

# TERRESTRIAL LASER SCANNING FOR PALEONTOLOGISTS: THE TAUTAVEL CAVE

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## ABSTRACT:

Paleontologists working in prehistoric caves often show interest in geomatics technologies to improve their research: 3D models are indeed useful for either reconstruction, geomorphological studies or virtual visits (especially if the site is not open to the public)... Paleontologists from the IPH (*Institut de Paléontologie Humaine*) and from the CERPT (*Centre Européen de Recherche Préhistorique de Tautavel*) contacted the ENSG (*Ecole Nationale des Sciences Géographiques*) in 2007 to study the feasibility of using geomatics technologies in the Tautavel cave (south of France) with a priority: to integrate the location of the cave walls into their existing database of prehistoric objects.

A group of students and teachers from the ENSG worked in the Tautavel Cave in October 2007 and carried out a 3D acquisition of its interior by laser scanning. The integration of this set of data into the database was completed later through an internship hosted by the CERPT. A pragmatic and efficient solution based on Quantum GIS, a free GIS software, was developed. This project confirms that geomatics technologies and, in particular, terrestrial laser scanning are well-adapted to the 3D needs of paleontologists.

## RÉSUMÉ :

Les paléontologues travaillant dans des grottes préhistorique portent souvent un intérêt au domaine de la géomatique en vue d'améliorer leurs recherches: les modèles 3D s'avèrent en effet utiles que ce soit pour des reconstitutions, des études géomorphologiques ou des visites virtuelles (en particulier si le site est fermé au public)... Les paléontologues de l'IPH (*Institut de Paléontologie Humaine*) et du CERPT (*Centre Européen de Recherche Préhistorique de Tautavel*) ont contacté l'ENSG (*Ecole Nationale des Sciences Géographiques*) en 2007 afin qu'elle étudie la possibilité d'utiliser les techniques de la géomatique dans la grotte de Tautavel (Sud de la France) avec une priorité: intégrer une localisation fine des parois de la grotte dans leur base de données du matériel préhistorique.

Des élèves et des enseignants de l'ENSG ont travaillé dans la grotte de Tautavel en octobre 2007 et ont réalisé l'acquisition 3D de son intérieur par scanner laser. L'intégration dans la base de données a été réalisée plus tard au cours d'un stage hébergé par le CERPT. Une solution pragmatique et efficace, basée sur le SIG libre Quantum GIS a été développée. Ce projet confirme que la géomatique et en particulier les scanners lasers terrestres sont adaptés aux problématiques 3D des paléontologues.

## 1. INTRODUCTION

### 1.1 Context

The Tautavel cave (or Arago Cave) is located in the southern Corbières region of France. As it is a natural shelter and an observation point, prehistoric man chose to live in it. When the excavation site opened in 1964, 15 meters of sedimentation levels dating from 700,000 to 100,000 BC filled the cave. Excavations began in 1964 (still in progress) bringing knowledge about human evolution. The current cave is 35 meters long and 5 to 9 meters wide but geophysical studies showed that the original cave was bigger: parts of the walls and roof collapsed some time in the past.

### 1.2 Partners

The IPH (*Institut de Paléontologie Humaine*) and the CERPT (*Centre Européen de Recherche Préhistorique de Tautavel*) are in charge of this archeological site. These institutes coordinate the excavations in the cave, organise its protection

and carry out research in prehistory, paleoanthropology, paleoenvironment and geology of the quaternary.

Most of this research requires spatial analysis. Usually, paleontologists work in a local coordinate system defined with an excavation grid. This excavation grid is "a coordinate system of labelled, contiguous squares set up on the surface of an archeological site, allowing for the accurate measurement of horizontal locations in an excavation (or surface collection)" (Colorado 2009). The third dimension is given by the vertical. The figure 1.A shows an example of such a grid in the Tautavel cave: the coordinate system is made up of cables and plumb lines. Materials excavated are georeferenced in 3D in this system; sedimentation levels are studied through vertical cross-sections in the two baseline directions (transversal and lateral), etc... Until now, the measurement of the material's position or of the shape of the inner walls was made with basic topographic tools such as a meter ruler, distance-meter and sometimes tacheometer in this paleontological coordinate system.

