E.Stone, an archive for the Sardinia monumental witnesses

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Abstract. The "E.Stone" project is based on the survey, documentation investigation and physical, geochemical and petrographic characterisation of the great 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 "state 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 any material of the original item.

Keywords: Stones, Sardinia, Landscape, Laserscan, Survey, Geology, Decay, 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: the natural processes and the anthropic processes. These manifestations taken different times and conditions to evolve; some of these mutations are clearly visible in a human 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, sculpted by the sea and by the wind, it comes immediately clear how long it will remain at its place and in its conditions if compared to a bare foot impression left by a man on the sand: the 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 time we are able to damage or even completely demolish the whole patrimony of monumental rocks which is richly present in the Sardinia Island. Sardinia is the larger Island in the Mediterranean Sea and is the place some meaningful natural masterpieces, in some

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cases this curious and fascinating stones are enriched by the work of men (like it is for the Elephant Stone where some “Domus de Janas”/”Fairy House”, a specific kind of ancient tombs, were carved in the prehistoric age). The fact that Sardinia Island shows very ancient rocks, with some formation coming from an age far more then 500 millions of years from our time, create a great emphasis about these stones, giving to the observer 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 Sardinia Monumental Witnesses”, the reason for this choice are first of all linked to the specific approach to the research, which is based on advanced digital tools, so the “E” of “Electronic” is placed in front of the word “Stone” written in English also in the Italian version of the name to underline the intention to share and to disseminate these contents at an international level. The term “Witnesses” is used according to the word often used in geology to refer to the rocks testifying a previous condition. The use of the term "monuments" should be understood in its value described in the definition of the Treccani vocabulary: "[...] to indicate what, for its size, is giving an impression of grandeur and solemnity [...]".

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

1.2 Documentation and Dissemination

To allow the preservation of these monuments the first step is knowledge, but not only as a theoretical work ending in itself but as a passage of awareness based on a dissemination process. The tools available today make it easier and more versatile than ever before. In this way, this particular monument will be treated like they deserve, like any other monument from the earth heritage, giving to the "monumental witnesses" their right value and preserving their memory from the risk of deterioration and decay, creating the right conditions for knowledge and protection.

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

Procedures based on a wide digital approach, from a massive use of laserscan survey to the digital modelling aimed to produce multimedia contents, can simultaneously 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 the territory that they have all around.

The possibility to use both the current prototyping techniques to produce partial or total reproduction of these items in different material can operate in three main areas: the creation of "spare parts" for the monument, the reconstruction of the monument, and the easy and effective deployment in museums, exhibition areas or schools where the visitor will be able to touch the shapes of the monument. (and this will be a great occasion for the blind or visually impaired as well as for the people with normal sight), in this way, developing well oriented models, it will be possible to disassemble, to understand, 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 any catastrophic issue can take place. Operationally, all the monuments will be studied in detail about their minero-petrographic and physical characteristics, including various forms 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 of one year, at the starting phase of the project it will be immediately activated an Internet space to allow collaboration between the research teams. Within the first six months of activity the main campaigns of survey and documentation will start, inclusive of sampling and study of geomaterials from the monuments, the archive will begin to be formed immediately and simultaneously, together with the progress of the treatment 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 Castelsardo (surveyed in 2006), the Bear stone in Palau, the remains of the turtle stone and of the other stones with zoomorphic or phytomorphic shapes around San Teodoro, the remains of the Columns and Mushroom stone (this one surveyed in 2010) on the island of San Pietro (Carloforte), the red rocks of Arbatax, the "Pipe organ" of Guspini, Punta Goloritzè (Baunei), S'Archittu (the small arch) near Santa Caterina Pittinuri (Cuglieri), the monolith (also know as “the shaped cake”) on the Pulchiana Mountains in the Gallura area, the San Giorgio’s staircase in Osini. For each of these natural monuments it will be also catalogued and stored all the data on the compositional 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 units, the use of phase-shift or time of flight technology, will be choose according to the specific 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 vantage of the phase shift solution, which is capable to measure a range equal to a full dome (320 vertical degree and 360 horizontal degree) with an accuracy up to four millimetres collecting up to 200.000 points for each operative second, make this kind of laserscan very interesting a reduce the operative time, but when the operative range 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 tools 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 stages of processing and analysis. The main steps of processing the data will be made up by the development of traditional two-dimensional representations, views zenith, plans, 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 aimed to preserve the greatest correspondence between the collected points and the final result. These models will be useful for the analysis and the study about the surfaces and the shape of the object, they will be used to study specific functions and, when mapped with photographs, to create images of graphics rendering.

