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February 2009

## Naica Caves

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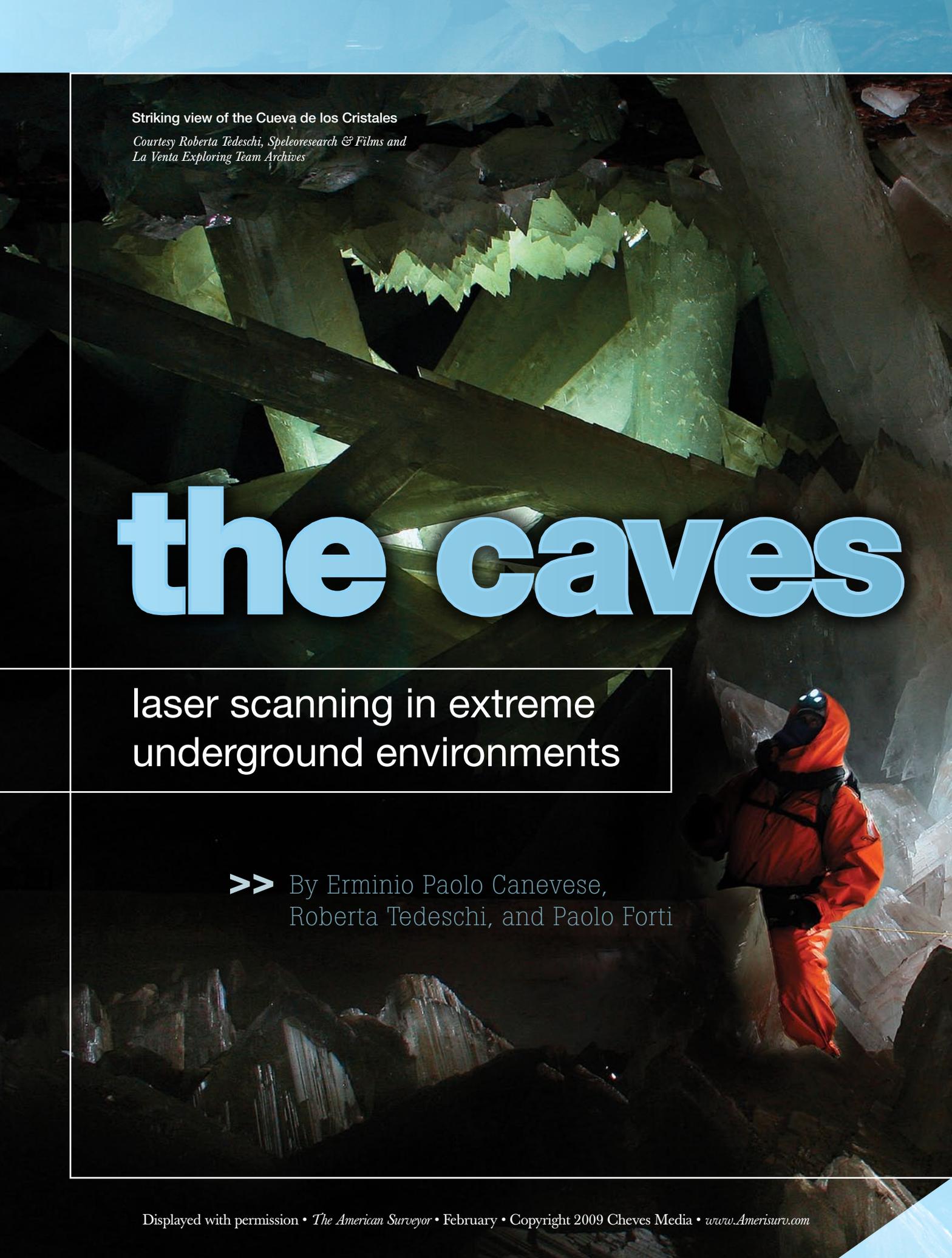
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Striking view of the Cueva de los Cristales

*Courtesy Roberta Tedeschi, Speleoresearch & Films and  
La Venta Exploring Team Archives*

