The Parpalló Cave: A singular archaeological acoustic site

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The Parpalló Cave is located in the slopes of Montdúber, in Valencia (Spain). It is one of the most important Palaeolithic sites, not only in Spain, but in the world. It was a privileged location for its inhabitants from the Upper Palaeolithic onwards. It has one of the most spectacular collections of Palaeolithic art mobilier found to date. The Parpalló cave features a considerably large opening which, undoubtedly, influences its acoustic properties. Indeed, the sound pressure field inside the cave is not excessively reverberant and intelligibility is significantly better than in similar enclosures. In this work a study of the acoustic properties of the Parpalló cave is performed by using ray tracing simulation.

1 Arqueoacústica

The study and interpretation of the signs found by the arqueology can not be conceived in a deaf world, without sound. The space in which sound messages where pronounced is one of the main factors that conditions its content. In many cases, it can be determinant for the existence of particular communication ways and artistic expressions. [1, 2]

Arqueoacoustics is an experimental branch of the Arqueology and the Antropology and explores acoustic phenomena encoded in ancient artifacts.

The main archaeological deposits of Prehistory have been found inside caves. Thus, many scientific studies have been consecrated to find a relationship between the presence of artistic artifacts and the acoustic features of the enclosure where they were found. In several works of S. Giedion [3], A. Glory [4, 5, 6], L. Dams [7], M. Dauvois o X. Boutillon [8] observe that some stalagmite formations could have been used as natural litophones. M. Dauvois and I. Reznikoff [9] analyzed and related the presence of rupestrian paintings of “Le portel”, “Fontanet” y “Niaux caves in France with the transverse resonance modes of the caves. Authors explain that the position of the paintings can be linked with the acoustical features of the cave. More Recently, S. Waller studied around 100 deposits [10, 11,12]. In his Works, he explains the big correlation between the emplacements with important echos and rupestrian art.

Many works have been consecrated to emplacements after the Palaeolithic era. In this cases, emplacements where created by men. Some examples can be highlighted like the studies of R. Jahn, P. Devereux and M. Ibison [13] concerning enclosures like dolmens and megalithic tombs or the studies of A. Watson and D. Keating [14, 15] about big closed tumulus and stone circles. In those studies, many acoustic phenomena are analyzed, like the distribution of the resonant modes, the psicoacoustic effect of resonances

2 The Parpalló Cave

The Parpalló Cave is placed at the slope of the Monduver Mount in Gandia, Valencia (Spain). It is one of the main spanish palaeolithic deposits since an exceptional art collection has been found in it. There are traces of human occupation from the Upper Palaeolithic to the Neolithic. Many art objects and painting techniques have been found all long its chronology.

The scarcity, quantity and diversity of the rests explain the singularity of this deposit. Amont the rests found in the site, the set of approximately 5000 engraved plaquettes must be highlighted. This collection is a proof of the great affluence in Parpalló [16, 17].

The acoustic features of the cave are very singular: On the one hand its great opening reduces the persistence of sound: the reverberation time is abnormally small compared to the volume of the cave. On the other hand plate elevated platform probably could be used as stage by the speaker.

The present work aims to evaluate the possible relation between the acoustic phenomena of the cave and the huge affluence of the cave in the past. With this aim, measurements and simulations with the ray tracing method will be analysed.

3 Ray tracing simulation

The first step in order to create a 3D model of the enclosure was to determine the physical geometry of the cave. The geometric coordinates were obtained from the planes of the cave defined in the archaeological works of L. Pericot [17], by defining a mesh of 2000 points to process in the software. *(Fig.1)*

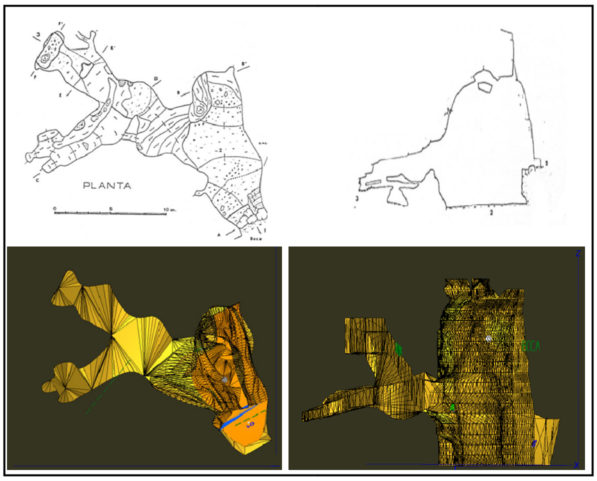

Fig.1 The archaeological planes of the cave and the geometric model generated by the software