Gradually, paleontologists began to feel the need to get an accurate 3D model of the cave, inside and outside (walls, roofs...). Indeed, a more precise knowledge of the cave's countours should improve understanding the deposits in the different strata. Moreover, it will help to reconstruct the primary countours of the cave and guide future excavations. Finally, paleontologists are also asking for a visual 3D model to improve communication with the public at large for virtual visits, since the cave's access is restricted.

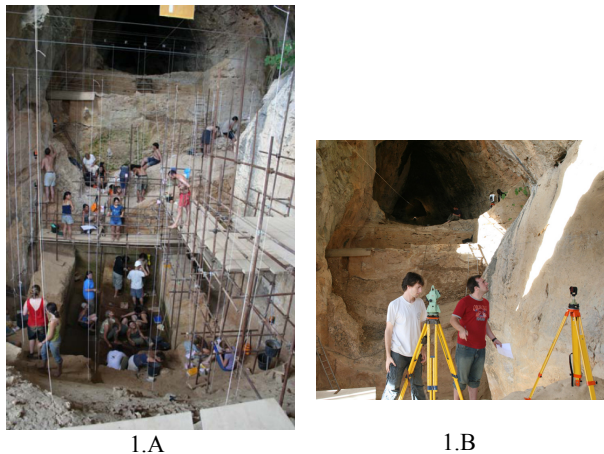


Figure 1. General view inside the cave:  
A. during excavations with the excavation grid (A.S. Lartigot, July 2006)  
B. during the ENSG campaign (L. Heydel, October 2007)

During the spring of 2007, the ENSG (*Ecole Nationale des Sciences Géographiques*) was contacted by the IPH and CERPT to evaluate the feasibility of the acquisition of a 3D model of the cave.

The ENSG (ENSG, 2009) is an engineering school specialised in geomatics sciences including topography, geodesy, photogrammetry and terrestrial laser scanning (TLS). After discussions and reconnaissance fieldwork, teachers from the ENSG agreed that TLS was the appropriate technology to acquire such a 3D model and decided that this work could be done by supervised students. Working in that kind of context would be quite exciting and should motivate the students.

### 1.3 Project

In October 2007, five post-graduate students in the Specialised Masters in Photogrammetry, Positioning and Deformation Measurement (PPMD) and three teachers went to Tautavel for a two week field project (see Figure 1.B). In this short time and with a training context, only the inside of the cave was scanned. This fieldwork is described in part 2.

Following this project, six months later, another ENSG student, Floryne Roche, pursued this work by integrating the laser data into the paleontological database. This task was the tricky point in this project: since paleontologists already had their own database and their own spatial analysis tools and wanted to keep them, it was compulsory to integrate the new data into the previously constituted database. A solution, detailed in part 3, was suggested, accepted and carried out to its conclusion (documentation and training).

## 2. FIELDWORK AND DATA ACQUISITION

The work introduced in this part was carried out between October 14-25, 2007 by a group of students supervised by three teachers.

### 2.1 Specifications

Specifications for the acquisition were chosen according to the paleontologists' needs. It included the density of laser 3D points, the absolute accuracy and the area covered by the fieldwork. To define the point density and the accuracy, the paleontologists' first objective was considered as a guideline: they wanted to integrate the walls in their vertical cross-sections of materials. These cross-sections are made every 10cm in the two baseline directions (transversal and longitudinal, see Figure 2).

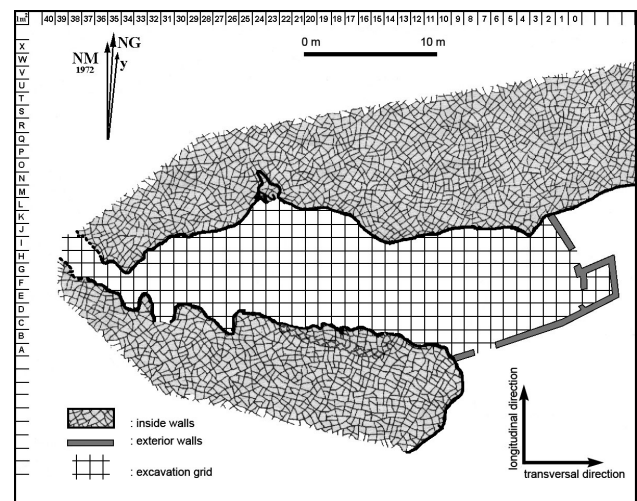


Figure 2. Ground map of the cave with the paleontological coordinate system

As a consequence, the density of the laser points had to fit with a 10cm truncation in the excavation area. It was decided to keep a 1cm point density with maximum 2cm of absolute positioning. These specifications were also largely sufficient to be consistent with the accuracy of the materials positioning. Indeed, the absolute error of the object positioning can reach a few centimetres: the grid excavation is composed of "squares" whose sides are between 90 and 110 cm long, the tools used to measure the position in these squares allow a 1cm positioning. The centre position is sometimes difficult to measure, in particular, for non-regular objects.