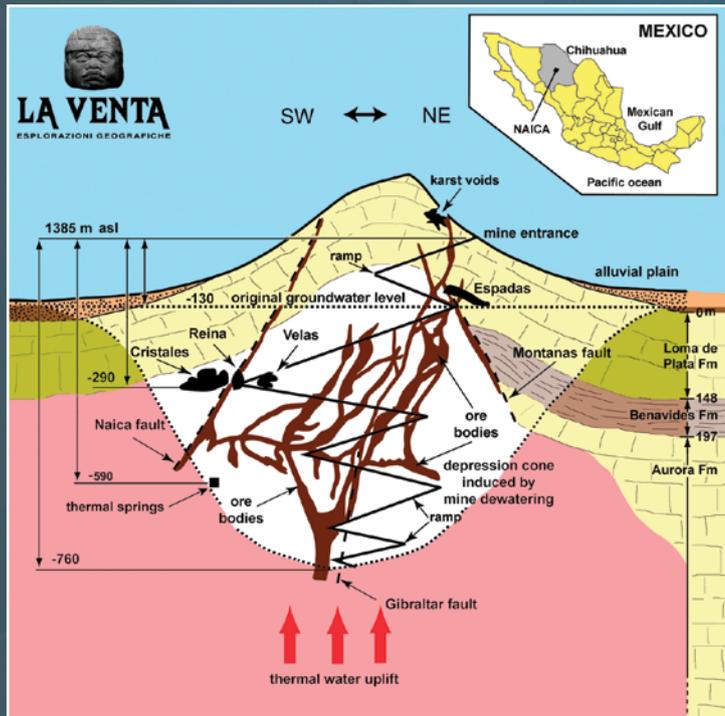
# the caves

laser scanning in extreme  
underground environments

>> By Erminio Paolo Canevese,  
Roberta Tedeschi, and Paolo Forti

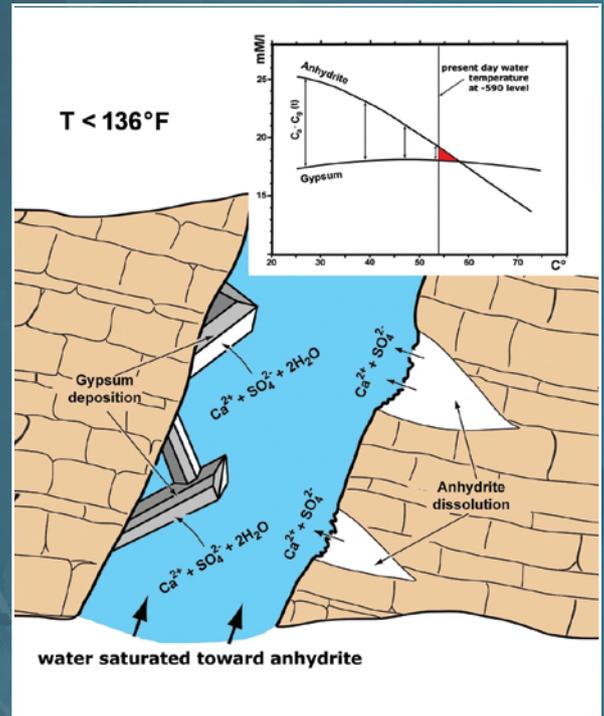


# of naica



Geological diagram of the Sierra de Naica, showing the caves, ore bodies and faults.

(Diagram courtesy of Paolo Forti)



These diagrams show how the temperature of the thermal solution in the caves affected the growth of the gypsum crystals.

(Diagram courtesy of Paolo Forti)

Since it began operation in the late 1800s, the Naica Mine in Chihuahua, Mexico has proven to be one of the richest silver deposits in the world. In 1910, at a depth of 120 meters, a small cave was discovered. Named the *Cueva de las Espadas* (Cave of the Swords), this cave was completely covered with gypsum crystals, some reaching up to 2 meters in length. The cave was quickly stripped of a large part of its treasures, and many are exhibited today in mineralogical museums around the world.

In 2001, at a depth of 290 meters, three new caves were discovered that contained truly gigantic gypsum crystals. In one cave, the *Cueva de los Cristales* (Cave of the Crystals), even larger, very transparent gypsum crystals were discovered, some of which reach up to 12 meters in

length and almost 2 meters in diameter, creating a true forest of crystals.