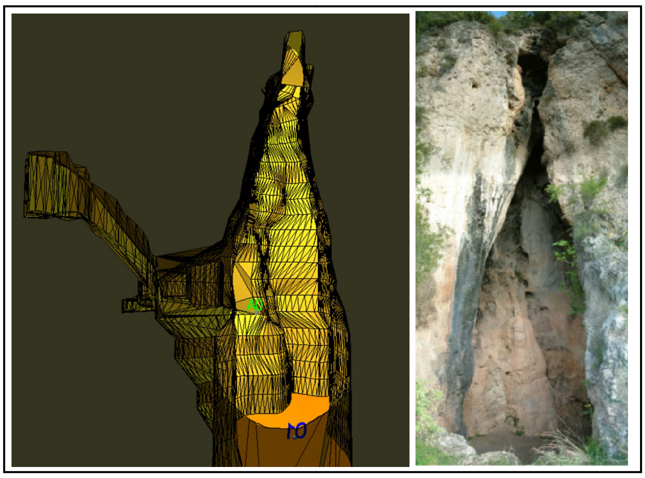

Fig.2 Simulation and photography of the cave

The opening of the cave *(Fig.2)* is an element that should be carefully considered by the simulation: totally absorbent planes were considered on the whole opening. During a meeting, the cave would never be empty, persons, and other objects were distributed all around the ground [29] and the coefficient of absorption and dispersion will be quite higher than the sand. *(Fig. 3)*

Frequency (Hz)	125	250	500	1k	2k	4k
Stone	0.015	0.025	0.025	0.025	0.03	0.04
Dry sand	0.15	0.35	0.4	0.5	0.55	0.8
Audience	0.36	0.43	0.47	0.44	0.49	0.49
Model ground	0.4	0.4	0.5	0.6	0.7	0.8

Fig.3 Absorption coefficient of the walls considered by the model

The sound source *(S1 on Fig.4)* was placed on the elevated platform of the cave, as the logical place for the position of a speaker.

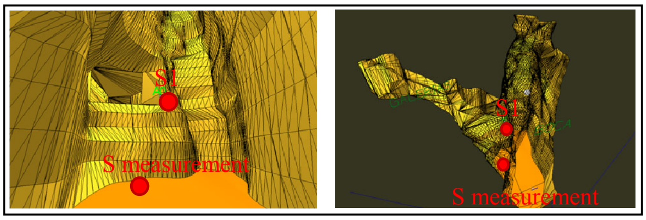

Fig.4 Representation of sound sources in the simulated model

Receivers *(R1, R2, R3; Fig.5)* were distributed over the surface evenly.

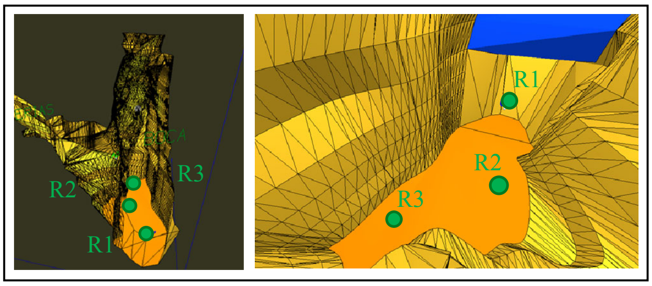

Fig.5 Representation of acoustic receivers on the simulated model

Another interesting aspect was the creation of several models for the different ages of archaeological cave due to the silting of sediment in it. The chronological and cultural stratification of the cave Parpalló runs the Paleolithic Upper from Gravetian (30.000 B.C.) until Upper Magdalenian (8.000 B.C.) *(Fig.6)*

