stone of Sedini with the presence of salts within to the vitreous matrix of volcanic

In the Mushroom stone the decay (that produced a particular kind of “u” shape) shows: 1) exfoliation in the stem of the mushroom; this alteration form is characterized: a) where there are mechanisms of water wash-out, that remove consolidated flakes produced by other alteration processes, b) on face of stem exposed to wind come from the sea. The meteoric water run along the stem by fractures and fissures present into the top head of mushroom; on the base of first mushroom

Fig. 6. Physical decay of stem of Mushroom stone of Carloforte with exfoliation produced by mechanisms of absorption/desorption and wash-out of meteoric water

Fig. 7. Macroscopic alteration form of alveolation under the head of Mushroom stone of C

observation, probably parts of head collapsed due to the presence of these fr articulated alveolation (that penetrated until about 8 cm from surface below head where coexist two important factor of decay: a) physical decohesion therefore to continue mechanisms of absorption/desorption of meteoric water humidity, containing a small quantities of seawater (with salt), (note: the thickness of mushroom is about maximum 30 cm), b) turbulence induced near the mushroom by the sea-wind, which can frequently remove the thin flakes of weathered.

In the near future it is planned to investigate what is happened to cause collapse of the “umbrella” (with determination of properties of resistance physical-mechanical of stone under stress of own lithostatic load) and to define actually state of this natural stone monument.

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