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Acoustics measurements, analysis and comparative study for caves used for Pan and Nymphs' ancient rituals.

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ABSTRACT

This project investigates the possibility that caves dedicated to the worship of the goat-legged god Pan and the Nymphs in Classical Greece had unique acoustics that were suitable for such rituals. Two such caves in Attica, Greece known for their ancient ritual use were measured acoustically and were compared to the acoustics of another cave not associated with ancient ceremonies whatsoever. The ancient worship of Pan and the Nymphs have special connections to sound and resonance and hence it is important to examine a reciprocal potential relationship between their ritual performances and the sonic qualities of grottos. The acoustics measurements were taken in two sacred caves (cave of the Nympholept Archedimos in Vari, Lychnospilia cave on Mt. Parnitha) and for comparison, in a third cave with no evidence of ritual use (Korakovouni I on Mt. Hymettus).The measurements were taken using: (a) an omnidirectional mic to derive the acoustics parameters of caves and (b) with a binaural dummy head to calculate binaural parameters and allow subsequent virtual soundscape auralizations. The thorough analysis examines the acoustic suitability of these sacred underground.

Keywords: cave acoustics, Greek god Pan, acoustics measurements

1. INTRODUCTION

In the past few decades there has been a turn towards the acoustical and sensual properties of the material past. Especially within sensual archaeology, increasing research has been done on the aural perspectives of ancient sacred grottos and other rural sacred places, offering the potential to enrich interpretations of how ancient buildings or natural spaces were used, and proclaiming the importance of sound as one of the determinants in their identification as places of divine presence and worship [1,2,3].

Caves are understood as complicated enclosed spaces composed of numerous surfaces, objects, and geometries, creating an acoustic arena which behaves differently from analogous open-air spaces [4]. Likewise, the underground sanctuaries dedicated to the Nymphs and Pan in ancient Greece should not only be perceived as landscapes with certain visual characteristics, but also as soundscapes with important auditory features [5]. As a result, an acoustic survey of these caves and an appropriate analysis of their aural characteristics, combined with archaeological and musical methods is necessary, in order to understand whether sound was a determining factor in the selection of caves as appropriate sacred sites to host the combined cult of Pan and the Nymphs in antiquity.

2. HISTORICAL AND ARCHAEOLOGICAL DATA

The principal seat of Pan's worship was Arcadia and from thence his name and cult spread over other parts of Greece [6] . The Athenians were the first who established his cult inside a cave after his cult was transferred to Attica in the first quarter of the 5th century BC (Herodotus, Histories, VI, 105–106). The presence of water sources, evidence of previous use, closed entrances, high altitude and liminality, made caves particularly attractive as homes and sanctuaries of the Nymphs and Pan [7].

Pan is a deity connected with natural sounds, echoes and loud noise; sound is an important component of his cult. For the sake of Pan's love of noise the ritual protocol involved the production of various sounds and the resulting resonating and echoing effects of caves would have been regarded as signs of his divine presence. During a Pan ritual, the participants, through their noise-making, dancing, music, and feasting, were creating a system of ritual action, in which they themselves became agents of the god's epiphany.

Within the geographical region of Attica, fourteen underground cult sites have been identified so far dedicated to Pan and the Nymphs (Acropolis, Marathon, Dafni, Mt Hymettus, Mt Penteli etc). However, here only two caves were selected for archaeoacoustic research, the "Cave of the Nympholept" at Vari and Cave "Lychnospilia" on Mt. Parnitha.

3. THE CAVES

The places of the three caves under investigation are shown in Fig. 1. They are all placed in Attica, and with the exception of Cave Lychnospilia, the other two are surrounded by the urban web of the city of Athens.

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3.1 The "Lychnospilia" Cave

Cave "Lychnospilia" is located at the southwest foothills of Parnitha, at a height of 35m. from the left bank of the Goura stream at an altitude of 773m above sea level. The cave is accessed relatively difficult through road that has been opened since the antiquity leading from the medieval settlement "Roumani" to the north side of the cave's terrace. The cave was partly excavated by Andreas Skias in 1900-1901 revealing extensive evidence of the worship of Pan and the Nymphs especially in the 5th - 4th centuries BC [8].