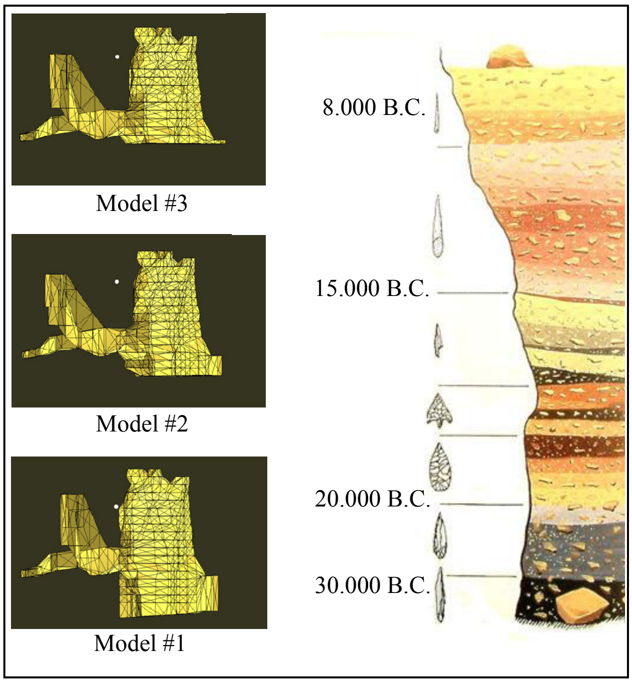

Fig.6 Chrono-stratigraphic sequence of Parpalló and his approach to 3 geometric models.

3.1 Simulation results

Noting the values of reverberation times doesn't vary at change the position of the receiver. The differences between the values of reverberation times are in no way greater than ± 0.3s, which shows that the sound field on the surface is relatively uniform. *(Fig.7)*

The shape of the tonal curve shows higher reverberation times for the low frequencies than the upper bands, ranging between 1.5s and 0.8s. *(Fig.7)*

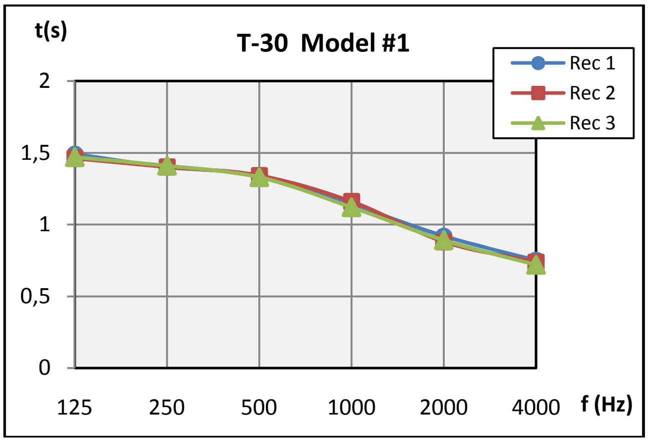

Fig.7 Simulated tonal curves for the 3 receivers on the Model #1

As shown in figure 8, EDT ranges between 1.1 and 0.7s and there is a difference of about 0.2s between EDT and T-30.

The differences between the values of EDT, T-15, T-30 show that the energy density decreases quickly at the first part of the curve and fall more slowly in the rear part.

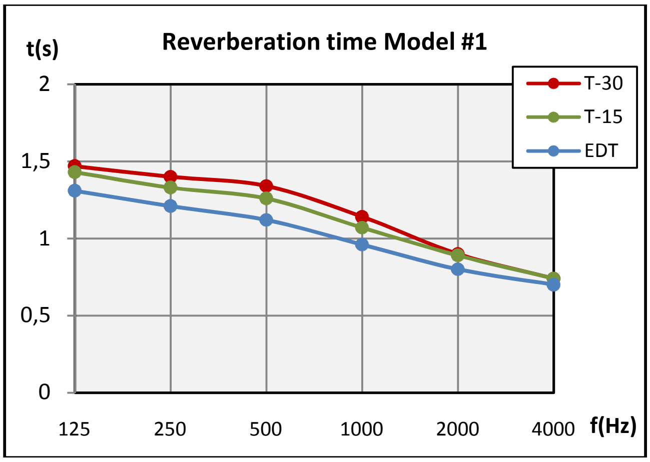

Fig.8 Reverberation time EDT T-15 y T-30 simulated for the Model #1

These features can be extrapolated to the results of the three different models, with the only difference that the values of model #2 (silting in 2m on the current state) the persistence of sound inside the cave is reduced 0.2s and in the model #3 (silting in 4m) do so in 0.4s. *(Fig.9)*

