

# Three-dimension (3D) presentation of a hominid cave using ground-penetrating radar

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**KEY-WORDS:** Ground-penetrating radar, Three-Dimensional presentation, Reversal polarity, void measurements cave.

## Highlights:

- Determination of the ceiling, floor, and the void of the hominid cave.
- Using time-depth adjustments to correct the floor position.
- Statistical method to determine the cave-void and the real floor depth.
- Creation of a 3D representation for the cave.

**Type of presentation: Oral**

## Introduction

Ground-penetrating radar (GPR) is an active non-invasive method that is typically used to investigate archeological features that are buried in the ground. Here, we employ it in a different environment, which is a fossil-bearing cave in Spain (Bermejo, et al. 2020). It is called the Sima del Elefante/Peluda Cave, which is discovered in the late 1800s, when a railroad “trench” was dug in the mountains to make a gently sloping grade for the trains’ tracks in Atapuerca, north of Burgos, Spain. A GPR survey was done in the railroad trench above the Peluda Cave and adjacent to the Sima del Elefante Cave (Bermejo, et al. 2020). There has been some success using GPR in caves elsewhere using antenna frequencies between 50-270 MHz, but typically, these surveys have had limited resolution (Bermejo, et al. 2020; Esmaeili, et al. 2020; Gosar and Čeru, 2016; Gosar, 2012; and Chamberlain, et al. 2000). The antenna frequency used here was

270MHz, which provided a good resolution and up to 6 meters depth penetration of energy in the limestone bedrock. A grid of 9 GPR profiles was collected 100m long and spaced 1m apart. These data were collected using a 270 MHz antenna, in a time window of 300 ns with 30 traces/meter (Bermejo, et al. 2020). These long profiles were then clipped to 32m, as only that part of the grid contains the reflections associated with the cave (Figure 1).

To detect the ceiling/void interface, the first deflection in any trace, which represents the direct ground wave (Figure 1) was used to determine the normal polarity. All reflections below that first arrival were analyzed and all were of this polarity until a wave was received that represents the reflection from the interface between the limestone ceiling and the void space (figure 1). That reflection, which was reversed polarity was then used to “pick” the same interface in all profiles. The high amplitude reflection directly below it was then chosen as the floor reflection. Some minor errors in this method occurred in some places where the ceiling–void interface shows a weak normal polarity which may occur due to water saturation contrasts in limestone rocks of the ceiling rock itself. The radar wave’s velocity as waves are passing through the ceiling rocks is about 0.13 m/ns. When the radar wave then travels in the cave air void, velocity increases to the speed of light (0.3 m/ns). This wave speed-up “pulls up” the reflection of the cave’s floor (‘Figure 1). Bermejo, et al. (2020) noted that that the void height of the cave appears to be about 1.5m on the profile shown in Figure 1, but its actual height is closer to 2.4m. This discrepancy was adjusted using the speed of light for those waves traveling in the void, placing them in the correct depth position.

### **3D presentation of the cave**

In order to map in three-dimensions, the outline of the cave ceiling and the floor needed to be placed in space, and the digital values of each determined in depth and thickness. The ceiling depth was readily determined as velocity is known and the reflections were “picked” using the phase following application in ReflexW. Those values were downloaded in two-way travel time (ns) and then converted to a depth below the ground. The floor depth computation was a little more problematic due to the air void effect, which speeded up the velocity of the radar wave.

Those values were picked in the same way with ReflexW but then adjusted in space as the waves had traveled from the ceiling to the floor and back again in the air.