Starting from these models, a complex process of treatment of the data will produce a new series of three-dimensional digital models, designed for online viewing 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. In this sense, the models allow users to access downloadable versions of the scaled digital model, using 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 collection of the monumental witness. Any school or association in the United States, South America, Australia or Japan, will be able to receive digital data a start to build scale models or even real-sized models. This solution will allow also the access to this kind of monument to blind and visually impaired people, they will be able to experience and understand the shapes of these stones thanks to tactile models.

Considering the fact that three dimensional printing may still result a difficult operation to many users, the models will be prepared in a sort of “assembly kit” based on a sequence of sections, laser engraved with specific machines or simply printed with a common printer on paper to be transferred to appropriate thickness and then cut manually. So, starting from the digital model and following simple installation 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 all 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 videoconferencing will be possible to solve the main participation trouble among the groups. At this stage, only active members of research teams, will access to the complete materials under development. However a small part of the whole research, set up 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 on 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 interest, conservation status, risk status and accessibility or each monumental witness.

E.Stone project, step 3: Starting the survey and documentation campaign, on-site sampling and analysis of geomaterials. During this phase an intensive campaign of survey will start. The operations program will bring the survey units to operate on various monumental witnesses. Regarding the study of geomaterials in the monumental witnesses, it is expected to develop individual campaigns, with duration up to some days for each of the monumental witnesses; in this time the study about the macroscopic characteristics of lithological materials will be done, the material samples will be collected and the forms of alteration detection will be performed. When 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 technical operators who handle land management (municipalities, provinces, Soprintendenze), scholars, students of schools and the professionals who work in Cultural Heritage and Landscape, as architects, engineers, geologists, archaeologists, surveyors, etc..

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

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

E.Stone project, step 5: The second stage of data processing (advanced models, physical model development). At this stage the treatment of data collected will be in its advanced phase, with the production of the first models aimed to multimedia broadcasting and public access through the project site. The production structure for the models will be organized around three main lines of development models: for online viewing with photorealistic features; models for specific information viewing (decay, thematic maps, etc ...); for 3D printing process solutions.

E.Stone project, step 6: Interpretation of data about geomaterials processes of change and proposals for the preservation of monumental witnesses. The handling and analysis on the collected data going to store them into the database system of E.Stone. In detail, all geomaterials which are in the selected monuments will be studied in detail, the geochemical characteristics (fluorescence, spectrometry, X-ray), mineral-petrographic (optical microscopy and X-ray diffraction) and physical characteristics. The analysis of materials will be mainly done on the outcropping geological parts which formed the area around and not directly on the witness. This study will define the causes and processes of ongoing deterioration in the each monument. A 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 reference catalogue of monumental testimony will be posted on the site of E. Stone. The section 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 and the progress of research will be disseminated through the traditional forms of research and discovery of information from the Internet.

E.Stone project, step 8: Consolidation and management of the Internet dedicated 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 resources (Google Earth and similar systems). The areas dedicated to individual monumental witnesses will enrich the discussion forum with the participation of users outside 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 in the site and will also give the opportunity to ensure a continuous update about the condition of the monuments, forming a sort of "public" monitoring.

E.Stone project, step 9: When the E.Stone website will arrive to complete the main tasks and to present exhaustive set of information about the monuments a series of 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 the 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 workshops 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.

- Creating an archive based on the logic of sharing and the continuous enrichment of the catalogue, integrating it with the continuity of training experiences like degree Thesis and Ph.D.
- Sharing and dissemination of knowledge; networking with other groups of scholars, to promote and enhance the state of knowledge and the state of the art in dealing with this category of heritage subject.
- Creating the conditions to allow a better approach to conservation and restoration of this particular stones.

