

HESPERIA

THE JOURNAL OF THE AMERICAN SCHOOL
OF CLASSICAL STUDIES AT ATHENS

VOLUME 93: NUMBER 4 | OCTOBER–DECEMBER 2024



Copyright © American School of Classical Studies at Athens, originally published in *Hesperia* 93 (2024), pp. 597–616. This offprint is supplied for personal, non-commercial use only, and reflects the definitive electronic version of the article, found at <<https://muse.jhu.edu/pub/55/article/947463>>.

HESPERIA

Jennifer Sacher, EDITOR

EDITORIAL ADVISORY BOARD

Nathan T. Arrington, *Princeton University*
Effie F. Athanassopoulos, *University of Nebraska-Lincoln*
Angelos Chaniotis, *Institute for Advanced Study*
Jack L. Davis, *University of Cincinnati*
A. A. Donohue, *Bryn Mawr College*
Jan Driessen, *Université Catholique de Louvain*
Sylvian Fachard, *University of Lausanne*
Marian H. Feldman, *Johns Hopkins University*
Thomas W. Gallant, *University of California, San Diego*
Sharon E. J. Gerstel, *University of California, Los Angeles*
Guy M. Hedreen, *Williams College*
Catherine M. Keesling, *Georgetown University*
Carol C. Mattusch, *George Mason University*
Alexander Mazarakis Ainian, *University of Thessaly at Volos*
Lisa C. Nevett, *University of Michigan*
John H. Oakley, *The College of William and Mary*
Josiah Ober, *Stanford University*
Jeremy B. Rutter, *Dartmouth College*
Monika Trümper, *Freie Universität Berlin*

Hesperia (ISSN 0018-098X) is published quarterly by the American School of Classical Studies at Athens. Founded in 1932 primarily to publish the work of the American School, the journal now welcomes submissions from all scholars working in the fields of Greek archaeology, art, epigraphy, history, materials science, ethnography, and literature, from earliest prehistoric times onward. *Hesperia* is a refereed journal, indexed in *Abstracts in Anthropology*, *L'Année philologique*, *Art Index*, *Arts and Humanities Citation Index*, *Avery Index to Architectural Periodicals*, *Current Contents*, *EBSCO Humanities International Index*, *IBZ: Internationale Bibliographie der geistes- und sozialwissenschaftlichen Zeitschriftenliteratur*, *European Reference Index for the Humanities (ERIH)*, *Periodicals Contents Index*, *Russian Academy of Sciences Bibliographies*, and *TOCS-IN*. The journal is also a member of CrossRef.

HESPERIA SUPPLEMENTS

The *Hesperia* Supplement series (ISSN 1064-1173) presents book-length studies in the fields of Greek archaeology, art, language, and history. Founded in 1937, the series was originally designed to accommodate extended essays too long for inclusion in *Hesperia*. Since that date the Supplements have established a strong identity of their own, featuring single-author monographs, excavation reports, and edited collections on topics of interest to researchers in classics, archaeology, art history, and Hellenic studies.

Recent issues of *Hesperia* are hosted online by Project MUSE (muse.jhu.edu). Back issues of *Hesperia* and *Hesperia* Supplements are electronically archived in JSTOR (www.jstor.org), where all but the most recent titles may be found. For order information and a complete list of titles, see the ASCSA website (www.ascsa.edu.gr). The American School of Classical Studies at Athens, established in 1881, is a research and teaching institution dedicated to the advanced study of the archaeology, art, history, philosophy, language, and literature of Greece and the Greek world.

THUNDER, LIGHTNING, AND EARTHQUAKES AND THEIR IMPACT ON THE SANCTUARY OF ZEUS ON MT. LYKAION

ABSTRACT

We present here an interdisciplinary inquiry exploring why a sacred site was established on the southern peak of Mt. Lykaion and developed into a major Greek sanctuary to Zeus, documented by ancient authors and in use for thousands of years. The site offered many attractions, but most compelling may have been the dynamic expressions of natural forces experienced there: powerful earthquakes, ground motion, lightning, and thunder. Scientific quantification of the frequency of lightning and thunder identifies Mt. Lykaion as one of the best places in Greece to see lightning and hear thunder, and the place in the Peloponnese where the most distant lightning could be viewed and thunder heard.

The Sanctuary of Zeus on Mt. Lykaion is situated in the west-central Peloponnese in the mountains of Arcadia (Fig. 1).¹ The Mt. Lykaion Excavation and Survey Project, initiated in 2004, has revealed that the site on the mountain's southern peak (Profitis Elias, 1,382 msl) was in use since the Final Neolithic period (ca. 4500 BCE).² From the Late Bronze Age or Mycenaean period (ca. 1600 BCE) onward, burned animal sacrifices and terracotta figurines were dedicated directly on the bedrock of the mountaintop, representing activity at a Mycenaean open-air shrine.³ Ample remains of ritual activity on the peak identify it as the ash altar of Zeus, which continued to be used through the Roman period (1st–2nd century CE). A temenos, or

1. The authors thank Sarah Cohen, who recognized the cross-disciplinary potential of this topic. This paper reflects a culmination of nearly 20 years of archaeological investigation and research at the site involving a variety of interdisciplinary investigators, to whom Romano and Voyatzis extend their heartfelt appreciation. Excavations and research at Mt. Lykaion have been funded by the Institute for Aegean Prehistory, the National Science Foundation, Friends of

Mt. Lykaion, and other donors.

2. The Mt. Lykaion Excavation and Survey Project is a collaboration (*synergasia*) between the University of Arizona, the Greek Ministry of Culture, and the Ephorate of Antiquities of Arcadia, and is under the auspices of the American School of Classical Studies at Athens. The director of the project is Anna Karapanagiotou, director of the National Archaeological Museum, and the codirectors are David Gilman

Romano and Mary E. Voyatzis of the University of Arizona. See <https://www.lykaionexcavation.org> for more information. Earlier excavations at the site were undertaken in the late 19th and early 20th centuries by Konstantinos Kontopoulos and Konstantinos Kourouniotis from the Archaeological Society of Athens; see Kourouniotis 1904, 1909.

3. Romano and Voyatzis 2014, pp. 589–610, 616–617.



Figure 1. Map of the Peloponnese showing the highest mountain peaks. D. G. Romano and A. Riehle

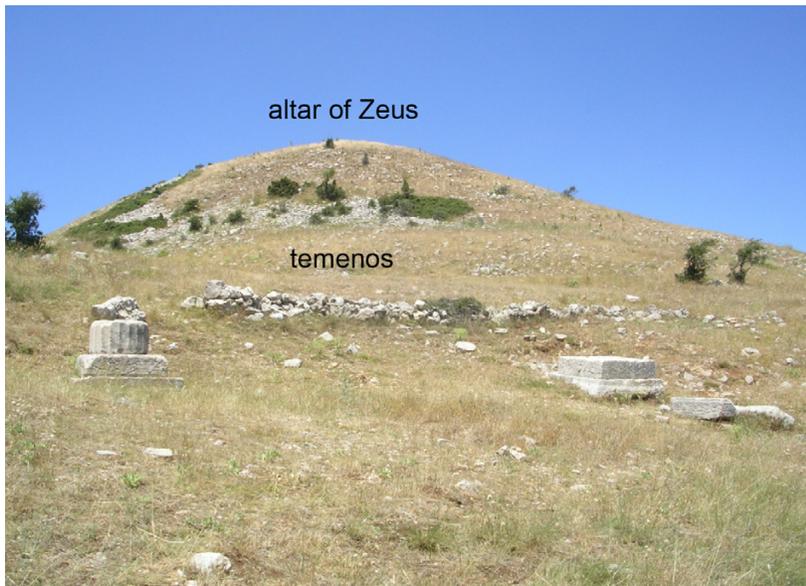


Figure 2. View of the temenos and ash altar of Zeus, from the east. Photo D. G. Romano

sacred area, was established just below the altar (Fig. 2), and athletic events may have taken place nearby.⁴ A mountain meadow ca. 200 m below the temenos began to be used in the Archaic period (ca. 650 BCE), and in the Classical period (ca. 370 BCE) it was expanded to include major athletic and administrative facilities, as well as the Sanctuary of Pan (Fig. 3).⁵

Known in antiquity as the “Arcadian birthplace of Zeus,” Mt. Lykaion is located about 35 km from ancient Olympia (see Fig. 1), another sanctuary of Zeus with athletic events, although founded much later than Mt. Lykaion.⁶ The results of ceramic analyses (chemical and petrographic) of a selection