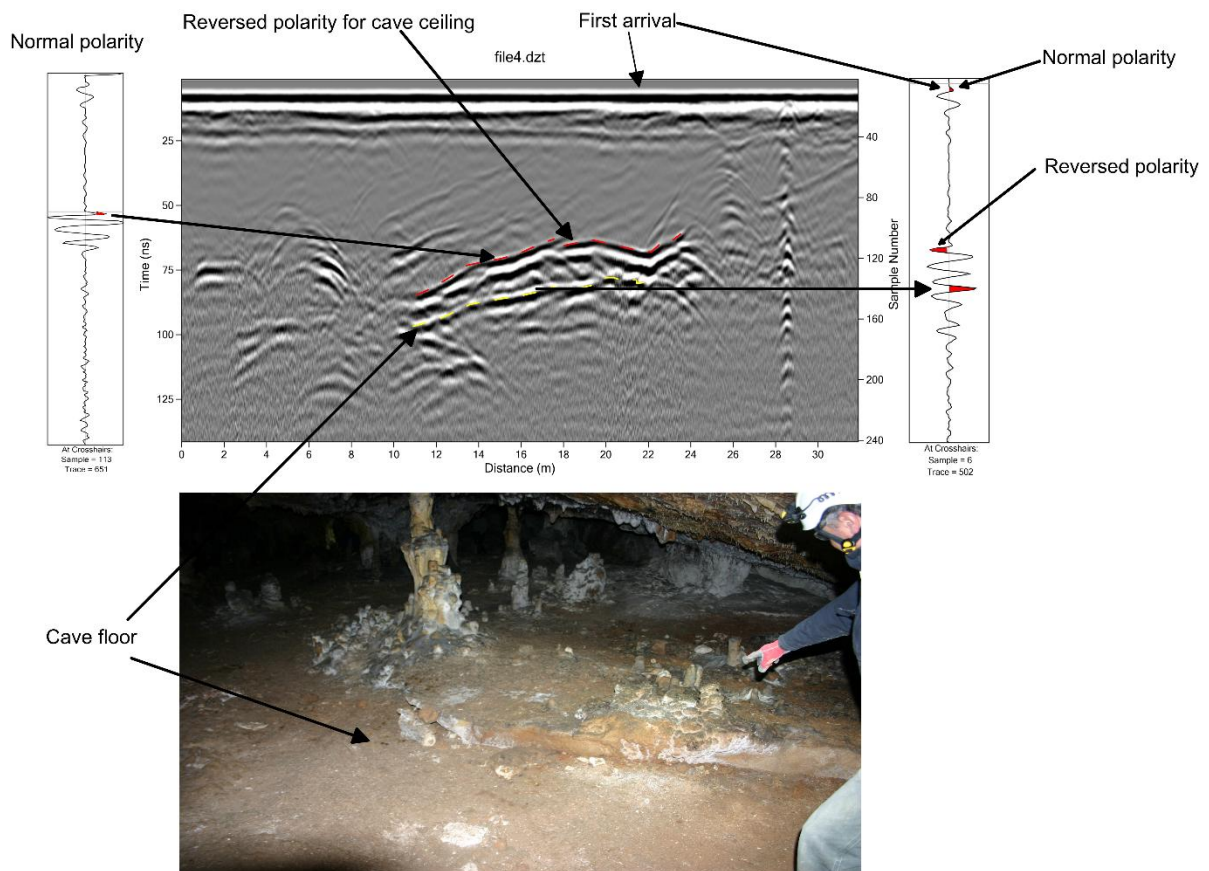


Figure 1: Shows a) The cave's reflections on the profile 4, and the normal and reversed polarity, b) The cave from inside

As an example, in profile 4, this type of adjustment was done in ReflexW by the transformation of the time axis into depth. In this way, the floor location is corrected to its actual position (Figure 2c), and the resultant ceiling and the floor depth by this method are between (3.9 – 5.4m) and (6.1 – 7.2m) respectively. However, the other parts of the profiles are distorted (Figure 2c). This limitation may cause serious issues when building a 3D representation for underground features. We, therefore, developed a statistical method to calculate the floor depth and place it in its actual position.