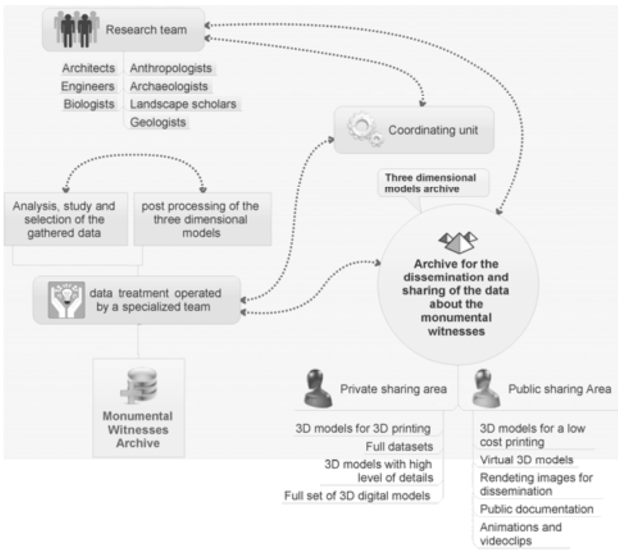

Fig. 2. Schematic view of the E.Stone archive project

2 What Was Done Until Today

At the time for this project/work two stone monuments were examined: the Elephant of Castelsardo (Anglona, north Sardinia) and the Mushroom of Carloforte (north of San Pietro Island, southwest Sardinia). For the first stone operations in the following activities were set up: 1) laserscan technology complete survey 2) study of various forms of macroscopic alterations and their distribution in the same stone; 3) removal of small sample from the stone monument; 4) experimental determination of physical, geochemical and petrographic characteristics of geomaterials by laboratory analysis, using many instruments: helium pycnometer, polarized microscope, electronic microscope (SEM), X-ray diffractometer (XRD), X-ray fluorescence spectrometer (XRF), etc.; 5) interpretation of first data of laserscan survey and laboratory analysis; 6) evaluate the grade decay and the causes of chemical and physical alteration of geomaterials. For the second stone, the work activities were limited only to the following points: 1), 2), 3) and 5). The end of this study, based of the results obtained, will be proposed strategies for the conservation of stone monuments.

2.1 Geomaterials and Geologic Settings

Planning The Elephant and the Mushrooms stones are big blocks of ignimbritic rocks of the Sardinian Cenozoic volcanism that forms a magmatic arc running along the western margin of Sardinia and southern Corse microplates (Lecca et al. 1997 and references therein).Volcanic activity, with a calcalkaline affinity l.s., began in Oligo-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, showing 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 dacitic-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 with a subduction of oceanic lithosphere in a N-NW direction along the European continental paleomargin that produced the Oligocene rift between Sardinia and Provence (Cherchi & Montadert, 1982). The volcanic activity preceded and partly accompanied the opening of the western Mediterrean sea through the formation of the Provençal Balearic and Algerian basins. This lead to a 60° counterclockwise rotation of Corsica-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 of the Oligo-Miocene 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 Corsica–Sardinia continental microplate separation and Western Mediterranean back-arc basin opening (Sowerbutts, 2000). The first phase, initial late Oligocene extension created a half-graben geometry with syn-rift clastic deposits shed locally from fault-bounded 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 phase mid-Aquitanian–early Burdigalian extensional faulting, recognized from localized clastic syn-rift stratal wedges, truncated and subdivided the half-graben. The syn-rift sediments were sealed by a regionally correlated ignimbrite that in turn was offset by late second-phase faulting. Third phase extensional fault movement, which reactivated the original fault trend then occurred. The pyroclastic rocks of Anglona show a 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 the pyroclastic rocks were divided into two main groups: 1) pyroclastic flow deposits with high- to medium-welded grade (including lava-like 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). During the final phases of Cenozoic magmatism (Arana et al. 1974), three important episodes of volcanism occurred in the area of San Pietro, characterized by the eruption of a peralkaline rhyolitic lavas and ignimbritic complex, interlayered in the products of a regionally extended calc-alkaline activity. In a first, has a calc-alkaline volcanism (older than 15 My) with a character fissural and led to the formation of lavas and ignimbritic deposits to regional extension. In the second phase, there is a type of comenditic volcanism, with the formation of lavas and peralkaline ignimbrites. The last phase will have a calc-alkaline volcanism, with the emplacement of products with textural aspects typical of pyroclastic flow.