4. Romano and Voyatzis 2014, pp. 574, 629–630, fig. 2.

5. Romano and Voyatzis 2015, pp. 208–260.

6. Romano 2019; Romano and Voyatzis 2021, pp. 15–23.

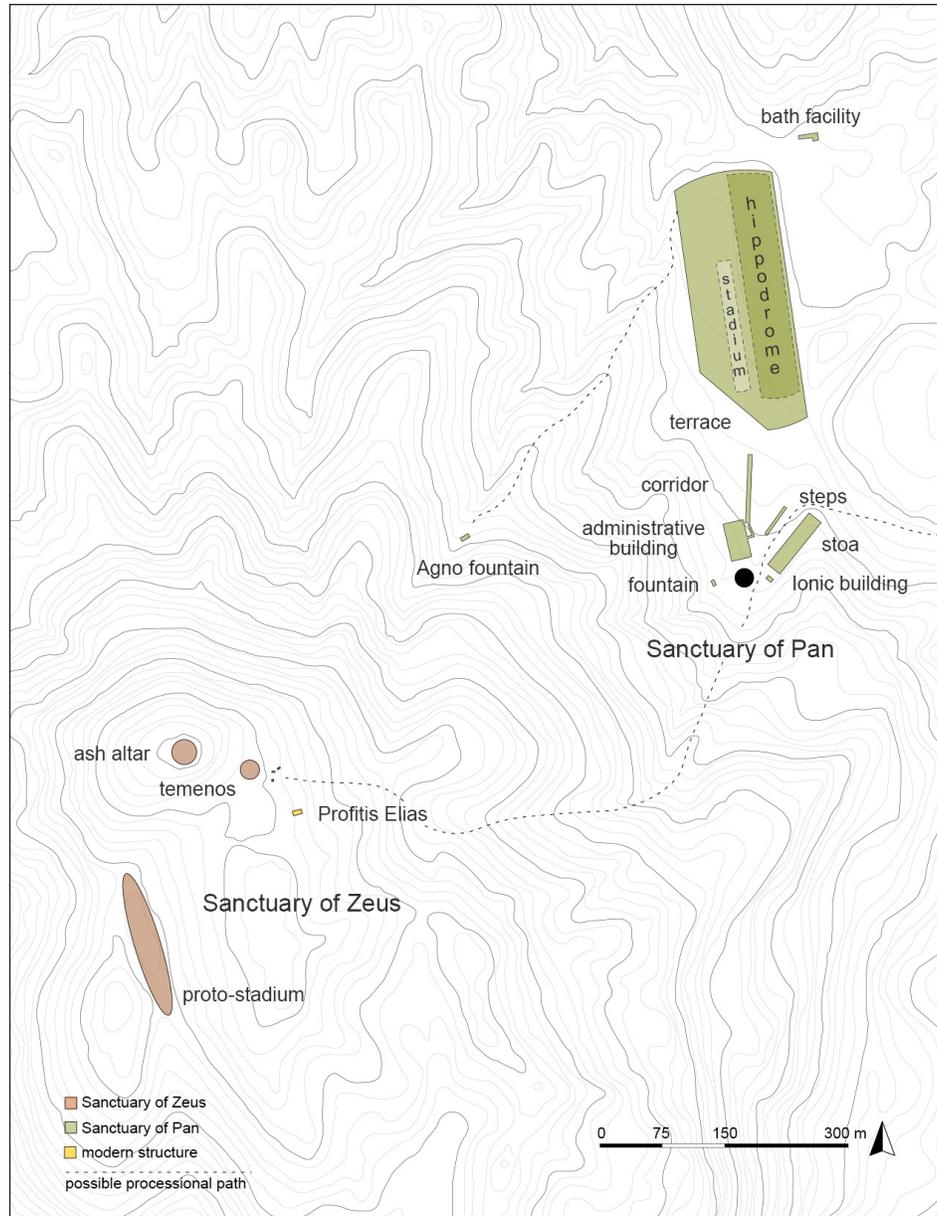


Figure 3. Plan of the Sanctuaries of Zeus and Pan on Mt. Lykaion. D. G. Romano and A. Riehle

of pottery from the altar suggest that the earliest visitors to Mt. Lykaion came from relatively nearby, but by the Late Bronze Age they were coming from much farther away.⁷

We wish to understand what initially attracted people to the mountain, and why they kept coming. One of the clues may be found in the name of the site itself. The word *Lykaion* is related to the Proto-Indo-European term for “light” and “bright.” The name Zeus is derived from the Proto-Indo-European sky and weather deity.⁸ So, the god worshipped there, Lykaion Zeus, could be understood as the “bright sky god.”⁹ Perhaps there was something about the qualities of light and sky on the mountaintop that was encapsulated in the name of the god (Fig. 4). Furthermore, it is known that the priest of Lykaion Zeus was involved in “rainmaking” by means of sacrifice and the use of an oak branch (Paus. 8.38.4), indicating a strong religious relationship between the site and its weather.

7. Kordatzaki et al. 2016; Voyatzis 2019, pp. 138–139.

8. Cook 1914, pp. 63–68; Zolotnikova 2013, p. 105; Mahoney 2018, pp. 15–16.

9. Kerényi 1975, pp. 4–10, suggests that Zeus meant “the moment of lightning up.”



Figure 4. Early morning light at the altar of Zeus on Mt. Lykaion. Photo D. G. Romano

Throughout antiquity there were many stories referring to Mt. Lykaion that included wolves and werewolves. These stories began as early as Hesiod, ca. 700 BCE, as reported by Eratosthenes (*[Cat.]* 8). Many scholars have suggested that the name of the mountain and the myths relating to the early cult have to do with wolves. But while the Greek word for “wolf” has some similarities with the mountain’s name, the name Lykaion is likely derived from words for “light.”¹⁰

The typical explanation for why a sanctuary was established on Mt. Lykaion is that Zeus was a sky and weather god honored at many sites throughout the Greek world, often on mountains (Olympia being a significant exception).¹¹ Attractions at Mt. Lykaion included abundant springs, large flat spaces for athletics, and access to building stone.¹² But the southern peak was in use thousands of years before the Greek pantheon was established, as evidenced by large quantities of pottery from the Final Neolithic to the Middle Helladic period (ca. 4500–1600 BCE).¹³ Conceivably, shepherds brought their flocks up the mountain in the summer months from the earliest periods on, a practice known on Crete at sites of later peak sanctuaries of the Early Bronze Age.¹⁴

But there must have been compelling reasons for people to climb to this site that were more visceral than access to abundant springs, meadows, and building stone. The unique shape and physical aesthetics of the peak

10. The linguistic argument that the origin of the word Lykaion derives from the Greek word for “wolf” (λύκος) cannot in fact be substantiated since this argument revolves around the adjectival form of the noun λυκαῖος, which normally would be from an α-stem noun. The adjectival form of λύκος (wolf) is λύκειος, which

would derive from an o-stem noun. The underlying noun of the adjective λυκαῖος is *λύκα, which is not a Greek word since the word for female wolf is λύκαινα. However, the words that can be associated with this stem are related to “light.” See Cook 1914, pp. 63–68; Jost 1985, pp. 250–251; Zolotnikova 2013, p. 105; Mahoney

2018, pp. 15–20.

11. Belis 2015, pp. 50–55, 201–203; see Table 1, below.

12. Davis 2017, pp. 4–5.

13. Romano and Voyatzis 2014, pp. 584–589.

14. Peatfield 1990, p. 126; Chaniotis 1999, pp. 181–220.

in relation to the majestic sweeping views create a sensational impact, discussed below. The most energizing attractions, however, may have been the dynamic expressions of natural physical forces experienced there, related to earthquakes, ground motion such as landslides and rockslides, lightning, and thunder.

In the 8th century BCE, Hesiod (*Theog.* 504–505) made a stark distinction between Zeus’s lightning bolt, the visible flash it created, and the sound of thunder: δῶκαν δὲ βροντὴν ἠδ’ αἰθαλόεντα κεραυνὸν / καὶ στεροπὴν: τὸ πρὶν δὲ πελώρη Γαῖα κεκεύθει ([The gods] gave [Zeus] thunder and the burning thunderbolt / and the flash of lightning: for before then monstrous Earth had hidden these). Each component was wielded individually by Zeus, yet always in conjunction with the others. The myth captures three levels of power embodied in the experience—sound, sight, and physical impact. For those living in the Mt. Lykaion area, regular powerful lightning, thunderstorms, and earthquakes likely affected their perceptions of the natural forces of the mountain. Pausanias mentions that the Neda River begins on Mt. Lykaion at a place called Mt. Kerausios, which must mean “thundering.”¹⁵

Our case for the influence of natural forces begins with the ancient tectonics, which shaped the unique landscape, and the active plate tectonics, causing ground motions and land ruptures. We then focus on the unique vantage point that Mt. Lykaion offers for sensing and observing thunder and lightning. We broadly quantify the frequency of lightning and intensity of thunder at and surrounding the sanctuary, and we note the frequency and intensity of earthquakes, moving from general influences of ground shaking and atmospheric to specific impacts on the site.

TECTONIC DIMENSIONS

Mt. Lykaion lies in the Pindos belt, a mountain range created by plate-tectonic collision ca. 70 to 55 million years ago.¹⁶ Today, the folded, thrust-faulted rocks are exhumed as a 50 km wide north-trending swath of alternating ridges and valleys.¹⁷ The southern peak, where the upper part of the Sanctuary of Zeus, including the ash altar, is located, projects upward from this tectonic grain as a smooth, symmetrical, conelike summit (Figs. 5, 6). Figure 5 is a view from the east of the position of the ash altar, perched high above Megalopolis. Its soft landscape of weathered sandstone and thin-bedded limestone contrasts with jagged expressions of subjacent thick-bedded limestone. Note the steep and rugged landscape that had to be surmounted by those visitors who traveled to the Sanctuary of Zeus (see Fig. 5).

15. Paus. 8.41.3: εἰσὶ δὲ αἱ πηγαὶ τῆς Νέδας ἐν ὄρει τῷ Κεραυσίῳ: τοῦ Λυκαίου δὲ μοῖρά ἐστι (The source of the Neda is on the Kerausios mountain, which is a part of Mt. Lykaion). While Κεραύσιος is not a Greek word,

κεράνιος (LSJ⁹) means “of a thunderbolt” or “thunder-smitten.”