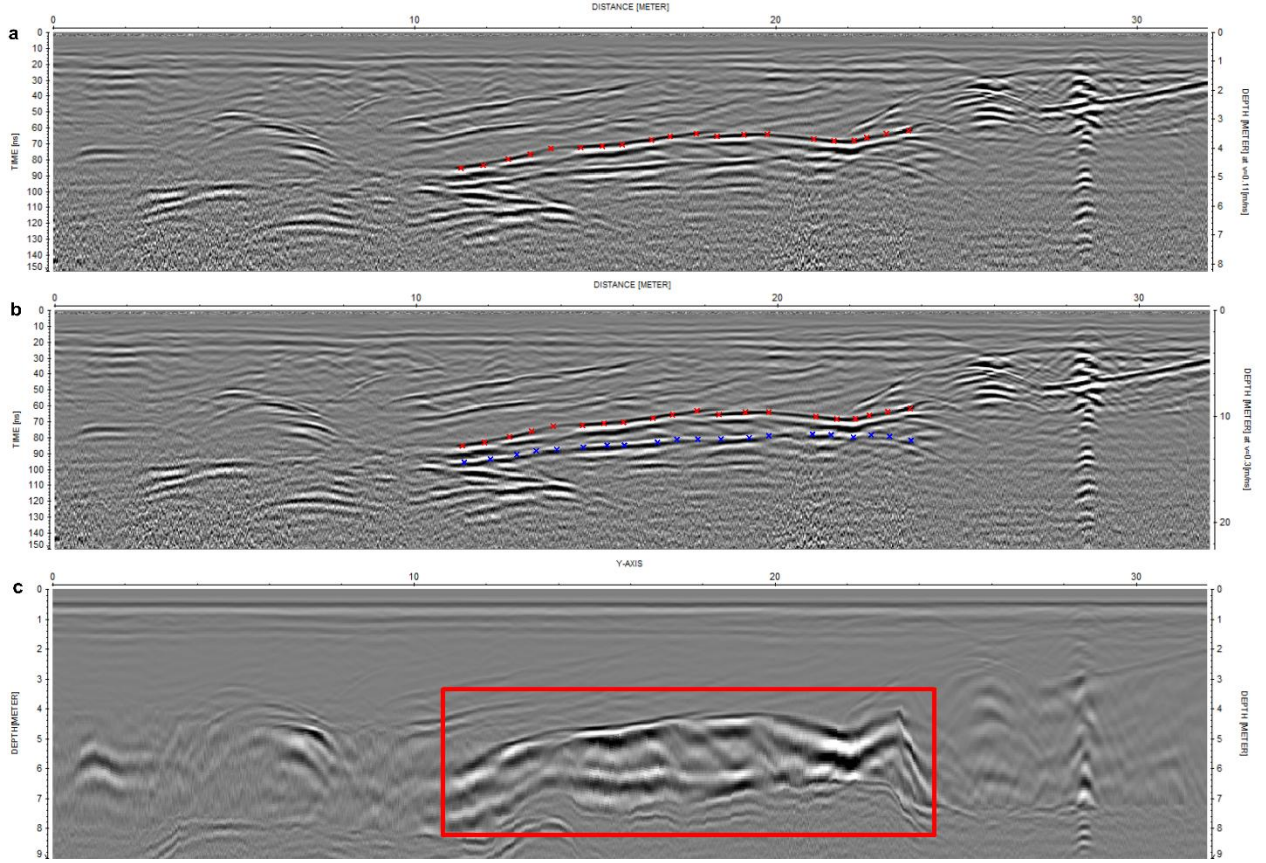


Figure 2: a) The ceiling picking at the velocity of 0.13m/ns, b) The ceiling and the floor picking at the velocity of 0.3m/ns, and c) the time-depth 2D adjustment for the cave reflections.

This method is based on determining the void height by picking both the ceiling and the floor at the velocity of 0.3m/ns (the speed of light) using Reflexw software (Figure 2b). Then subtracting the picking values of the ceiling and the floor by the equation below:

$$vd = fd_{vel\ 0.3} - cd_{vel\ 0.3}$$

Where  $vd$  is the void height,  $cd$  and  $fd$  are the ceiling and floor depth at the velocity of 0.3m/ns respectively. Then the resultant values of void height (Table 1) should be added to the picking values of the ceiling when the velocity equals 0.13m/ns (the velocity of the wave in the

cave

rocks)

(Figure 2a), to get the actual floor position. This is done by applying the flowing equation:

$$fd_{vel\ 0.13} = vd + cd_{vel\ 0.13}$$

Where  $vd$  is the void height,  $cd$  and  $fd$  are the ceiling and floor depth at the velocity of 0.13m/ns respectively. The resultant ceiling and the floor depth by this method is between (3.9 - 5.4m) and (6 – 7.3m) respectively for profile 4 in Figure (1)

Table 1: shows the picking values for the ceiling and the floor at the velocity of 0.13m/ns and the void height for profile 4