The volcanic outcrops in the 'Punta delle Oche' (north island), where the mushroom stone is located, are ignimbritic rocks (with a calc-alkaline affinity l.s.,) formed in the latter phase.

2.2 The Elephant Stone

Until laserscan technology, this monument was not really surveyable, the strange shape, the huge massive structure was a real problem for anyone who would try to realize a serious survey of the whole stone. Thanks to the laserscan technology this work became as easy as a complete photographical campaign. The older survey, published years before, was about the tombs and was a good work, but it was a simple, classical bidimensional set of drawings, moreover it was aimed to document only the ancient graves, and gave no information about the stone in itself. To face this work we choose to use a Leica HDS 3000 panoramic scanner, based on the time of fly 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 allow an 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 special 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 process and for the better and easier scanning planning; it is important because when the 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 a part of 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 external to the monument. In facts it would be possible to reply a new survey from any new position of the laserscan and there will be no need to have a complete new survey while 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 digital survey. In this way, having a reference system based on the general environment, allows to monitor any change not only in the shape of the stone but also in its position on the ground. The survey was completed in two single days, twelve scan stations were operated, and the whole work was organized in three main development paths, one going around the stone, one for the long distance stations and a final one crossing inside 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 collected points. The accuracy obtained was around six millimetres for each scans. When the scanner was placed inside the graves the use of a wireless access point was very useful to have a remote control of the scanner from the outside.

The topographical network was based on six topographical stations and took the 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 all the single scans in a unique digital model. This was done following two classical criteria for this kind of survey: for first the single pointclouds were registered over the topographical survey, then they are geometrically compared (using the "cloud constrain" function in Leica Cyclone) to improve the alignment of each pointcloud over the other.

After the registration, the first operation taken on the resulting pointcloud were 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 collected data. On the surface digital model a first texturing treatment was applied to have a better evaluation of the result.

Bringing this model to generic rendering software like Maxon Cinema 4D allowed testing how was versatile the obtained model. Inside this software it was possible to produce a series of rendering view of the digital model and it was possible to use this environment to develop some 3D interactive simulations to allow a better sharing of the first result without the need to share the heavy and hard to manage surface 3D model. The 3D interactive simulations were developed using the Quicktime VR output, a pre-compiled system of visualization capable to bring the perception of a full 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 quick 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 survey, while the whole project is planned to achieve a more complex structure.

All the process is aimed to produce three main results, each result integrates the other:

- The first result is to have a very high quality survey of the monument, useful as a precious documentation of the conditions of the stone in the November 2006.
- 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 important monument.

- The third result is to build a rich set of information, which will be available as a starting point for the enhancement of the knowledge of this ancient patrimony and as an incentive to the research about this awesome theme.

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, but it 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 new and specific way. So a different approach was chosen, no more direct modelling from 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, capable to switch gradually from a full resolution representation to a lower polygon representation, crossing all the intermediate steps of the representation.

The keywords for this process of variable simplification were: edge loop modelling, Re-Topology modelling. To greatly enhance the representation two advanced digital modelling and texturing solutions were adopted, the classical texture Unwrap procedure based on the photographical documentation campaign of the stone 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 aimed to monitoring or accurate information extraction, but greatly suitable for multimedia and 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 this kind of items, to produce a method to face and develop high performance models of rich shaped stones and natural monument, the case study operated on the Elephant Stone demonstrate the full opportunity offered by the method, capable to produce a high

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

level documentary model, useful to create an accurate memory of the real shape of the item and a versatile multimedia model, capable to adapt its level of detail to the representation scale and to the environment in which it will be inserted to. The points of strength that link the procedure to the monuments the stone of the elephant represent are the natural shape, the human artefacts producing smooth parts in the stone carving, the impossible task to define a regular geometric pattern as real solution to the description of the monument; the real need to have a continuous variation of the level 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 some meaningful sample collection is just completed and the geological research unit is working on the materials study. All the collected and treated information will be then linked to the 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-grade and a strong heterogeneity, due to variable presence of lithic fragments, lithoclast (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 lithic fragments of lava-like ignimbrites with strongly welded); the matrix of these pyroclastic rocks, characterized from low- to medium-welded grade, the open porosity varies about from 15% (into unaltered matrix) to 45% (in altered matrix). In some sample strongly altered, the porosity comes to 50%.