16. Skourlis and Doutsos 2003, pp. 892–895.

17. Davis 2019, pp. 1182–1183.

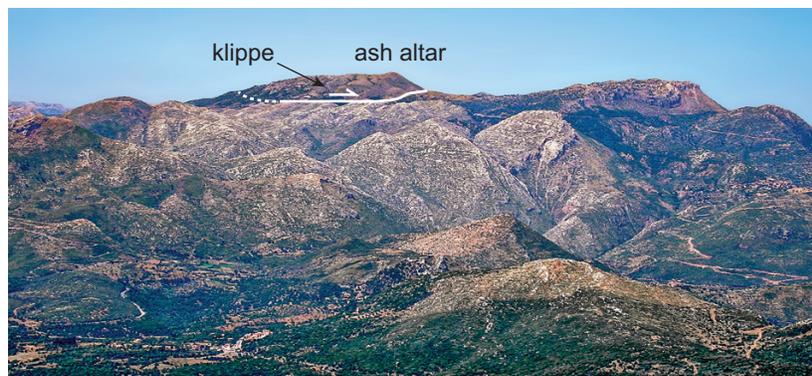


Figure 5. View from the east above Megalopolis toward the ash altar of the Sanctuary of Zeus. Photo G. H. Davis

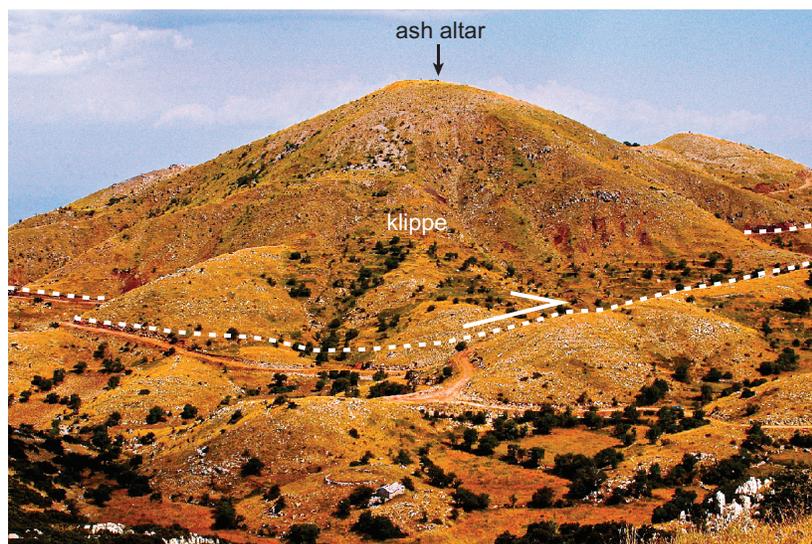


Figure 6. View of the Lykaion klippe and thrust fault trace from the northwest. The dotted line is the trace of the thrust fault. The white arrow indicates the relative fault motion of the bedrock now exposed in the klippe. Photo G. H. Davis

The upper sanctuary occupies a tectonic klippe, which is an erosional outlier of what was once a kilometers-thick, overthrust, regionally extensive rock mass. Its base is a fault zone from which springs emanate from place to place. The upper part of the sanctuary lies directly above the trace of the Lykaion thrust fault (solid white line in Fig. 5). The Lykaion thrust fault can be followed circumferentially around the peak (see Fig. 6).¹⁸ One part of its trace coincides with the upper limit of the lower sanctuary.

The aesthetically pleasing landscape expression of the Lykaion klippe may have been imbued with supernatural meaning for local people. Similarly, for the Blackfoot tribe in Montana (United States), Chief Mountain klippe (Ninaistako, “Stands Alone”) has been a sacred ritual site and traditional home of Thunderbird, the creator of thunder, for thousands of years.¹⁹

The reason the Lykaion peak occupies such a high perch is the combination of ancient and active tectonics. The highest standing terrain in the Peloponnese, including the Mt. Lykaion region, was raised to that level during regional thrust faulting and crustal thickening caused by tectonic compression in Late Cretaceous to Eocene time. In contrast, crustal stretching (extension) caused the crust to thin and regions to break apart, which in turn caused the original high-standing region to drop, profoundly in places. In fact, the ca. 1 km of topographic relief measured between the summit of Mt. Lykaion and the elevation of the Megalopolis basin expresses the

18. On the fault, see Lalechos 1973; Papadopoulos 1997; Davis 2008, pp. 8–9; 2018, pp. 2, 4, 5, fig. 5.

19. National Park Service 2006; Davis 2017, pp. 5–6, fig. 3:b.

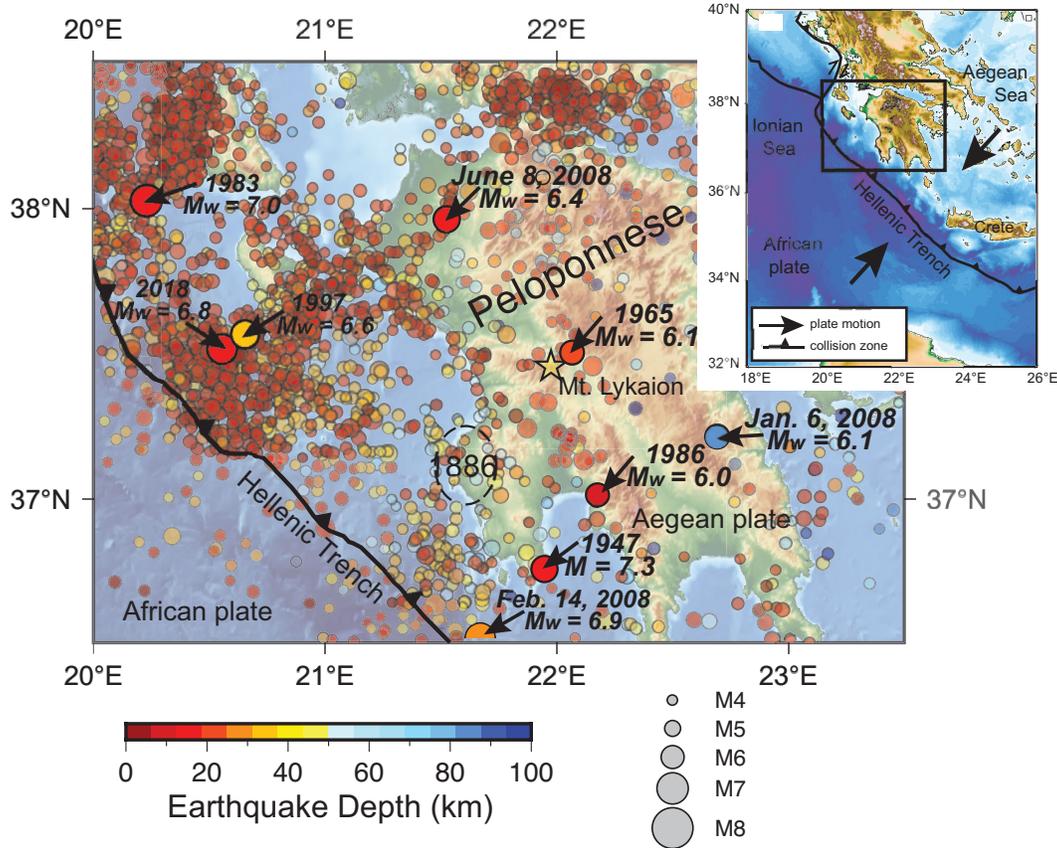


Figure 7. The Hellenic Trench and earthquakes of magnitude >4 in 1960–2021, with dates and magnitudes of major earthquakes indicated; the inset shows the plate tectonic setting. S. Beck; data United States Geological Survey ANSS Comprehensive Earthquake Catalog, <https://earthquake.usgs.gov/data/comcat/catalog/us/>

cumulative effect of such faulting. This 1 km of topographic relief is twice that shown in Figure 5.

The Peloponnese may be described as an earthquake factory. Plate tectonic interactions between the African, Aegean, and Eurasian plates have been actively extending the Peloponnese lengthwise for 20 million years.²⁰ The African oceanic plate subducts beneath the Aegean continental plate along the Hellenic Trench south of Crete, while the Aegean upper plate overrides the African plate at six times the speed of the latter,²¹ thus creating extensional forces responsible for earthquake-generating faulting (“normal faulting”) that accommodates tectonic stretching. Both the east–west oriented Gulf of Corinth and the northwest–southeast Megalopolis basin bordering Mt. Lykaion are discrete expressions of this stretching.²² Indeed, this normal faulting is pervasive, as evidenced by earthquakes, ground shaking, landslides, damage to built structures, and loss of human life. Figure 7 shows a map of the Hellenic Trench and earthquakes of $M_w > 4$ in 1960–2021, with dates and magnitudes of major earthquakes indicated.²³

As today, ancient peoples near the Lykaion peak would have felt earthquakes with magnitudes $M_w > 6$ generated anywhere within the Peloponnese, as well as ground motions of larger, more distant earthquakes. The strongest documented shaking on Mt. Lykaion is attributable to the Megalopolis earthquake ($M_w = 6.1$) on April 5, 1965. Its epicenter was just 4 km from the southern peak of Mt. Lykaion (see Fig. 7). Shaking was felt within 300,000 km², and the toll included 20 persons killed, 160 injured, 110 houses collapsed, 5,000 damaged beyond repair, 6,000 damaged seriously, and 7,000 slightly damaged. Based on damage reports, it was classified as level VIII on

20. McClusky et al. 2000, pp. 5711, 5714–5717, fig. 7.

21. Ganas and Parsons 2009, pp. 1–3, 5.

22. Papadopoulos 1997.

23. The “moment magnitude” (M_w) scale for earthquakes provides an estimate of earthquake size, that is, total energy released. A magnitude of 6 would cause considerable damage to buildings and other structures.

