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Cover photo : Keir Vaughan-Taylor on Lake 2, Koonalda Cave, Nullarbor Plain. (Photo by Kevin Moore)

Back Cover : The Khan and Beagum in Kubla Khan Cave Tasmania (Photo by Garry K. Smith)

Inside The Glaciers Project: Laser Scanning Of The Grotta Del Gelo (Mount Etna, Italy)

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Abstract

As part of activities of the "Inside the Glaciers" project, managed by an Italian team of speleologists and geologists with the purpose of studying several ice-caves in Europe and South America, a research campaign was recently carried out in Mount Etna (Sicily, Italy). This volcano is the highest active in Europe and hosts more than 200 caves including Grotta del Gelo (Ice Cave) which is located on the Northern flank of Mount Etna at an altitude of about 2040 m a.s.l. This cave was formed during the Etna's long and most destructive eruption dated from 1614 to 1624 and is one of the most famous because it hosts a small glacier, maybe the southernmost of the Northern hemisphere.

Aim of this project was to realize a detailed survey of Grotta del Gelo using a Leica HDS 7000 terrestrial laser scanner in order to acquire precise data measurements of the ice deposits. This survey was the first step of a monitoring project that will be developed in the next years in collaboration with the Etna Regional Park, the Sicilian Regional Speleological Federation and the Centro Speleologico Etneo of Catania which by many years are involved in the topographic monitoring of this particular cave.

The proposed article introduces the methods used for this first laser scanning survey campaign of Grotta del Gelo and the results obtained.

Keywords: Laser scanning; 3D modelling; ice caves; geomorphology; documentation

1. Introduction

Starting in October 2014 with the 1° International Glacier-Caving Camp on the Gorner Glacier (Zermatt, CH), the main objectives of the "Inside the Glaciers" (ITG) Project are to organize scientific expeditions and research campaigns related to the exploration and study of glacier-caves and ice-caves all over the world.

New technologies are widely used during these projects, especially in the field of 3D mapping.

In the last decennia Terrestrial Laser Scanning (TLS) has been increasingly applied for the survey of underground environments including natural caves. One of the most interesting application of TLS in caves is the possibility to monitor underground ice deposits.

For this reasons, in this study we applied TLS surveying to the Grotta del Gelo (Mount Etna, Southern Italy) to measure the glacial mass present inside this particular cave.

The Etna area has been protected since 1987 by the Sicilian Regional Government as a Regional Park which covers an area of 59,000 hectares divided into an "A" zone of total reserve area (19,000 hectares), a "B" zone of general reserves (26,000 hectares) and a pre park area of about 14,000 hectares.

The Grotta del Gelo opens in the "A" zone of the Etna Park and the authority's permission was therefore necessary for these research activities. These, entirely non-invasive, were carried out minimizing the number of speleologists and hours of permanence inside the cave.

Figure 1. Scanning operations with the laser scanner inside the cave. The tripod was fixed with ice screws to scan on the ice floor (Photo: Alessio Romeo).

2. Geology Of The Area And Cave Description

Mount Etna lies in a complex geodynamic zone due to the convergent margin between European and African plates, the subduction of the Ionian slab under the Aeolian arc and to the Hyblean-Maltese escarpment, which represents the boundary between the subducting Ionian plate (oceanic crust) and Sicily (continental crust). Located at an altitude of about 2.040 m a.s.l., Grotta del Gelo is well known among Mt. Etna volcanic

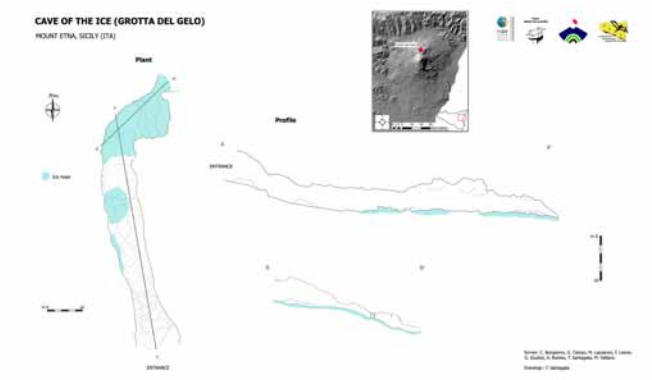

Figure 2. Topographic plant and section of the cave derived from point cloud digitizing. The ice part are highlighted in cyan (Photo Tommaso Santagata).

caves due to the presence of a stack of ice on it's walls and floor which occupies about the 30% of the cave's volume. This small lava tube of less than 125 m long shows only one entrance of big dimensions (roughly 10 m wide and 5 m high). The cave is SW oriented and was formed by the lava flows called the "Lave dei Dammusi" during the Etna's longest eruption that affected it's northern flank from 1614 to 1624 A.D. Lava from this eruption has flowed in different channels, often overlapped, that have formed several lava tubes.