What happens inside the vitreous matrices, already characterized by poor welding original (Macciotta et al. 2001). Microscopic analysis indicated that the ignimbrite of Elephant stone have a porphyritic structure (with porphyritic index between 10÷15%) with phenocrysts of opaque minerals (magnetite and/or titanomagnetite), plagioclase, ± 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 arrive too late” a large part of the stone remembering the “umbrella” of the mushroom collapsed 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 atmospheric agents (e.g. wind with marine aerosol, meteoric water, thermoclastism, etc.; see paragraph 2.4 Decay of stone witnesses) over a very articulated volcanic stone.

A particular alteration process has produced a kind of “umbrella” over a more solid rock. The reasons of the fall are probably due to a natural issue, but this simply underlines how urgent is a survey of these fragile system. So, even if in its hardly damaged 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 like the Cam2 Faro Photon 80. The survey was based on spherical target system, to allow the reconstruction of each single scan into a unique model.

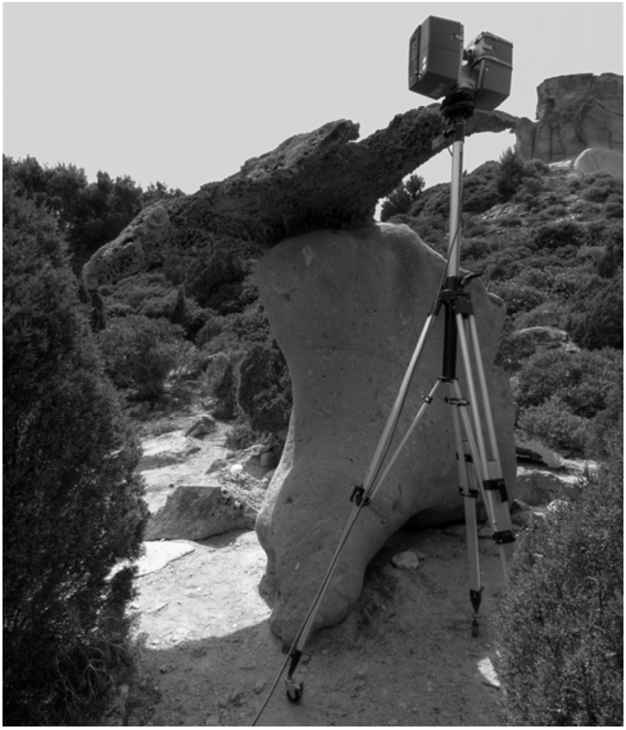

Fig. 4. The digital survey of the mushroom stone

The scans were taken in three series, a first series with the scanner placed directly 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 to try a scan of the opposite side, it was preferred to avoid this fearing to produce any 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 site with the gathering of small samples from monument stone.

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

2.4 Decay of Stone Witnesses

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

Decay processes are mainly concentrated in the vitreous matrix of pyroclastites, characterized by a higher porosity and low degree of welding, and carry on two different ways: (a) geochemical and mineralogical alteration and (b) physical degradation. In the first case (a), late-stage chemical alteration processes transformed partially the original paragenesis to a greater or lesser extent, altering the mineral assembly and the glass (with incipient devitrification) with the formation of new secondary minerals. In the second case (b), the mechanisms of physical degradation are principally related by: 1) presence of soluble salts (from soil or atmosphere) that exert a crystallization pressure into open porous of stone; 2) differential thermal dilatation induced by normal day range of temperature and solar radiation; 3) absorption/desorption in the stone of meteoric water (Columbu et al. 2008) or water from soil or air moisture; 4) 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 physical and mineral-petrographic characteristic of geomaterials.