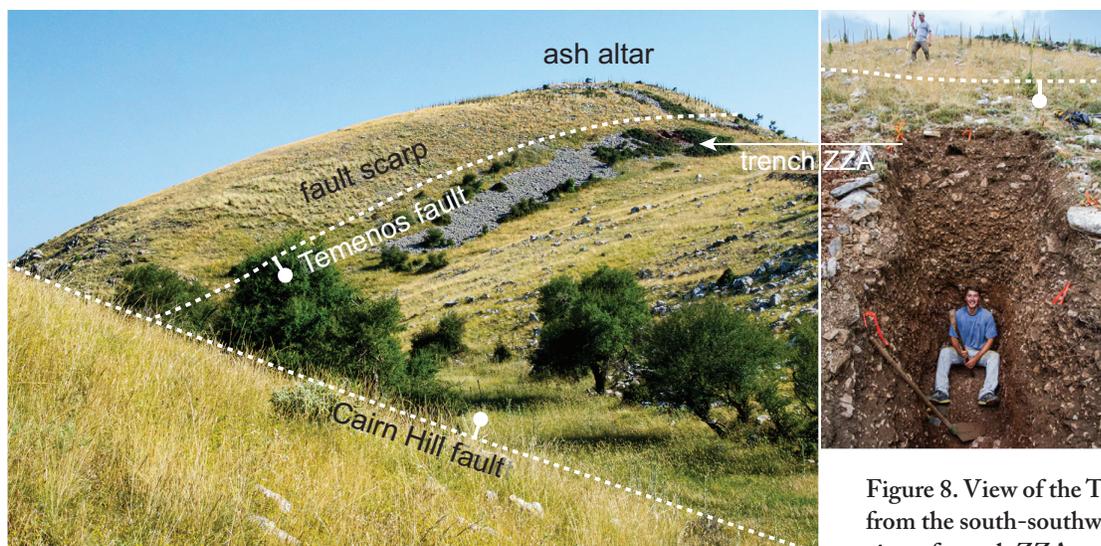


Figure 8. View of the Temenos fault from the south-southwest; the detail view of trench ZZA at right shows the thick hillslope debris that has accumulated on the side of the fault that dropped. Photos G. H. Davis

the Modified Mercalli Intensity scale (MMI).²⁴ Other notable earthquakes occurred within ca. 80 km of Mt. Lykaion in 1947, 1986, and 2008, causing mild shaking (MMI intensities of levels V and III).²⁵ In 1983, 1997, 2008, and 2018, very large earthquakes were generated near the Hellenic Trench (see Fig. 7). Though their epicenters ranged from ca. 100 to 180 km from the Lykaion peak, ground shaking could still be felt in the Mt. Lykaion subregion. Nine significant earthquakes between 1805 and 1899 in the southwest Peloponnese would also have been felt at Mt. Lykaion.²⁶ The 1886 earthquake (estimated $M_w = 6.8-7.3$) may have been the largest: it caused at least 326 deaths and the near destruction of most structures near the coastal town of Filiatra, ca. 50 km from Mt. Lykaion, and was felt in the Mt. Lykaion region.²⁷ The earthquake record over the last two centuries provides a window into the magnitude and frequency of earthquakes in antiquity, since the pace and nature of regional plate motions have not changed in millions of years.

The fault slip that generates earthquakes also frequently produces normal fault scarps.²⁸ Those associated with active faulting are conspicuous in the landscape of Greece: the land surface steps down, and the backwall of the step (the fault) is a steep surface. In a single earthquake event, the step produced is typically less than 1 or 2 m, but, over the course of geological time (thousands to millions of years), a normal fault zone may accommodate hundreds of meters of total offset. Significant faults are present in the area of the ancient sanctuary. Just 1 km east-southeast of the ash altar are two long, continuous steplike fault scarps marked by very steep headwalls, the upper of which is ca. 130 m tall. Open fissures abound. These scarps are marked by abundant evidence for active mass wasting down the scarp faces. Rockfalls have delivered blocks up to 3–4 m on a side. East of the fault zone is a landslide complex mapped by Davis as covering an area approximately 1.5×1 km.²⁹ Some of the rockfalls likely attracted the attention of visitors to the sanctuary. Along the southeast margin of the altar, there is a scarp in the landscape whose base coincides with an obvious normal fault that Davis mapped as the Temenos fault (Fig. 8).³⁰ A broad band of limestone scree (gray band in Fig. 8) has accumulated at the base of this scarp through down-slope creep, perhaps partly driven by subregional to

24. Ambraseys 1967, p. 1030.

25. See the United States Geological Survey earthquakes website, <https://earthquake.usgs.gov/earthquakes/>.

26. Papadopoulos, Baskoutas, and Fokaefs 2014, pp. 391, 396–401, table 1.

27. Sakellariou, Kouskouna, and Makropoulos 2010, p. 1; Papadopoulos, Baskoutas, and Fokaefs 2014, pp. 397–399.

28. Goldsworthy and Jackson 2000, p. 968.

29. Davis 2017, p. 6; 2018, pp. 4, 5, fig. 5.

30. Davis 2017, p. 4; 2018, pp. 5–6, figs. 5, 6.

regional earthquake ground motion. Paleoseismic trenching conducted by Davis at trench ZZA, just below the trace of the fault,³¹ revealed that the down-dropped block of the normal fault has accumulated 2+ m of recent colluvial material (see Fig. 8, detail view), with no such material on the block above it. This suggests active faulting along the Temenos fault, though we continue to evaluate whether slip is active and thus whether any slip along this fault may have been experienced in antiquity.

THUNDEROUS SOUNDSCAPE AND ITS PERCEPTUAL CONTEXT

Mt. Lykaion was and is an extraordinary place from which to experience two of Zeus's primary symbols—thunder and lightning. With a viewshed from the northern peak extending ca. 100 km in ideal conditions, thunderstorms and lightning can be visible across vast distances. Figures 9 and 10 show the extent of the unobstructed viewshed out to a distance of 60 km from an observer on the highest peak of Mt. Lykaion (1,421 masl) for terrain and objects with an altitude at least 1.5 km above sea level (kmasl). This would include cloud bases, rain shafts below clouds, and lightning flashes. Given that thunderstorms may reach 10–12 kmasl (see Fig. 10), they may be visible even when they occur well outside the area shown. Crucially, the reverse is also true—a lightning strike on Mt. Lykaion is visible throughout a wide landscape. Given the number of thunderstorm days on Mt. Lykaion (discussed below), individuals in the surrounding valleys would likely associate lightning and thunder with the mountain and divine activity. Thunderstorm perception thus connected many disparate peoples scattered across valley and mountainside villages to the sacred associations of Lykaion Zeus.

A thunderclap typically can reach 120 dB SPL near the source;³² it is one of the loudest sounds perceived by preindustrial humans up to 15–25 km away, independent of visibility (Fig. 11). Thunder is produced by pressure waves generated during expansion of hot channels carrying electrical current between electrified regions of clouds or between one region and ground. Our hearing detects the acoustic signal produced by lightning, traveling at the speed of sound (ca. 330 m/s), and our sight detects visible light associated with the hot channels, traveling at the speed of light (ca. 300 m/μs), one million times faster. Thus, if one observes isolated lightning with its closest hot channel 10 km away, the sound will arrive about 30 seconds after the flash is seen. For persons at a distance, the lightning and the thunder could be perceived as two separate phenomena.

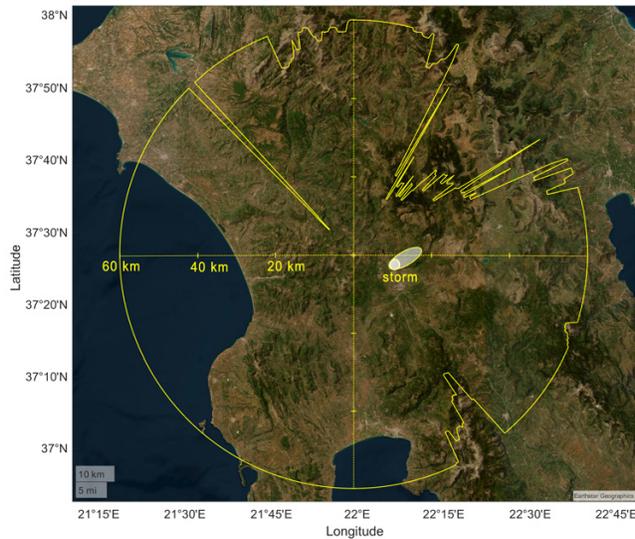
Evidence of how ancient Greeks understood the phenomena of thunder and lightning lies scattered among ancient (often fragmented) texts, translations, and later interpretations. Gathering them together, we find thunder discussed in two explanatory modes: technical, based in phenomenological observation, and sacral, based in mythological accounts and ritual practices. The technical mode formed a largely mathematical approach to understanding the natural systems of the world, including human speaking, instruments, and sound more generally.³³ The technical understanding of thunder in antiquity was derived from the work of philosophers and mathematicians observing natural phenomena.³⁴ Many

31. Trenching was carried out by George Davis, assisted by Alex Weber, in June and July of 2016.

32. Lacroix et al. 2018, p. 12058. For a definition of dB SPL, see https://ec.europa.eu/health/scientific_committees/opinions_layman/en/hearing-loss-personal-music-player-mp3/glossary/def/decibel.htm.

33. Pythagoras and his followers explored sound extensively; see the helpful review of harmonics in Barker 2007. Various components related to sound were revisited in: Archytas, fr. 1 (see also Huffman 2005, pp. 103–105); Arist. *De an.* 2.8; *Pl. Ti.* 67a–c, 79e–80b (he clearly states that a myth about a thunderbolt is in fact a representation of a natural phenomenon); Plut. *De recta ratione audiendi*; Porph. *Harmonics*; Ptol. *Harm.*; Theophr. *Sens.* See also the thorough summary of Ptolemy's and Porphyry's commentaries in Barker 2015, and the summary of ancient sound-driven investigations in Barker 2019, p. 92, n. 1.