From 2001 to 2008 few people were able to visit the extraordinary sites, however, beginning in 2005, and thanks to an agreement with the mine owner, Compañía Minera Peñoles, a multi

**Some of the crystals reach up to 12 meters in length and almost 2 meters in diameter, creating a 'forest' of crystals.**

disciplinary, systematic study of the caves, called the Naica Project, was begun by Speleoresearch & Films from Mexico City and the Italian exploring team La Venta. Also on the team was the Italian company Virtualgeo, who was brought onboard

to survey the caves with laser scanning technology and create a 3D digital model of the Cueva de los Cristales.

The meticulous, all-encompassing documentation of the caves of Naica is not merely to satisfy scientific curiosity, but rather necessary to understand how

the crystals came to be, and furthermore, due to the threat posed by the cessation of mining activities and groundwater removal, provide a digital representation that will allow future generations to study the caves.



3D laser scanning in the Cueva de los Cristales in Naica, Mexico.

©Speleoresearch & Films

The purpose of the Naica Project, which will last four years, is to answer many questions: Why did such big crystals grow? When did it happen and how long did it take? Which relationships exist between ore bodies and crystals? Was the crystal formation at least partially influenced by microorganism? Apart from the huge crystals, what kind of stalactites and stalagmites grew? What was the evolution of the caves of Naica? Are the caves evolving at the present time? What was and what is the impact of human activity on the caves and crystals? How can the caves of Naica be preserved and at the same time allow public access? Is it possible to keep accessible the caves and their crystals after the end of mining activities? An international team of researchers, composed of more than 40 scientists from 17 universities and two

research centers, has been organized to answer these questions.

The first results of the Naica Project were presented in December 2007 during the conference “Naica Caves: Exploration, Documentation, Research” organized at the Department of Earth and Geo-Environmental Sciences of Bologna University in Italy. Besides reporting on the first outputs of the laser scanning survey, Virtualgeo set up a facility equipped for stereoscopic visualization, by means of which a “virtual” visit of the caves was possible.

### Geological Setting

The mine of Naica is in a semi desertic region about 100 kilometers southeast of the city of Chihuahua. The area is crossed by a series of low ridges. The mine opens on the northern side of one such ridge, the Sierra de Naica. It is an

anticline, outcropping from a wide alluvial plain, and composed of carbonate formations 12 kilometers long and 7 kilometers wide. Intrusive magmatic activity, which affected this part of the North American subcontinent, occurred between 25 and 26 million years ago. Recent coring, by the mine owner revealed an igneous body about 1,140 meters deep. The whole mining area sits on top of this magma body that heats the groundwater: water flowing into the mining galleries has a temperature close to 127°.

The main minerals present in the ore body are pyrites, pirrhotite, sphalerite, galena and chalcopyrite, but quartz, calcite and anhydrite formed later when the hydrothermal fluids started to cool down. Other minerals present at Naica are native silver, barite and fluorite. The ore bodies have been further influenced by two faults, the Gibraltar fault and Naica fault. These



3D laser scanning in the Cueva de las Espadas in Naica, Mexico.

©Speleoresearch & Films

faults have always controlled the hydrothermal circulation, and in fact, continue to influence the waters coming out of the deep mining galleries even today. Today, the mining activities have reached 760 meters in depth, and it is necessary to pump out about a cubic meter of water per second in order to continue mining. The end of mining activity (estimated to be in 5-7 years), which might cause an end to the dewatering, will cause all of the caves and their crystals to be submerged under 170 meters of thermal water.

### Creation and Evolution

Although the three caves found at the 290-meter level (Cueva de los Cristales, Ojo de la Reina and Cueva de las Velas) are in close proximity to each other, the gypsum crystals in each cave are different both in dimensions and shape. In all three, the crystals are transparent and very pure even though some contain fluid inclusions. Their remarkable dimensions, particularly acute angles and the vertical alignment of crystals sometimes create an impressive huge "shark tooth-like" structure.

In two of the three caves, crystals almost completely cover the cavity

walls, transforming them into gigantic geodes. Only in Cueva de los Cristales is the roof not covered with crystals. The Cueva de los Cristales has the largest crystals: about one hundred prismatic crystals, developed from the floor to the roof of the cavity, often exceeding the length of 8 meters. The growth of these crystals ceased about 20 years ago when the mine dewatering suddenly deprived them of the thermal water in which they were growing.