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

These macroscopic forms are distributed differently in them extern surface of each stone. In the Elephant the decay processes are mainly concentrated: 1) in the basal part of the big block of stone (that rests directly on the soil and is characterized by presence of circulating water solution by capillarity), with strong backward vertical profile of stone; in this zone differential degradation, with enucleation of lithic fragments and lithoclast, and exfoliation are the principal alteration macroscopic forms; 2) on the top and median parts of Elephant stone that exposure to the SE-S-SW-W and 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 absortion/desorption; the alveolation is present mainly under the ‘proboscis’ of Elephant and into the outer room of ‘domus de janas’. In the other outer parts of the monument with exposure to the NE-N, there are bio-deterioration agents (e.g. musk, lichens, etc.). In the Elephant stone, oxidation processes were observed. XRD analysis performed on the collected samples take on extern surface of parts of monument exposed to south and to west, indicated the presence of hematite, consequently to alteration of Fe-Mg minerals.

Diffractometric analysis on other samples taken on the outer crust of precipitation indicated the considerable amounts of gypsum.

It is planned to investigate which is the origin of this phase; probably, it come 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 CaCO3.

Inside the 'domus de janas' of Elephant stone, precipitation crust are present in surface of wall and ceiling of the small rooms. These crusts will be studied for determination the composition of secondary phases.

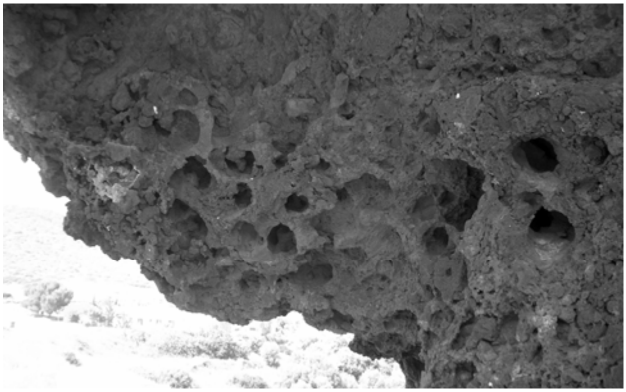

Fig. 5. Macroscopic alteration form of alveolation on the surface under the proboscis of Elephant stone of Sedini with the presence of salts within to the vitreous matrix of volcanic rock

In the Mushroom stone the decay (that produced a particular kind of "umbrella") shows: 1) exfoliation in the stem of the mushroom; this alteration form is concentrated: a) where there are mechanisms of water wash-out, that remove constantly thin flakes produced by other alteration processes, b) on face of stem exposed to the north-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 macroscopic

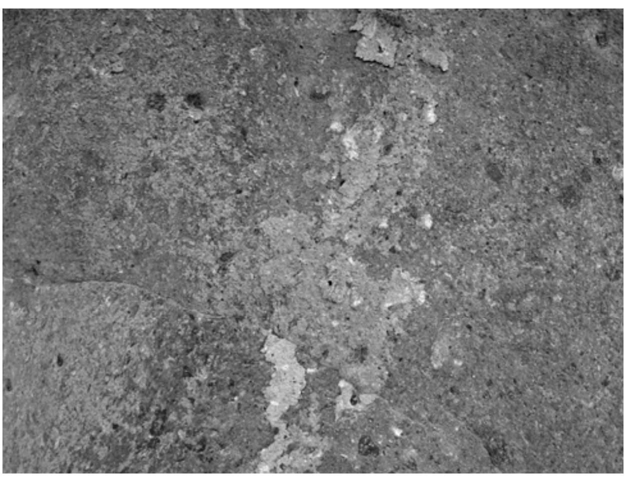

Fig. 6. Physical decay of stem of Mushroom stone of Carloforte with exfoliation processes by mechanisms of absorption/desorption and wash-out of meteoric water

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

observation, probably parts of head collapsed due to the presence of these fissures; 2) articulated alveolation (that penetrated until about 8 cm from surface below) under head where coexist two important factor of decay: a) physical decohesion of stone, therefore to continue mechanisms of absorption/desorption of meteoric water or humidity, containing a small quantities of seawater (with salt), (note: the thickness of head of mushroom is about maximum 30 cm), b) turbulence induced near to the mushroom by the sea-wind, which can frequently remove the thin flakes of stone weathered.

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

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