34. Work by Anaximander and Anaxagoras was summarized in Plut. *Placita philosophorum* 3.3; Arist. *Met.* 2.3; see also the summary provided in Frisinger 1965, p. 785.



authors agreed that thunder was created by the interactions of clouds in some way: presuming that hot air could be caught in clouds, Aristotle (*Met.* 2.9) surmised that

it is squeezed out as the clouds contract, and collides in its rapid course with the neighbouring clouds, and the sound of this collision is what we call thunder. . . . [T]he variety of the sound is due to the irregularity of the clouds and the hollows that intervene where their density is interrupted.³⁵

But these theories emerged relatively late in the period that the sanctuary at Mt. Lykaion was in use. Under a lens of mythology, starting well before the mathematicians and philosophers, thunder and lightning, the most powerful observable natural forces, were solely within the purview of Zeus. Many ancient texts equate thunder to his voice, particularly in anger, with the potential for direct message divination. But thunder's power was also symbolically and practically two-sided. It could portend destruction by lightning strike and fire, or bring life-supporting rainfall and draw anthropogenic symbolism.³⁶

Practices of sound-making, including thunder reenactments, were linked with Zeus's ritual practices. The large metal cauldrons at the Sanctuary of Zeus at Dodona may have been sounding vessels serving multiple functions: apotropaic, to ward off evil with resonating din; mantic, as bearers of prophecy from Zeus; and mimetic of thunder.³⁷ Similar functions were attributed to a bronze gong hung between two columns at Dodona.³⁸ Such vessels have not yet been associated with or found on Mt. Lykaion. Nevertheless, sound beyond objects designed for sound-making must have been sacred at the site; the entire context supporting the games held on Mt. Lykaion was ritualized, including the sounds produced in processions, sacrifices, competitions, and associated activities. Within the heightened experience of ritual space and activity, all sounds would be elevated from quotidian contexts, a deliberate dynamic within sanctuaries broadly.³⁹ The experience of thunder from a nearby lightning strike would have been

Figure 9 (*left*). A 60 km viewshed from the highest peak of Mt. Lykaion at an altitude of 1.5 kmasl with a thunderstorm indicated (the rain shaft is brighter white). Base image EarthStar Geographics; annotations K. Cummins

Figure 10 (*right*). The same thunderstorm as seen in Figure 9, with a rain shaft in the Megalopolis valley, observed from the east slopes of Mt. Lykaion, August 2022, with the Rapouni Oros peak at far left. Photo P. Jordan

35. Trans. E. W. Webster, Oxford, 1931.

36. Nagy 1990, pp. 140, 196–198; Forte 2022, p. 26.

37. Cook 1902; Nicol 1958, pp. 133, 139–140; Power 2019, p. 17.

38. Cook 1902, pp. 6–7.

39. Mylonopoulos 2006, p. 92.

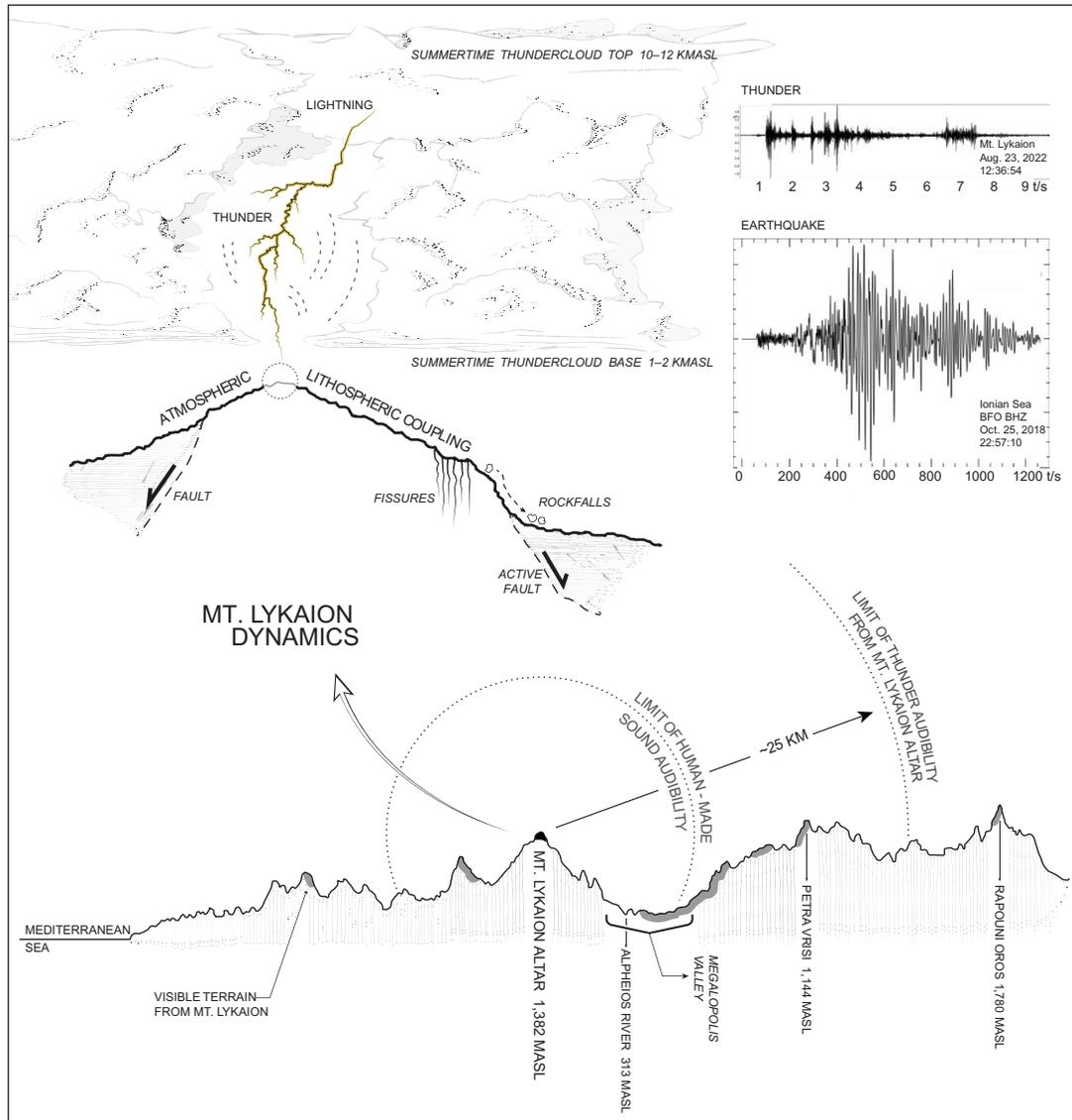


Figure 11. The integrated coupling of sonic, visual, atmospheric, and lithic dynamics on Mt. Lykaion: southwest–northeast cross section; ca. 5× vertical exaggeration for the mountain range profile at bottom. P. Jordan; data G. H. Davis, K. Cummins, and S. Beck

extremely impactful to those already in a heightened sensorial state at the sanctuary.

Thunder enables a listener to gauge a storm’s position and movements, and it connects disparate locations without visual access. It thus defines a boundary of associated perception around Mt. Lykaion different from that based on vision. The association of thunder with Zeus could automatically emplace anyone who heard it within a wider divine landscape centered on the mountain. The perceptive boundary defined by lightning would be apparent from the sanctuary, especially from the summit, where observers could easily locate lightning strikes in the surrounding region. But the perceptive boundary defined by thunder could be experienced equally well in the surrounding terrain as at the summit, and equally well during the day as at night, as visual connection was unnecessary. The reciprocity of these experiences could have held different and exceptional meanings for ancient witnesses. Whether on the mountain or within

the greater landscape, the sensory influence of Lykaion Zeus could have been a sacred experience, a form of ritual communication extending far beyond the mountain itself.

The conditions for perceiving thunder and lightning on the mountain remain essentially the same as in antiquity. Even with topsoil erosion, the bedrock landforms have not significantly changed,⁴⁰ and the flat expanse of the hippodrome exists in a form that is likely similar to that in ancient times. The landscape of the sanctuary, wherein all sound reverberates, thus provides a resonant experience representative of ancient conditions, although it must be said that, by and large, the buildings and structures are no longer standing. Vegetation can have some scattering and absorptive effects on sound transfer, and the ancient floral components of the sanctuary are as yet unknown. Such material, however, would have little effect on thunder propagation or lightning perception, and this variation does not stand in the way of sonic determinations.

The wider landscape beyond the sanctuary is also reminiscent of ancient conditions, as it remains sparsely populated, without extensive development. The rural condition of the mountain maintains a limited array of modern sound sources. Sound likely propagates on and from Mt. Lykaion similarly as in ancient times, and with only occasional masking interference from newer sources. There have been more landscape-level changes in the surrounding region, including a modern large open-pit lignite mine, natural and human-constructed alterations to the course of the Alpheios River, and the introduction of pavement, highway tunnels, and new buildings throughout the region. Newer constant sounds—what we understand as background sounds—include the lignite processing and power plants.⁴¹ While thunderstorm perception on the mountain is likely unmodified, perception from within the surrounding terrain could be mildly to moderately altered by these changes. There is, however, frequent air pollution due to the lignite mine and the electrical plant in Megalopolis. This can negatively affect the air quality and the vistas from the mountaintop and would significantly change the nature of the experience for modern visitors to the site compared with their ancient predecessors.

The most significant discrepancy between ancient and contemporary times is us—the way we interpret sound. Our cultural backgrounds and sonic conditioning are different from those of people in antiquity. We explain thunder and lightning without the import of omens or survival, we are accustomed to more and louder sounds in everyday experience, and we differentiate foreground and background sounds according to our industrial and mechanized lived experience and expectations. Personal context influences how we perceive, judge, and interpret sounds. However, the mechanism by which we hear and initially process sound, the ear-to-brain connection, is the same now as in antiquity. Thus, the loudness of thunder would be experienced in the same way by ancient and contemporary listeners, while their interpretation of and emotional response to that same loudness could be vastly different. Psychoacoustics investigates this thin border between sonic perception and its interpretation. With the consistency of landforms, sonic environment, and human physiology, psychoacoustic investigations on the mountain give us a way to investigate

40. Davis 2017, pp. 5–8, figs. 4, 5.

41. Schafer 1994, pp. 151–153.

current perception on the mountain as a gateway to understanding how ancient perceptions might have been structured.⁴²

Even in antiquity, Greek thinkers grappled with the import of individual perception to hearing. Kidd traces how Aristotle differentiated hearing a sound from a sound existing: perception was key.⁴³ Aristotle proposed *phantasia* as a means to understand the effect of sensory stimuli; it is a still-contested concept, “a change arising because of an act of perceiving” that effectively identifies our sense perceptions.⁴⁴ It could be one way to explain the fear felt after hearing Zeus’s thunder echo across the landscape. Whether through *phantasia*, psychoacoustic measurements, or other investigatory modes, we continue a long tradition of investigating how sonic experience serves to define a space and its importance.