Before discovering the caves, only four chemical processes were known to cause the creation of gypsum crystals. Research has revealed a different reason at Naica and it has to do with the water temperature of the thermal aquifer. At a higher temperature, anhydrite dissolved into the water. As the temperature fell, gypsum crystals began to be formed. Additionally, research revealed that the reason why the crystals grew so large is due to the thermal stability: the thermal aquifer of Naica does not have a natural spring, therefore heat can disperse by conduction only. It is believed that the crystal growth took place over a time period of 400–500 thousand years.

### Laser Scanning Survey

Virtualgeo's work in the Naica Project consisted of scanning the Cuevas de los Cristales and de las Espadas. The aim of the survey was to document the present conditions of the caves by constructing a high precision three-dimensional geometric database, including color parameters. Scanning was an essential operation—and probably unrepeatably—since the caves are destined to be submerged when the mining activity ceases in a few years.

Virtualgeo has applied advanced instruments and software solutions in the fields of geomatics, software development and communication since 1994. In these fields it supplies services for the study, preservation and advancement of cultural and environmental heritage. In its first official expedition of the project in May 2007, Virtualgeo carried out the survey with a phase shift scanner thanks to the work of geologist Roberta Tedeschi.

Due to cavities and irregular surface shape, surveying in caves presents problems not found in aboveground surveying. Cave surfaces are difficult to measure with high detail by traditional survey techniques because of their complexity, resulting in only "rough" surveys. In addition, the caves of Naica have other peculiar features making them even more difficult to survey. The survey campaign was carried out in extreme ambient conditions (118-degree temperature and humidity close to 100% in the Cueva de los Cristales).

Of particular concern was the health of the technicians as well as the scanner functionality (which is guaranteed by the manufacturer to work from 41 to 104 degrees Fahrenheit, without condensation). The extremely high temperatures, coupled with the risks associated with moving around the crystals to set up the tripods and laptop, cables, power supply devices, etc., severely impacted the ability of the technicians. Added to this was the fact that they had to wear special equipment (both for breathing and body temperature control) prepared by the La Venta team.

The total duration of all the necessary survey operations in the caves was three hours (over two working days), of which 20 minutes were needed for the scanning. In the Cueva de las Espadas and Cueva de los Cristales, four scans were

acquired. The spatial coordinates and, thanks to the camera incorporated in the laser scanner, RGB color values of more than 43 million points were gathered.

### Data Output from Scanning

After registering the scans of the Cueva de las Espadas, post-processing of the data acquired with the scanner was performed with CloudCUBE, software developed by Virtualgeo for managing point clouds in AutoCAD. After the point cloud was imported into AutoCAD it was carefully cleaned and filtered to remove noise and insignificant points (see **Figure 1**). **Figure 2** displays a point cloud divided into sub-clouds, identified with different colors, each corresponding to a single gypsum crystal.

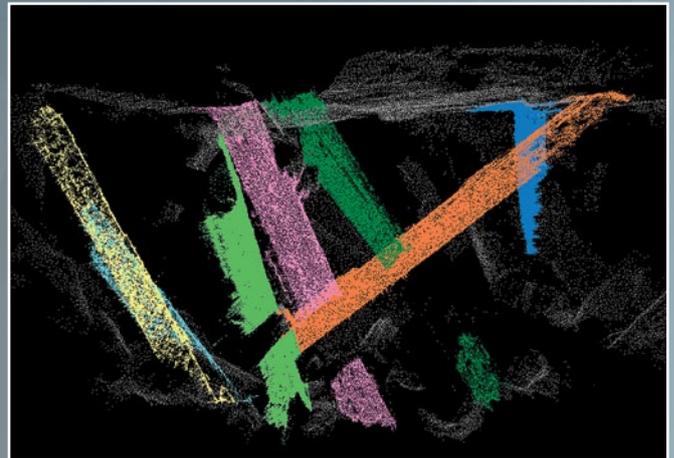
**Figure 3** shows the 3D digital model of the Cueva de los Cristales in shade modality. With CloudCUBE it is possible to rapidly obtain from the 3D model any type of dimensional information, including horizontal and vertical “compound” sections (which are sections combined with line elevations and point cloud images), and axonometric projections. The digital model can be generated with levels of detail that can be customized according to the specific nature of the use to which the model is destined. Such use can be scientific (to allow “distant” study of the caves) or related to public dissemination.