The cave seems to work as a cold trap where the snow coming from the outside is able to preserve and feed the glacier. Grotta del Gelo plays a primary scientific and climatological role due to the evolution of the ice mass. The first important monitoring project was carried out from 1996 to 1999 performing a series of studies managed by the Etna Park in collaboration with speleologists of the Centro Speleologico Etneo and volcanologists from the Italian National Institute of Geophysics and Volcanology to monitor temperature and humidity by means of automatic micro data loggers and measuring the variations in height of the ice deposits by measuring some fix points marked on the ceiling and on the walls of the cave.

3. Laser Scanning Survey

Laser scanners are measuring instruments able to automatically acquire spatial coordinates of a region or a surface of an object. This technology is based on the emission and reception of a light beam that emits their own electromagnetic radiation and collects and measures the reflected emissions with high accuracy. For this work a Leica HDS7000 laser scanner was used. This device is equipped with a CLASS 1 laser with a flow range of 187 m and a wavelength of 1.5 micron. The survey phase was completed with the acquisition of 17 scans of which 11 in the area of the cave with the floor covered by ice. Scanning operations were performed in less than 5 hours starting the survey from the inner parts of the cave. To put the instrument in the areas of the cave with the floor covered by ice, it was necessary to fix the tips of the tripod with the head of ice screws that were positioned inside the ice trying to maintain the correct angle in order to put the scanner at the right level.

The data was processed to give a three-dimensional model of the entire cavity in the form of point cloud from which it was possible to derive a triangulated mesh model and perform morphological analysis in particular on the glacial deposit.

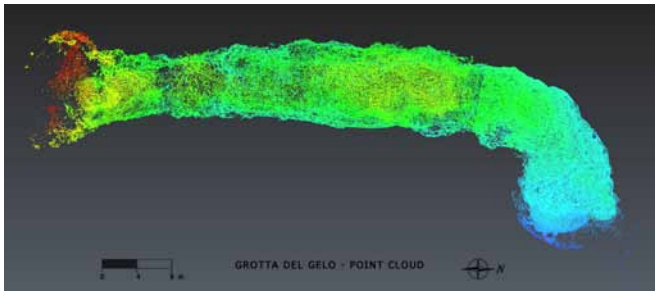

Figure 3. Point cloud 3D model of the Grotta del Gelo obtained by the union of the 17 scans realized (Photo Tommaso Santagata).

4. Data Analysis And Results

Through digitization of the point clouds, 2D and 3D polylines were extracted to produce different types of topographical works (plant, sections, contour lines), that will serve as a fundamental basis for all future monitoring of the ice mass present into the cave. The overall length of the entire cave calculated is of about 120 m with a vertical drop of 12 meters with the height of the ceilings vary from a few cm to 7 m. The width of the cave walls is substantially constant on all the 7 m along all the lava tube, except in the area near the entrance where the width is more than 12 m. The total volume of the cave, calculated on the basis of the mathematical model given by the triangulation of individual points from which it was possible to reconstruct the surface of the cavity, is reported to be 4,107 m^3. As regards the glacial deposit present in the terminal part of the cave, the development calculated is higher than 30 m in length with a few cm from the end part to the heights of the cavity ceiling variables up to 6.30 m in the central part of the cavity and a volume of approximately 1,500 m^3.

5. Conclusions And Future Perspectives

Laser scanners offer many advantages in comparison to more traditional surveying techniques, in fact these devices are able to deliver a very high amount of precise measured points quickly, and making it possible to realize 3D models.

The TLS survey of Grotta del Gelo have allowed us to calculate the precise volume of the ice mass present in this cave and obtain a high amount of information that will be used in the next years to study the ice mass.

Further analysis on the data have allowed us to evaluate the presence of the ice inside the cave by the possibility of digitizing the surrounding environment in a very short time.

This first survey campaign represents just the first step of a monitoring project that will be developed in the next years with the aim to study the evolution of the ice deposit inside this cave.

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