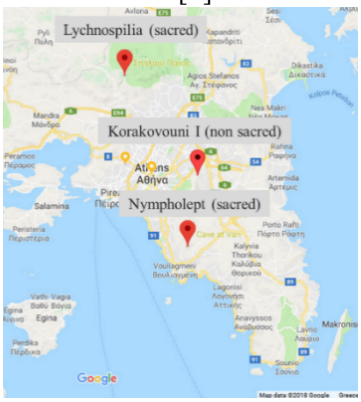

Figure 1 – The location of the three caves [9]

The triangular mouth of the cave located at the southern part of the plateau is 1.05m wide. The opening is surrounded by rough carvings and niches for the placement of votive offerings, as well as Late Roman inscriptions. The grotto is 62m long and extends from east to west, while its width ranges between 3.00-14.40m. After the entrance lies a large plateau (9.00x8.00m), while deeper in the interior the ground elevates especially near the southern wall (Fig. 2).

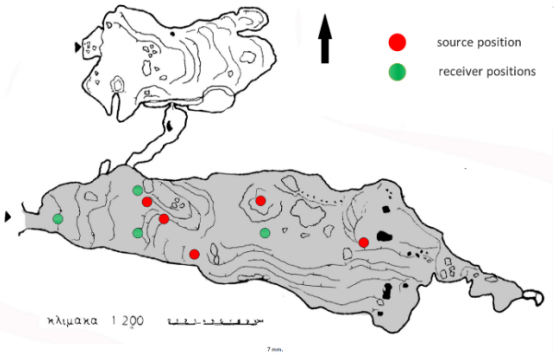

Figure 2 – Ground plan of Lychnospilia cave.

3.2 The "Nympholept" Cave

The Cave of the Nympholept or Nympholyptos Cave at Vari is located at the southern foot of Mt. Hymettus at an altitude of 290m above sea level. It is preserved in a very good condition and access to it must have been relatively difficult in antiquity. First traces of habitation date back to the 6th centu-ry BC, while in the third quarter of the 5th century BC Archedimos the Nympholept, seized by divine inspiration established there the cult of Pan and the Nymphs

The cave's oval mouth is vertical (4.00x2.00m), while a roughly carved staircase leads to the interior (21.00x23.75m, height 2.50m, depth 15.00m). A massive calcite formation separates the cave into two chambers: the southern is large and fairly bright (17.5x11.5m). The northern chamber is narrower, much darker, with no any special configurations and decorated with rich stalactite formations (18.5x8.00m). The shape of the interior facilitates the anticlockwise movement of the visitor, first through the steep, narrow and dark space to a much larger and brighter chamber. The latter is identified with the main sanctuary as most configurations are located there, such as the statue of a seated figure, altars, desks and niches for the placement of votive reliefs or other offerings, as well as scattered inscriptions from both ancient and modern visitors.

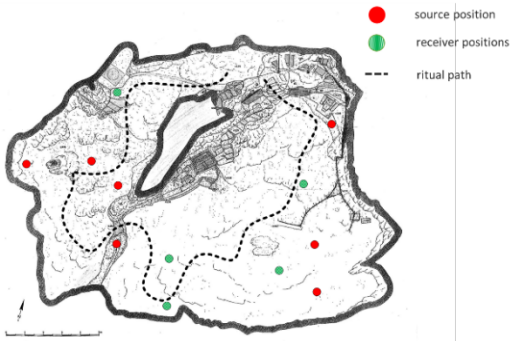

Figure 3 – Ground plan of the Cave of the Nympholept.

3.3 The "Korakovouni I" Cave

Cave "Korakovouni I" " is located at the relatively even northwest slope of Mt Hymmetus at a height of 691m above sea level and 500m West of the Cave "of the Lion", which was dedicated to the worship of Pan. Ceramic finds confirm the use of the cave since the Neolithic era, but also later during the Late Helladic, Archaic, Classical, Hellenistic and Late Roman periods (3rd - 6th century). The absence of finds with possible worship use indicates the cave was used as a place of residence or seasonal overnight.