MAPPING THUNDER AND LIGHTNING

Local perceptions of thunder and lightning were investigated further using modern lightning measurements at 18 prominent mountain peaks and sanctuaries in Greece to explore possible reasons for the selection and long life of the site at Mt. Lykaion (Table 1; Figs. 12, 13). The technical literature on the perceptual range for thunder, which dates back to the 1940s, suggests that thunder can typically be heard over 7–15 km of flat ground, depending on propagation path and local noise. The theoretical upper limit is about 25 km, due to thunderstorm-related wind, along with the vertical profile of pressure and temperature that decreases with increasing altitude.⁴⁵

In 1956, the World Meteorological Organization established a global distribution of thunderstorm days per year based on human observations.⁴⁶ Once lightning locating system (LLS) networks became reliable and widely available, direct estimates of lightning incidence replaced the older calculations based on thunder-day observations. We explore the spatial, seasonal, and diurnal variations in the incidence of lightning using observations of lightning recorded by Vaisala’s GLD360 global LLS.⁴⁷ This system employs a ground-based magnetic field sensor network to locate and quantify lightning. GLD360 produces lightning data as time-ordered reports of cloud-to-ground strikes and energetic in-cloud lightning discharges (collectively, “lightning events”). A lightning flash, the connected discharges lasting ca. 1 second and producing the perception of thunder, typically includes several such events. The measurements for each event that are relevant for our investigation include time of occurrence and location of the discharge accurate to 1–4 km throughout the globe. Another LLS providing coverage in this region is the ZEUS system managed by the National Observatory of Athens.⁴⁸ The GLD360 was selected for this

42. Jordan 2021a, 2021b.

43. Kidd 2019.

44. Kidd 2019, p. 86, n. 35.

45. Fleagle 1949.

46. World Meteorological Association [1953–1956] 1969, pp. v,

vii; see also Anderson and Eriksson 1980, pp. 65–69.

47. Said 2017.

48. Lagouvardos et al. 2009, pp. 1714–1716; Gatidis et al. 2018, pp. 181–182.

TABLE 1. KEY PEAKS AND SANCTUARIES OF ZEUS

<i>Site</i>	<i>Elevation (masl)</i>	<i>Latitude</i>	<i>Longitude</i>	<i>LD</i>	<i>TD</i>	<i>TH</i>	
1	Ash altar of Zeus, Mt. Lykaion	1,381	37°26'48" N	21°59'19" E	10.5	49	121.6
2	Sanctuary of Zeus Lykaios, Megalopolis	401	37°24'52" N	22°07'34" E	11.8	49.6	124.4
3	Sanctuary of Zeus, Mt. Ithome	795	37°11'09" N	21°55'28" E	17.1	46	125.8
4	Ash altar of Zeus, Olympia	35	37°38'19" N	21°37'49" E	15.7	46	130.2
5	Kronos Hill, Olympia	103	37°38'25" N	21°37'52" E	16.0	46.4	130.2
6	Mt. Taygetos	2,403	36°57'10" N	22°21'00" E	11.9	45.4	131.4
7	Mt. Helmos	2,288	37°59'04" N	22°11'54" E	4.5	33.2	76.2
8	Mt. Erymanthos	2,182	37°59'12" N	21°50'03" E	8.2	47.2	118.0
9	Mt. Kyllene	2,352	37°56'21" N	22°23'44" E	3.5	31.6	72.8
10	Sanctuary of Zeus, Nemea	334	37°48'35" N	22°42'37" E	4.7	27.4	61.0
11	Ash altar of Zeus, Mt. Phoukas	850	37°51'42" N	22°44'26" E	4.2	25.6	58.6
12	Sanctuary of Zeus, Mt. Arachnaion	1,132	37°38'25" N	23°01'45" E	6.3	30.2	74.4
13	Sanctuary of Zeus, Mt. Hymettos	1,000	37°56'55" N	23°48'55" E	6.8	28.4	67.6
14	Temple of Olympian Zeus, Athens	82	37°58'10" N	23°44'00" E	5.9	27.4	69.4
15	Sanctuary of Zeus, Mt. Oros, Aigina	528	37°42'03" N	23°29'44" E	4.3	22	50.4
16	Mt. Parnassos	2,363	38°32'09" N	22°37'12" E	4.9	31.6	70.8
17	Sanctuary of Zeus, Dodona	630	39°32'47" N	20°47'20" E	13.1	60.2	165.0
18	Mt. Olympos	2,917	40°05'18" N	22°21'29" E	6.4	41.6	103.4

Note: Locations are shown in Figures 11 and 12. Abbreviations: LD = lightning event density (events/km²/year); TD = thunderstorm days/year within 15 km; TH = thunderstorm hours/year within 15 km.

analysis because of its ability to locate a higher fraction of the lightning discharges with somewhat more precise discharge location.

Event densities during 2016–2020 inclusive were calculated over 0.01° (latitude and longitude) resolution grids (ca. 1 × 1 km) using a 7 km averaging radius for smoothing. Lightning incidence during our five-year study period is shown in an annualized lightning event density (LD) map (see Table 1; Fig. 12) with units of events/km²/year. Lightning incidence decreases from west to east across the Peloponnese, varying by a factor of 10. This spatial pattern of lightning incidence was also found by the Zeus LLS system, described above, for the period of 2005 through 2019.⁴⁹

Mt. Lykaion is in a region of moderate lightning incidence (10–11 events/km²/year), not a unique hot spot for direct lightning strikes. Its viewshed, however, includes hot spots, especially to the northwest and southwest (see Figs. 9, 12). In Figure 11, Mt. Lykaion is the solid circle (site 1), and the 17 comparison sites are indicated by their numbers in Table 1 (sites 2–18). Thus, viewers on Mt. Lykaion would be able to see many lightning strikes per year.

Another perspective on the lightning experience at this site is the broader perception of lightning—the combination of seeing lightning in the distance and hearing thunder reverberating from the mountaintop. To assess the hearing of thunder from visible lightning, the distance between each lightning event and the center of each 0.01° × 0.01° grid location was

49. See <https://meteo.gr/talos/mean-lighting-activity-per-month.cfm>.

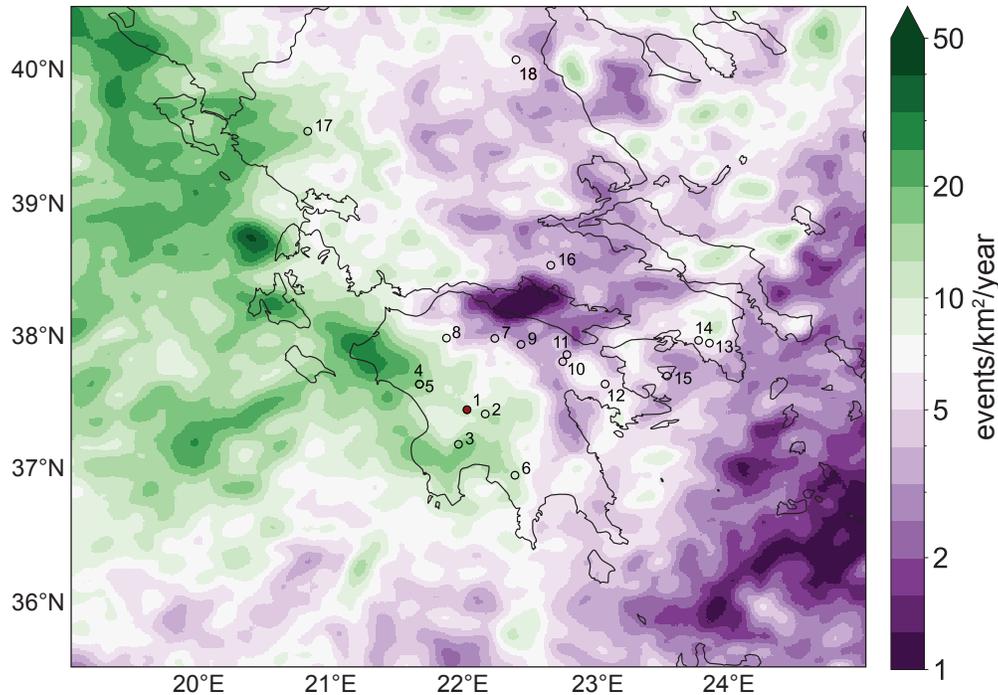


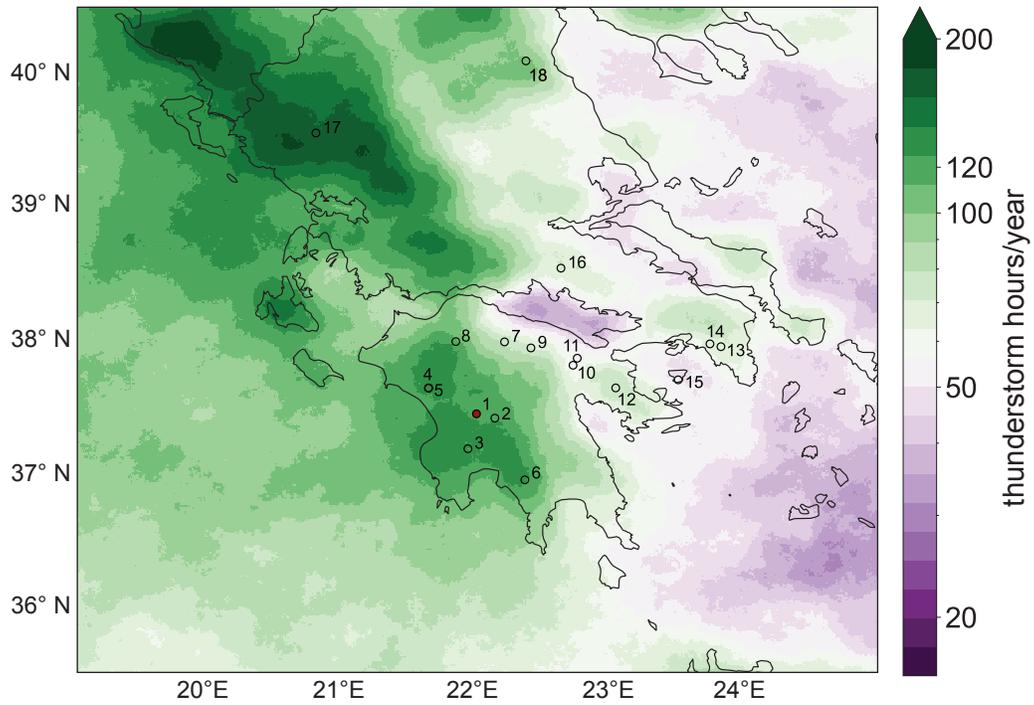
Figure 12. Lightning event density. Sites are listed in Table 1. R. Said; data Vaisala Inc.