x-axis	y-axis	Ceiling depth	Void height	Floor depth
11.233	3	-5.4801	1.7339	-7.214
11.7	3	-5.3421	1.9462	-7.2883
12.067	3	-5.2195	2.0524	-7.2719
12.533	3	-5.0814	2.2294	-7.3108
12.933	3	-4.9434	2.2294	-7.1728
13.5	3	-4.7288	2.3709	-7.0997
14.033	3	-4.6368	2.5478	-7.1846
14.5	3	-4.6368	2.2647	-6.9015
14.9	3	-4.5908	2.3355	-6.9263
15.4	3	-4.5294	2.4063	-6.9357
15.867	3	-4.4528	2.4063	-6.8591
16.333	3	-4.3607	2.477	-6.8377
16.7	3	-4.2841	2.5479	-6.832
17.233	3	-4.1614	2.7602	-6.9216
17.633	3	-4.0847	2.7955	-6.8802
17.967	3	-4.0387	2.9017	-6.9404
18.4	3	-4.0387	3.0079	-7.0466
18.633	3	-4.1461	2.6539	-6.8
19.1	3	-4.1154	2.6186	-6.734
19.467	3	-4.1154	2.5478	-6.6632
19.9	3	-4.1154	2.2647	-6.3801
20.267	3	-4.1767	-0.1415	-6.3801
20.8	3	-4.2534	1.8754	-6.1288
21.167	3	-4.3147	1.9109	-6.2256
21.567	3	-4.4067	1.6986	-6.1053
22.1	3	-4.4067	1.6632	-6.0699
22.533	3	-4.2534	2.1585	-6.4119
22.967	3	-4.1921	2.194	-6.3861
23.267	3	-4.0694	2.5125	-6.5819
23.6	3	-3.9621	2.8309	-6.793

These adjustments were then done to all profiles in the grid after picking and the true depth values of the ceiling and the floor were calculated. Those values were imported into Surfer for

display (Figure 3). It is be noted that in these procedures the floor reflection displays an uneven surface, which conforms to the actual situation of the cave that contains many drip features, stalagmites, and ceiling collapse units Figure (1b).

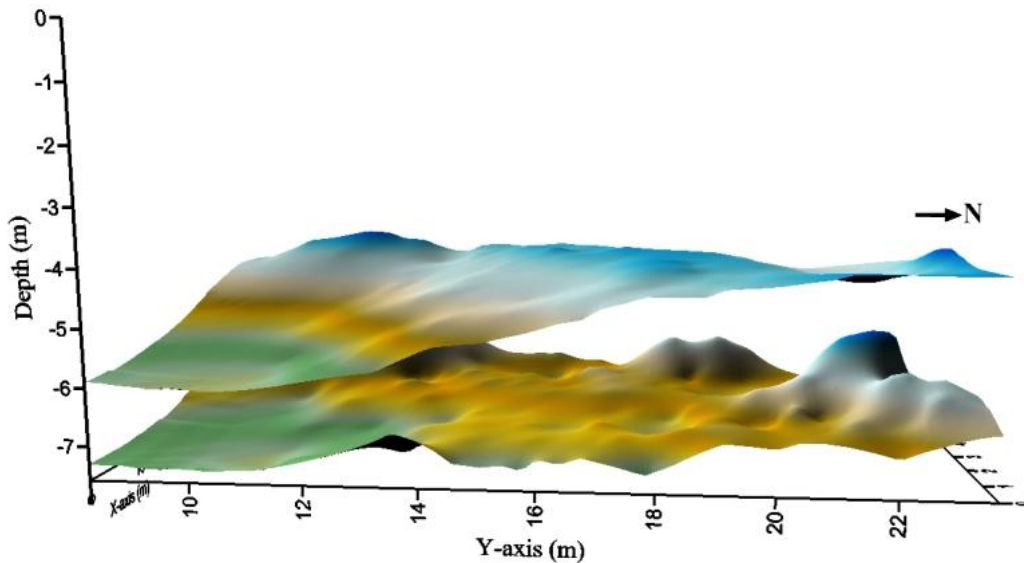


Figure 3: the 3D representation of the cave.

## Conclusion

Three-dimensional analyses of this sort are especially useful for determining not just a visualization of complex three-dimensional surfaces of this sort, but also for volumetric analysis. Here the volume of the cave is  $185 \text{ m}^3$ , which is an important value when analyzing air volumes and the genesis of this system. The three dimensional mapping of this complex cave system employed techniques that could easily be applied to any buried features that have distinct tops, bottoms or even sides that can be imaged with GPR. For instance it could be applied to the top and bottom of shell layers in archaeological deposits, specific layers in complexly bedded tel systems, or any stratigraphic horizons of interest. When the interfaces are “picked” and then measured in three-dimensions outcomes can obtain volumes of units, or images of the buried layers when viewed from multiple directions. Furthermore, it can be used for evaluation and analyzing different subsurface archeological features that contain air volume such as the underground tunnels and passages, historical large cemetery vaults.

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