As far as the field area is concerned, the initial objective was to produce a 3D model of the inside and outside of the cave. Indeed, this is useful among other things to simulate the original countours of the cave and also to improve geomorphological studies. Despite this request, it was decided to focus on the interior to be sure to have a complete set of data.

### 2.2 Field methodology

First of all, a local topometric coordinate system has been defined for the site: it was chosen close to the paleontological coordinate system but was orthonormal contrary to the excavation grid. Some points of the network were constructed to allow the connection for future topometric work. The

purpose of such a system was to produce all the geomatics data in the same system. This local topometric system was also linked to the national geodetic system by GPS measurement. Thus, three coordinate systems coexist: paleontological, local topometric and national.

Then, the TLS strategy was drawn. The terrestrial laser scanner can be seen as a total station which automatically scans the space (Schelstraete, 2009). This instrument provides clouds of 3D points (with reflectance values) in a laser coordinate system. As a consequence, it is necessary to georeference the different laser stations in a common system which is generally the topometric one. To achieve this, there are two main strategies: either the clouds are adjusted together by an optimisation on the distance between points in the overlapping area with the Iterative Closest Point algorithm (Besl, 1992) or rigid transformations between coordinate systems are computed for each station by using ground control points. In our case, the second method was used.

First, the network of laser stations was designed: this phase included where the stations have to be positioned and what part of the site each of them has to scan. Then, the number and location of the ground control points were decided. Three points minimum are required to compute one rigid transformation. In practice, to assure the exactness, each laser station had five points in its field of view. The number of points was of course minimised by using common points between stations in order to strengthen the network and to decrease the amount of fieldwork. These control points were spheres or targets. Their coordinates in the topometric system were obtained by measurement with Leica total stations, so a network of topometric stations had also to be defined.

As soon as this reconnaissance had been completed, acquisition could begin. For this project, we used the GS200 scanner laser from Trimble whose characteristics are available on the constructor's website (Trimble, 2009). This laser was kindly lent by the MATIS (*Photogrammetry, Computer Vision and Remote Sensing laboratory*), research laboratory at the *Institut Géographique National* (IGN France). Since its field of view is restricted in the zenith direction, an L-form angle-iron was used to give a 90° rotation. Finally, there were 14 laser stations (corresponding to 20 million points) and 12 topometric stations. Moreover, the nails where the cables of the excavation grid are fixed were also measured to be able to compute transformations between the paleontological coordinate system and the topometric system.



Figure 3. GS200 laser scanner positioning on the angle iron

## 2.3 Results

The different network adjustments were done with Comp3d software developed at the IGN. First, the topometric network was computed: the unit variance factor,  $\sigma_0$ , is equal to 1.36 without the observations on the excavation grid nails and equal to 1.47 with them since these nails are difficult to measure. The topometric network accuracy is under 1 cm. Secondly, the laser adjustment of the rigid transformations from each laser station system into the topometric system was calculated. Laser coordinates of the ground control points were manually measured in the point clouds and coordinates in the local system came from the previous computation. We get a  $\sigma_0$  equal to 1.42. Residuals between coordinates in the topometric system and coordinates coming from the laser station are less than 15 mm. Ellipsoid errors at one sigma have semi-major principal axes inferior to the centimetre (except for one single station where it is around 2 cm).

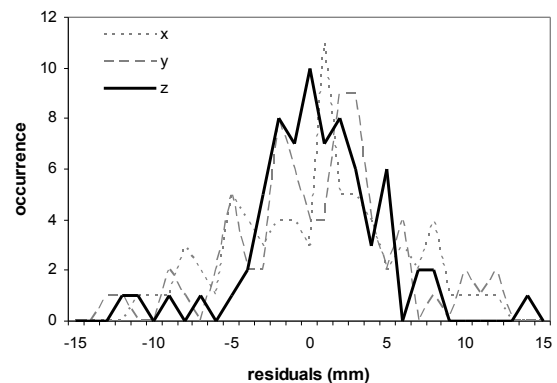


Figure 4. Histogram of laser residuals

## 3. INTEGRATION OF TLS DATA IN A PALEONTOLOGICAL DATABASE

The work presented in this paragraph was performed between June and August 2008 by Floryne Roche, a student from the ENSG, during an internship hosted by the CERPT and supervised by computer scientists and paleontologists from this institute.