### Conclusion

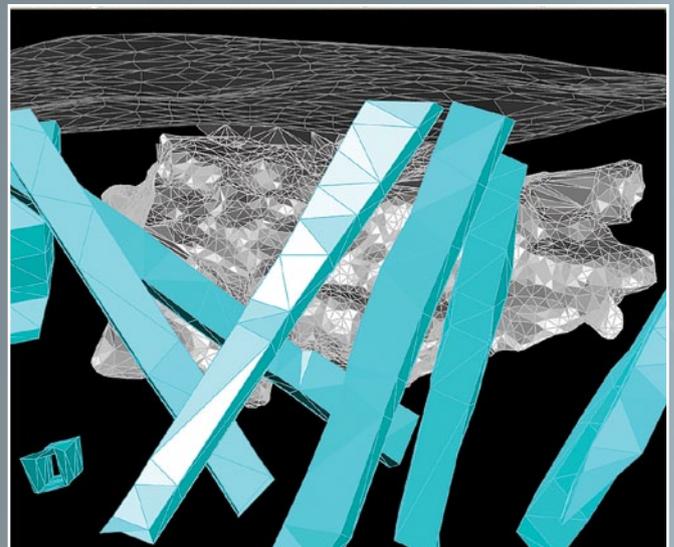
Even though the multi disciplinary research project on the caves of Naica started only recently, some of the results are already generating extraordinary interest. An absolutely new mechanism, based on the difference of solubility between gypsum and anhydrite below 138°, which allowed the gigantic gypsum to develop, was discovered. For the first time, perfectly preserved pollen has been found inside the gypsum crystals, which promises to be useful for paleoclimatic reconstruction. In the field of microbiology, the research on extremophile microorganism seems to be very promising and the discovery of new species is expected within a short time. It was verified that a laser scanner can be used for surveying caves, galleries and crystals of the mine, as well as to use the point clouds to perform reverse modeling with the tools provided by CloudCUBE.



**Figure 1** Cueva de los Cristales point cloud.



**Figure 2** Using Virtualgeo CloudCUBE software, the point cloud is divided into sub-clouds, with each sub-cloud corresponding to a single gypsum crystal.



**Figure 3** Using Virtualgeo CloudCUBE, a 3D model of the Cueva de los Cristales has been created.

All of this research will have to be completed within a short time. In fact, all of the caves at the 290-meter level will be accessible for only a few more years and, when the mining activities stop (expected within the next five to seven), the thermal water uplift will submerge the caves under a 170-meter head of hot water.

Actually, the gypsum crystals of Naica run the risk of being destroyed much sooner because of condensation. In fact, the walls of all the caves are cooling down quite rapidly because of the forced ventilation of the mining galleries. The ventilation will cause the cave walls to soon have a sufficiently low temperature, with respect to hot vapors rising from the bottom of the mine, to reach and go beyond the dew point with the immediate consequence of the gypsum crystals rapidly dissolving. This process has already started in the smallest cave (Ojo de la Reina), where the big gypsum crystals are dissolving and rapidly transforming into calcite stalagmites. It is predicted that the same process will start inside the Cueva de los Cristales within two years at most.

The main purpose of the Naica Project is to find the best way to safeguard

and transmit to future generations this unbelievable underground world. For this reason Speleoresearch & Films, with La Venta, has created a series of videos to document all the exploration and scientific research carried out inside the caves. As shown by Virtualgeo, laser scanners can play an important role in surveying caves and crystals to create high precision three-dimensional databases, and from that, 3D digital models and graphic representations for purposes of multi disciplinary study. *AS*

### Acknowledgments

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For more information, visit: [www.virtualgeo.it](http://www.virtualgeo.it); [www.sparta.it](http://www.sparta.it); [www.cloud-cube.com](http://www.cloud-cube.com); or [www.laventa.it](http://www.laventa.it).

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