The cave is in the form of a long relatively narrow smooth corridor with a total length of 90m and in a NE-NE direction, which widens to a depth of up to 6m. The width in its largest area is circa 2.00m, while height varies from 2.00 to 8.00m Approximately 25m from the entrance there is a narrow opening 0.40x0.50m., which divides the elongated part of the cave into two parts (Fig. 4). Along the first 25m extends to the NW a parallel corridor to a higher level with difficult access. After 60m the cave widens forming a fairly large space, while in its deepest part it is divided into two smaller narrow and long sections.

Its walls are relatively smooth, while in places, especially after the narrow opening in the middle, there is abundant stalactite material, part of which has been cut off by visitors. The highest concentration of stalactites occurs near the widest part of the cave, where steady drips have formed a large stalagmite volume, which dominates the center of the area.

3.4 Acoustical measurements

The caves, as mentioned before are far from any

access road, being isolated and difficult to reach. Lychnospilia cave is reached after half an hour walk, then having to descend a 10m slope. The Nympholyptos and Korakovouni I Caves can only be reached with off-road vehicles and after special permission to use mountain roads usually closed to public. The heavy equipment for the measurements (Table 1) was carried by the research team and workers of the Greek Ephorate of Palaeoanthropol-ogy and Speleology.

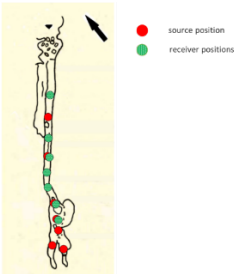

Figure 4 – Ground plan of Korakovouni I cave.

The measurement stimulus signal was a logarithmic sine sweep [10] of T=10 sec duration at Fs = 44100Hz and an SPL=88.5 dB /1m with a bandwidth covering 40Hz to 20kHz. The ears of the dummy head were at a height of 1.2m, which represents the mean height of Greeks of the period and the omni mic was positioned 15cm above the dummy head at 45^{o} angle vertically.

The source and receiver measurement positions for the caves are shown in Figures 2-4. The source positions were chosen based on archaeological assumptions for the potential locations of an ancient musician during performance, and the receivers were located at the possible positions where participants of the ancient rite would probably have stranded or danced. Especially in the cave of Nympholept, there is an obvious dark path that the believers followed entering the cave in order to reach the main hall. There were 9 measurement positions selected inside Cave Lychnospilia, 12 in Cave Nympholyp-tos and 13 in Cave Korakovouni I. In the Cave of the Nympholept an additional set of 14 binaural measurements were taken following the descending path (Fig. 3 black dashed line followed counter clockwise).

Given that there was no access to electric mains power in the caves, a portable gas-powered generator was used positioned about ca. 50m away from the entrance of the caves. The background noise level measured is shown in Table 2 and is very low to allow measurements with good SNR. The temperature and humidity levels were very stable: in Lychnospilia it was $8^{o}C$ with 55% relative humidity, in the cave of Nympholeptos it was $17^{o}C$ with 80% relative humidity and in Korakovouni I it was $12^{o}C$ with 70% relative humidity.

Table 1 – List of equipment used for the measurements

Model	Description
EV SXa100	12” 200W active Loudspeaker
MOTU 828x	audio interface
G.R.A.S. - KEMAR	Binaural dummy head
G.R.A.S. – 26AS	Miniature preamps
G.R.A.S. – 12AA	Power module
PCB 377A40	Free field microphones
SVANTEK SV 01A	1/2“ preamp
SVAN955	Sound Pressure Level Meter
CEL 284/2	Calibrator

Table 2 – Background noise levels

Cave	Background noise dB(A)
Lychnospilia	26.6
Nympholeptos	22.8
Korakovouni I	20.7

4. RESULTS

From the omnidirectional microphone impulse response measurements at the above positions, the acoustical parameters of T30, D50, C80, C50, and STI were calculated in 1/3 octave bands, according to ISO3382[12] using the Audacity 2.0.5 [12] with Aurora plug in software [13]. The IACC parameter was calculated from the corresponding binaural impulse response measurements.

The reverberation time of the caves is almost identical and ideal for speech (Fig.6). The slight rise at the low frequencies gives warmth to the sound and the value of 0.9s to 1.3s at the mid frequencies gives clarity to speech. In comparison, the non-sacred Cave of Korakovouni I introduces a slightly lower RT with more than 10% deviation in the whole frequency spectrum.