### 3.1 The existing database and the GenMap application

Information about the materials extracted from the cave is recorded in a database managed with PostgreSQL. For one object, it includes the 3 coordinates read in the parent square varying between 0 and 100 in X and Y and between -50 and 600 in Z. Z grows with the depth corresponding to the evolution of the excavations. PostgreSQL is an object-relational database management system and is a free software. Its spatial extension for geographic objects, PostGIS, is not used in the database. Consequently the 3 coordinates are just attributes and linear objects are not handled.

Paleontologists use a specific application, GenMap, in order to work on the database. It is a Python program which generates cross-sections in the transversal and longitudinal directions with queries on the different attributes available (see Figure 5). The results of one query is exported in a pdf

file. Unfortunately, it was not possible to directly modify this application and that's why it was necessary to develop a new solution.

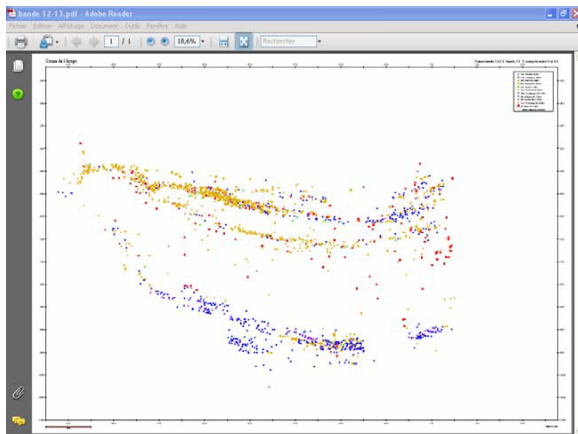


Figure 5. Projection of archeological material in the band 12-13 made with GenMap. Various symbols represent different types of objects (teeth, bones...)

### 3.2 The CERPT request

Paleontologists from the CERPT asked for a common application which could display materials (as points) and walls (as polylines) at the same time. This application had to have the following features:

- the database structure had to stay the same insofar as possible since it is used in other CERPT applications
- the link between the database and the solution developed had to be simple
- the solution had to be based on a free software, with a large user community
- the solution has to be user-friendly
- the solution had to enable user to display data (eventually in 3D), navigate, define customised legends, make queries, export in different file formats.

### 3.3 Solution proposal

**3.3.1 Walls cross-section generation:** after laser scanning adjustment, we got 3D points in the topometric system. Cumulus, a 3D point cloud processing software developed at the ENSG by Yves Egels, was used to produce cross-sections. First, it required the setting up of a 3D surface from the points. This was done by means of a 2D Delaunay triangulation on the spherical coordinates. Then, the parameters for the cross-section generation were carefully set since the cross-sections had to fit the excavation grid perfectly. Automatic generation gave imperfect polylines as several point clouds sometimes covered the same space portion. To correct these effects, all the lines were redrawn with the ProgeCad software.

**3.3.2 Free software comparison:** a preliminary study was made to find the most appropriate software. Eight free solutions were compared through a set of criteria with reference to the required features: Grass, Quantum GIS, Jgrass, uDig, OpenJUMP, gvSIG, SAGA et ProgeCAD. Their response to the criteria was evaluated by inspection of their documentation and through real tests. Table 1 sums up the results of this study. After discussion with CERPT staff, Quantum GIS was chosen: it is an easy-to-use software, with a user-friendly interface. Links with database and queries are simple. The main drawback of this software is the 2D display.