determined, and the number of hours per year with at least two events (thunder hours [TH]) within a specified distance were accumulated for each grid location. The average TH map derived from this lightning dataset, and assuming a 15 km perceptual range, is shown in Figure 13:a. The impact of lightning at Mt. Lykaion is more significant for this parameter, experiencing >120 TH annually. Using this same analysis method, but accumulated for daily rather than hourly periods, the average number of days per year during which thunder was heard (thunderstorm days [TD]) at Mt. Lykaion averaged ca. 50, assuming a 15 km perceptual range (see Fig. 13:b). This is the highest value in the Peloponnese. Interestingly, the tallest mountain in Greece, Mt. Olympos (site 18), has a significantly lower value (see Table 1).

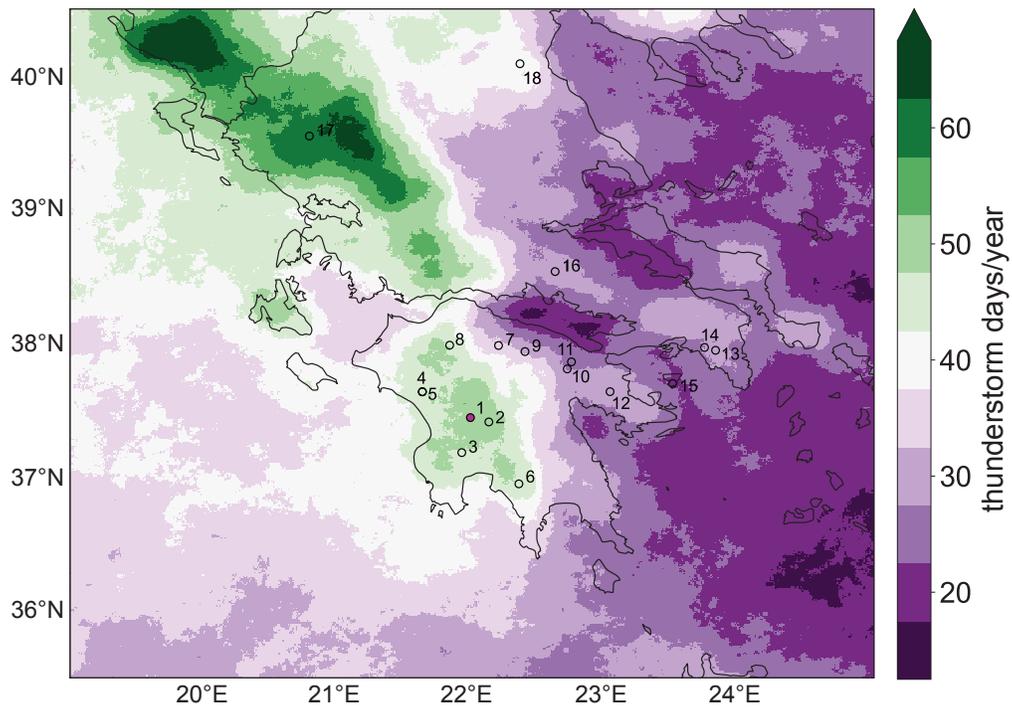
Two additional parameters that are relevant to the thunderstorm experience near Mt. Lykaion and are deducible from the thunderstorm dataset are provided here: diurnal and seasonal variations. Storms over the sea and coastal areas tend to occur overnight in the cooler months, and storms over land tend to occur in the mid- to late afternoon in warmer months. The Lykaion festival likely occurred during the warmer months, and therefore the participants would surely have witnessed storms that included lightning and thunder. More detailed information about the daily, hourly, and monthly variation in lightning activity is provided by the National Observatory of Athens, using information accumulated from the Zeus LLS discussed above.⁵⁰

The sites selected for Table 1 and this analysis include seven mountain peaks and 11 sanctuaries of Zeus, mostly in the Peloponnese, but several in central and northern Greece. In some cases, the sanctuary of Zeus was situated on or near a mountain peak, as was common in antiquity. These include Lykaion, Ithome, Phoukas, Arachnaion, Hymettos, Oros, and Olympos. Mt. Olympos (see Table 1, site 18), in northern Greece, is the

50. See <https://meteo.gr/talos/mean-lighting-activity-per-month.cfm>.



a



b

Figure 13. Thunder events: (a) thunderstorm hours/year (TH) assumes a 15 km perceptual range; (b) thunderstorm days/year (TD) at 15 km. Sites are listed in Table 1. R. Said; data Vaisala Inc.

highest mountain in Greece at 2,917 masl and was known as the legendary home of the gods. A sanctuary of Zeus was uncovered there just below the peak, at 2,817 masl (Ayios Antonios). Several of these sanctuaries of Zeus are found in relatively low-lying areas, including the examples at Olympia, Nemea, and Athens (see Table 1, sites 4, 10, and 14).

With respect to thunderstorm days, the ash altar of Zeus at Mt. Lykaion (site 1) and the Sanctuary of Zeus in the Megalopolis agora (site 2) show the same number of days, 49—the highest value in the Peloponnese. The elevation at Mt. Lykaion is 980 m greater, and the linear distance between the sites is approximately 15 km. They register the same number of thunderstorm days because they are in the same general geographical region. The site that shows the greatest number of thunderstorm days in Greece is the Sanctuary of Zeus at Dodona (see Table 1, site 17), in the Pindos Mountains in northern Greece, near the modern border with Albania. Dodona was known in antiquity as the oldest Greek oracle (Hdt. 2.54–55). Odysseus goes to Dodona “to hear the will of Zeus from the high-crested oak of the god” (Hom. *Od.* 14.327).

We assume that lightning incidence today is not dramatically different than it was 3,000 years ago because overall thunderstorm development is primarily dependent on atmospheric moisture, near-surface temperature, and the temperature profile throughout the troposphere, and these trends over the last millennia are not shown to be larger than typical decadal variations. Local factors impacting storm development and lightning, including altitude/orography and locations of land-sea interfaces, have not changed significantly (from a meteorological perspective) during that time. The annual number of thunderstorms may have varied, but we reasonably assume that the relative locations of storms have not.

The above evidence shows that people living in the vicinity of the Sanctuary of Zeus on Mt. Lykaion regularly experienced nearby lightning and had one of the best vantage points in Greece to see lightning and hear thunder from distant thunderstorms. Although not a hot spot for direct lightning strikes, Mt. Lykaion had a panoramic view of more distant lightning and the highest number in all the Peloponnese of days per year when thunder could be heard.

CONCLUSIONS

The motive that drives this research is the desire to understand what initially attracted people to Mt. Lykaion, and why they kept coming to it over the course of thousands of years. We conclude that the practical resources on or near the site (for example, springs, mountain meadows, building stone) would not necessarily have been the initial or only attractions, nor would they in themselves account for the sustained use that is now well documented by the Mt. Lykaion Excavation and Survey Project. There are additional powerful and visceral draws. The majesty of the site and the views from the mountain are constant features. Not unrelated is the uniqueness of the geomorphology of the landscape, so anomalous with respect to the typical topography of the Pindos mountain belt. In addition, strong earthquakes and related phenomena—ground shaking, destruction and death, landslides, rockfalls—are the result of ongoing crustal extension in the Peloponnese.

The occurrence of earthquakes in the Peloponnese, then and now, is sufficiently frequent that the awe and fear they inspire are never lost on a local community. Finally, the atmospheric expressions of powerful forces in the forms of lightning and thunder, though not occurring every day, are seasonal, reliable, awe-inspiring, and essential elements in the cult of Zeus, who came to be honored at the site. All these experiences no doubt enhanced reverence for the formidable natural forces of the mountain and may help explain the initial attraction of the site, its development into a famed sanctuary of Zeus, and its continued use over thousands of years.