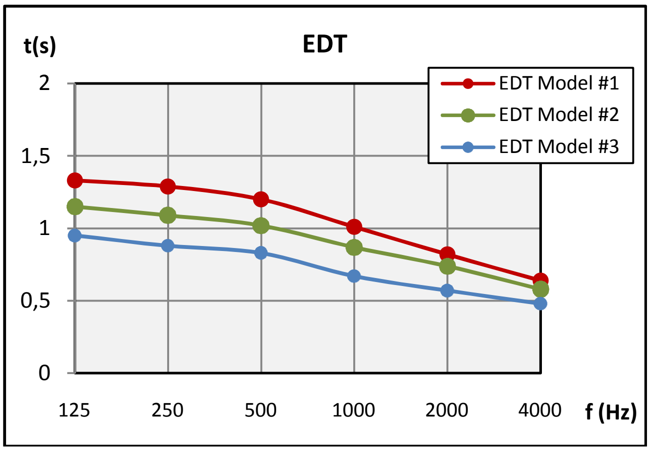

Fig.9 Compare of EDT for different models simulated

For the intelligibility analysis the clarity (C_{50}) and the RASTI were simulated for the different models. Contrary to what was happening with the distribution of sound pressure and the reverberation time, the parameters of intelligibility not behave so uniform, particularly in filling models. Clarity is much higher at the center of the cave and the highest values occur when the enclosure had the floor completely filled with sediments. *(Fig.10)*

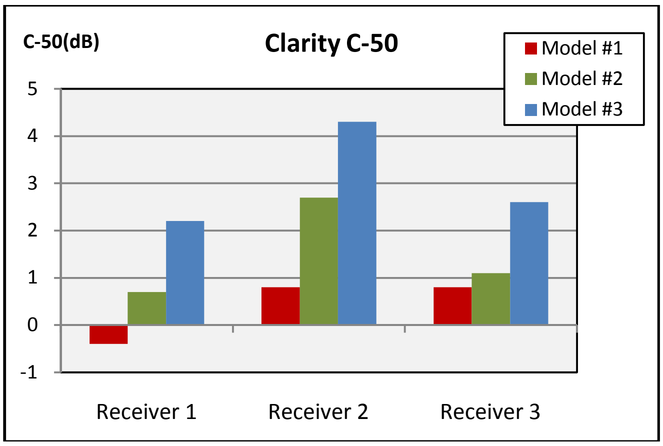

Fig.10 Clarity C_{50} for the 3 individual receivers on the 3 simulated models

4 In situ measurements

In order to compare the results of the simulations, measurements of the impulse response were done inside the cave. To obtain the response of the room, the cave was excited with signals MLS type 16A. After the deconvolution of the recordings were obtained the IR at different points. The spatial distribution of receivers was the same as for the simulation *(R1, R2, R3; Fig.5)*. Because of the size and the difficult access to the position of the platform, the positions of the source were distributed by the floor of the cave *(S measure; Fig.4)*. This fact is crucial for later comparison between the results of simulations and these measures.

The cave is currently empty sediment due to archaeological excavations. Cause of this, the acoustic measurements made inside will correspond to the model # 1, roughly corresponding to the period Gravetian, (30.000 B.C.)

The results for the measurements show the strong correlation between the measured and simulated data. Thus, the reverberation times of the simulation are virtually equal to those of the measure *(Fig.11)*. Only slightly differences can be seen at high frequencies, where the reverberation times measured are higher. Even so, we must bear in mind that the position of the source was not the same for the extent to which the simulation and this will heavily influence on the equivalence of results.

	Receiver 1	Receiver 2	Receiver 3
EDT Measure (s)	1.1	1.1	1.1
EDT Model#1 (s)	1.1	1.0	1.2

Fig.11. Comparison between measured and simulated EDT on the model # 1

For the parameters of intelligibility there is also a clear correlation on the values. Those data of RASTI range between 55 and 60, and the clarity C_{50} between -0.7 dB and 1.5 dB. *(Fig.12, Fig.13)*.

	Receiver 1	Receiver 2	Receiver 3
RASTI Measured	55	58	60
RASTI Model#1 (s)	58	60	59

Fig.12. Comparison between measured and simulated RASTI on the model # 1

	Receiver 1	Receiver 2	Receiver 3
C_{50} Measure (dB)	-0.7	0.5	1.5
C_{50} Model#1 (dB)	-0.5	0.7	0.8

Fig.13. Comparison between measured and simulated clarity C_{50} on the model #1

Conclusion

Numerical simulations and measurements in the cave haveprovided many data that can be used for the purpose .

As expected the reverberation time is quite small and important differences between EDT and T-30 has been obtained by simulations. This difference is due to the non-diffuseness of the field inside the cave and also explains irregular descent of the inner sound energy.

The great openness of the cave is the main responsible of the big values estimated for the clarity (C_{50}), definition (D-50) and intelligibility (RASTI). Thus, the Parpalló cave presents exceptional acoustic features for the transmission of oral messages.

Simulations with the ray tracing method have been realised for the cave at different eras: due to the sediments the volume has changed and so the acoustic features of the cave. In this way at the Gravetiense era (30.000 b.C.), the intelligibillity of the cave was smaller than at the Upper Magdaleniense superior (8.000 b.C).

Acknowledgments

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