	Grass	Quantum GIS	Jgrass	uDig	OpenJUMP	gvSIG	SAGA	ProgeCAD
Ease of link with the database	-	++	-	++	++	-	-	-
Poor changes in the database structure	U	-	U	-	-	+	U	++
User friendliness	-	++	U	++	+	+	U	+
3D capabilities	U	-	-	-	-	+	++	++
Navigation	U	+	U	+	+	+	U	++
Possibility to make queries	U	++	U	-	++	++	U	U
Ease of use of these query features	U	-	U	-	++	+	U	U
Legend management (symbol, colour...)	U	++	U	++	-	++	U	+
Layer drawing and editing	U	++	U	-	U	U	U	++
Access to the attributes	U	+	U	++	++	U	U	-
Image export	U	++	U	-	++	-	U	-
Large user community	++	++	+	-	+	+	U	-

Table 1. Software comparison through different criteria

Legend:	
--	The software does not meet the criteria
-	The software does not meet the criteria well
+	The software meets the criteria
++	The software meets the criteria fully
U	The criteria is undetermined for the software



**3.3.3 Solution implementation, documentation and training:** the first task was to modify the database in order to fit in the new requirements. Cross-sections were transformed from the local topometric system to the paleontological system and imported as PostGIS lines in the database. This process required the transformation between these two systems which was possible due to the observations made on the nails of the excavation grid. As Quantum GIS only offers 2D visualisation from the top, it was necessary to adapt the 3 axes to the type of section (longitudinal or transversal). In the future, these tasks will only be carried out by the database manager.

Finally, consulting the database and making exports is very simple (see Figure 6). Documentation and training courses were provided to the CERPT staff about how to redraw the cross-sections, how to upgrade the database and how to use Quantum GIS.

#### 4. DISCUSSION AND CONCLUSIONS

This project mixing geomatics and paleontology was successfully completed due to the pragmatic and efficient solution presented in this article. This solution gives an answer to the primary needs of the paleontologists: they can now visualise the materials and the walls in the same application and thus, improve their analysis. The methodology followed is not specific to the Tautavel cave (except maybe for the initial structure of the database) and could be the same for any site. In any case, attention must be paid to the transformation between the different coordinate systems.

Moreover, this work is compatible with other possible applications. It appeared indeed that paleontologists will

rapidly ask to use laser data for the reconstitution of the original walls and/or for virtual visits. In both cases, it implies 3D acquisition of the exterior of the cave. But, the needs in terms of resolution and accuracy may be different. For geomorphological studies, even a little rift brings information to the researchers, involving an acquisition of around 1cm. For virtual visits, constraints are different: resolution can reach a few decimetres where visual interpretation is the key point. Interior acquisition with its 1cm resolution will be sufficient.

This work confirms that geomatics technologies and, in particular terrestrial laser scanning, are well-adapted to the 3D requirements of paleontologists.

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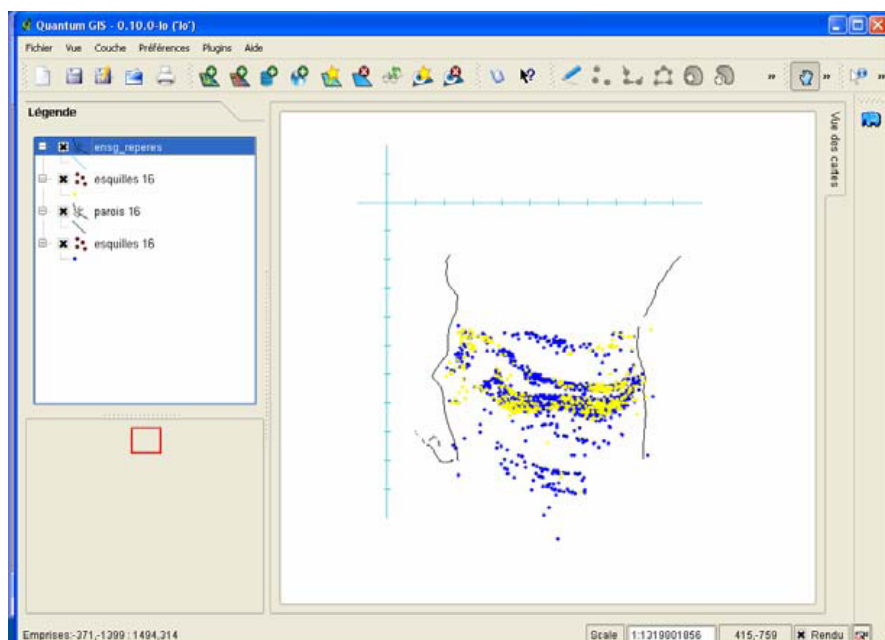


Figure 6. Visualisation with QuantumGIS of industry and sliver in band 16 between  $y = 0$  et  $y = 10$ cm.