The **clarity** index for speech C50 (Fig.7) and music C80 (Fig. 8) for the caves has acceptable values (above 0 dB) from almost 200Hz.

The **STI** (Fig 9) values of the caves indicate good to excellent speech intelligibility.

With respect to the binaurally accessed spatial qualities of the measured spaces, the **IACC** (interaural cross-correlation coefficient, Fig 10.) was derived from the corresponding binaural impulse response (BRIR) measurements. The results for the caves exhibit the expected nearly perfect diffuse and spaciousness character for frequencies above approx. 400Hz. Hence, the caves provide an increased sense of spaciousness to the listeners.

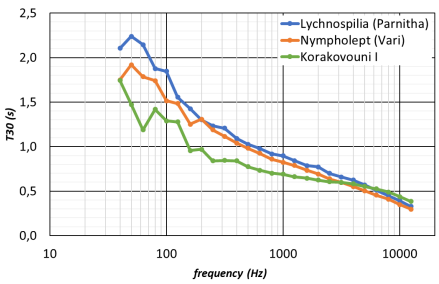

Figure 6 – Reverberation time for the three caves.

5. CONCLUSIONS

Overcoming the inaccessibility of the caves with well-established historical links to ancient rituals of Pan and the Nymphs in ancient Greece, a set of acoustical measurements has been obtained and analysed. Apart from the quietness and isolation offered in such spaces, the results

indicate that these caves had low reverberation time for their volume, exceptional clarity for speech and music and generate increased feeling of

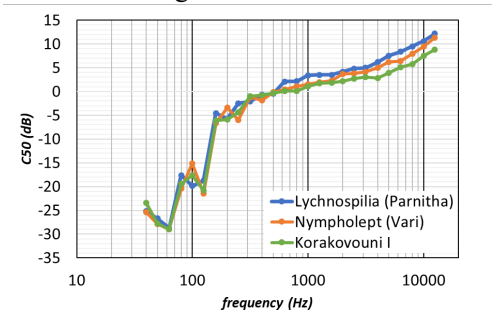

Figure 7 – Clarity index for speech

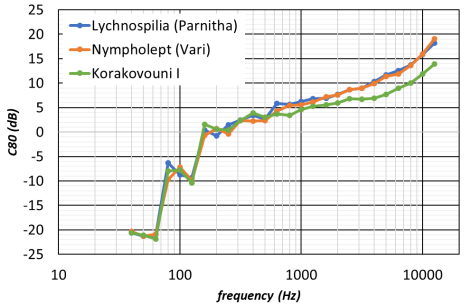

Figure 8 – Clarity index for music.

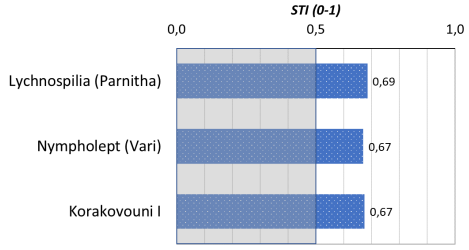

Figure 9 – The Speech Transmission Index (STI).

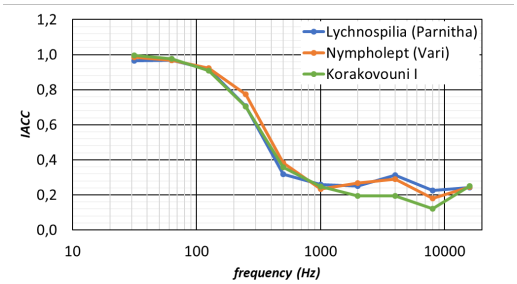

Figure 10 – Comparison of the IACC index.

spaciousness to the listeners, achieving also very good speech intelligibility within the range of positions where the ceremonies were performed. The comparison between sacred and non-sacred caves showed a potential of utilizing special acoustic characteristics for rituals but further investigation is needed to obtain more statistically valid results (measurement in more sacred and non-sacred caves).

As future work, the measurements obtained in the current work, will become available in public databases [14] and will be compared to other ancient places of worship [15]. Virtual auralizations of ancient musical instruments and speech along with perceptual tests will compare the listener preference for such ancient and modern spaces of worship.

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