REFERENCES

- Ambraseys, N. N. 1967. "The Earthquakes of 1965–66 in the Peloponnese, Greece: A Field Report," *Bulletin of the Seismological Society of America* 57, pp. 1025–1046.
- Anderson, R. B., and A. J. Eriksson. 1980. "Lightning Parameters for Engineering Application," *Electra* 69, pp. 65–101.
- Barker, A. 2007. *The Science of Harmonics in Classical Greece*, Cambridge.
- , ed. and trans. 2015. *Porphyry's Commentary on Ptolemy's Harmonics: A Greek Text and Annotated Translation*, Cambridge.
- . 2019. "Greek Acoustic Theory," in Butler and Nooter 2019, pp. 92–108.
- Belis, A. 2015. "Fire on the Mountain: A Comprehensive Study of Greek Mountaintop Sanctuaries" (diss. Princeton Univ.).
- Butler, S., and S. Nooter, eds. 2019. *Sound and the Ancient Senses*, London.
- Chaniotis, A. 1999. *From Minoan Farmers to Roman Traders: Sidelights on the Economy of Ancient Crete* (Heidelberg althistorische Beiträge und epigraphische Studien 29), Stuttgart.
- Cook, A. B. 1902. "The Gong at Dodona," *JHS* 22, pp. 5–28.
- . 1914. *Zeus: A Study in Ancient Religion* 1. *Zeus, God of the Bright Sky*, Cambridge.
- Davis, G. H. 2008. "Archaeological Elements of Mt. Lykaion Sanctuary of Zeus (Southern Peloponnese) in Relation to Tectonics and Structural Geology," in *Donald D. Harrington Symposium on the Geology of the Aegean, 28–30 April 2008, University of Texas at Austin, Jackson School of Geosciences, USA* (Institute of Physics [IOP] Conference Series: Earth and Environmental Science 2), ed. E. Catlos, pp. 1–17.
- . 2017. "Tectonic Klippe Served the Needs of Cult Worship, Sanctuary of Zeus, Mount Lykaion, Peloponnese, Greece," *GSA Today* 27.12, pp. 4–9.
- . 2018. "Geologic and Geoarchaeological Mapping of the Sanctuary of Zeus, Peloponnese, Greece," *Geological Society of America Digital Map and Chart Series* 23, <https://geosociety.org/maps/2018-DMCH023>.
- . 2019. "Partitioned Tectonic Shortening, with Emphasis on Outcrop-Scale Folding and Flattening, Pindos Fold-and-Thrust Belt, Peloponnese, Greece," *Canadian Journal of Earth Sciences* 56, pp. 1181–1201.
- Fleagle, R. G. 1949. "The Audibility of Thunder," *Journal of the Acoustical Society of America* 21, pp. 411–412.
- Forte, A. S. W. 2022. "Speech from Tree and Rock: Recovery of a Bronze Age Metaphor," *AJP* 136, pp. 1–35.
- Frisinger, H. 1965. "Early Theories on the Cause of Thunder and Lightning," *Bulletin of the American Meteorological Society* 46, pp. 785–787.
- Ganas, A., and T. Parsons. 2009. "Three-Dimensional Model of Hellenic Arc Deformation and Origin of the Cretan Uplift," *Journal of Geophysical Research: Solid Earth* 114.B6, B06404, doi: 10.1029/2008JB005599.
- Gatidis, C., C. J. Lolis, K. Lagouvardos, V. Kotroni, and A. Bartzokas. 2018. "On the Seasonal Variability and the

- Spatial Distribution of Lightning Activity over the Broader Greek Area and Their Connection to Atmospheric Circulation," *Atmospheric Research* 208, pp. 180–190.
- Goldsworthy, M., and J. A. Jackson. 2000. "Active Normal Fault Evolution in Greece Revealed by Geomorphology and Drainage Patterns," *Journal of the Geological Society of London* 157, pp. 967–981.
- Huffman, C. A. 2005. *Archytas of Tarentum: Pythagorean, Philosopher, and Mathematician King*, Cambridge.
- Jordan, P. 2021a. "Searching for Ancient Sonic Experience in Present-Day Landscapes," *Archeologia e calcolatori* 32, pp. 439–456.
- . 2021b. "Sounding the Mountain: Analyzing the Soundscape of Mount Lykaion's Sanctuary to Zeus," in *Soundscape and Landscape at Panhellenic Greek Sanctuaries* (Telestes: Collana di studi e ricerche di archeologia musicale nel Mediterraneo 6), ed. E. Angliker and A. Bellia, Pisa, pp. 51–65.
- Jost, M. 1985. *Sanctuaires et cultes d'Arcadie* (Études péloponnésienes 9), Paris.
- Kerényi, C. 1975. *Zeus and Hera: Archetypal Image of Father, Husband, and Wife* (Archetypal Images in Greek Religion 5), trans. C. Holme, Princeton.
- Kidd, S. 2019. "Sound: An Aristotelian Perspective," in Butler and Nooter 2019, pp. 79–91.
- Kordatzaki, G., E. Kiriati, N. S. Müller, M. Voyatzis, D. Romano, S. Petrakis, J. Forsén, G. Nordquist, E. Rodriguez-Alvarez, and S. Linn. 2016. "A Diachronic Investigation of 'Local' Pottery Production and Supply at the Sanctuary of Zeus, Mount Lykaion, Arcadia, Peloponnese," *JAS: Reports* 7, pp. 526–529.
- Kourouniotis, K. 1904. "Ἀνασκαφαὶ Λυκαίου," *ArchEph* 22 (1905), pp. 153–214.
- . 1909. "Ἀνασκαφὴ Λυκαίου," *Prakt* 64 (1910), pp. 64, 185–200.
- Lacroix, A., T. Farges, R. Marchiano, and F. Coulouvrat. 2018. "Acoustical Measurement of Natural Lightning Flashes: Reconstructions and Statistical Analysis of Energy Spectra," *Journal of Geophysical Research: Atmospheres* 123.21, pp. 12040–12065, doi: 10.1029/2018JD028814.
- Lagouvardos, K., V. Kotroni, H.-D. Betz, and K. Schmidt. 2009. "A Comparison of Lightning Data Provided by ZEUS and LINET Networks over Western Europe," *Natural Hazards and Earth System Sciences* 9, pp. 1713–1717.
- Lalechos, N. 1973. Geological Map of Greece: Kato Fighalia Sheet. 1:50,000. Institute of Geology and Mineral Exploration, Athens.
- Mahoney, K. 2018. "Mycenaean Mt. Lykaion and the Linear B Documents," in *Arkadien im Altertum: Geschichte und Kultur einer antiken Gebirgslandschaft. Beiträge des internationalen Symposiums in Graz, Österreich, 11. bis 13. Februar 2016 / Ancient Arcadia: History and Culture of a Mountainous Region. Proceedings of the International Conference Held at Graz, Austria, 11th to 13th February, 2016* (A.R.G.E.I.A. 3), ed. K. Tausend, Graz, pp. 11–36.
- McClusky, S., S. Balassanian, A. Barka, C. Demir, S. Ergintav, I. Georgiev, O. Gurkan, M. Hamburger, K. Hurst, H. Kahle, K. Kastens, G. Kelkelidze, R. King, V. Kotzev, O. Lenk, S. Mahmoud, A. Mishin, M. Nadariya, A. Ouzounis, D. Paradissis, Y. Peter, M. Prilepin, R. Reilinger, I. Sanli, H. Seeger, A. Tealeb, M. N. Toksöz, and G. Veis. 2000. "Global Positioning System Constraints on Plate Kinematics and Dynamics in the Eastern Mediterranean and Caucasus," *Journal of Geophysical Research: Solid Earth* 105, pp. 5695–5719.
- Mylonopoulos, J. 2006. "Greek Sanctuaries as Places of Communication through Rituals: An Archaeological Perspective," in *Ritual and Communication in the Graeco-Roman World* (Kernos Suppl. 16), ed. E. Stavrianopoulou, Liège, pp. 69–119.
- Nagy, G. 1990. *Greek Mythology and Poetics* (Myth and Poetics), Ithaca, N.Y.
- National Park Service. 2006. *Ninaistako (Chief Mountain)* (U.S. Department of the Interior Interpretive Resource Bulletin Series).
- Nicol, D. M. 1958. "The Oracle of Dodona," *GaR* 5, pp. 128–143.
- Papadopoulos, G. A., I. Baskoutas, and A. Fokaefs. 2014. "Historical Seismicity of the Kyparissiakos Gulf, Western Peloponnese, Greece," *Bollettino di geofisica teorica ed applicata* 55, pp. 389–404.
- Papadopoulos, P. 1997. Geological Map of Greece: Megalopolis Sheet. 1:50,000. Institute of Geology and Mineral Exploration, Athens.
- Peatfield, A. A. D. 1990. "Minoan Peak Sanctuaries: History and Society," *OpAth* 18, pp. 117–131.
- Power, T. 2019. "The Sound of the Sacred," in Butler and Nooter 2019, pp. 15–30.
- Romano, D. G. 2019. "Mt. Lykaion as the Arcadian Birthplace of Zeus," in *Natur-Mythos-Religion im antiken Griechenland / Nature-Myth-Religion in Ancient Greece* (Potsdamer Altertumswissenschaftliche Beiträge 67), ed. T. S. Scheer, Stuttgart, pp. 219–237.
- Romano, D. G., and M. E. Voyatzis. 2014. "Mt. Lykaion Excavation and Survey Project: Part 1. Upper Sanctuary," *Hesperia* 83, pp. 569–652.
- . 2015. "Mt. Lykaion Excavation and Survey Project: Part 2. Lower Sanctuary," *Hesperia* 84, pp. 207–276.
- . 2021. "Sanctuaries of Zeus: Mt. Lykaion and Olympia in the Early Iron Age," *Hesperia* 90, pp. 1–25.
- Said, R. 2017. "Towards a Global Lightning Locating System," *Weather* 72.2, special issue, *Developments in Lightning Detection*, pp. 36–40.
- Sakellariou, N., V. Kouskouna, and K. Makropoulos. 2010. "Macroseismic Intensities in Central-Southern Peloponnese During the 19th Century: Extract: The 1886 August 27 Filiatra Earthquake" (internal report, National and Kapodistrian University of Athens, Laboratory of Seismology 2010), <http://macroseismology.geol.uoa.gr/studies/SAKEL2010.pdf>.
- Schafer, R. M. 1994. *The Soundscape: Our Sonic Environment and the Tuning of the World*, 2nd ed., Rochester.
- Skourlis, K., and T. Doutsos. 2003. "The Pindos Fold-and-Thrust Belt (Greece): Inversion Kinematics of a Passive Continental Margin,"

International Journal of Earth Sciences 92, pp. 891–903.

Voyatzis, M. E. 2019. “Enduring Rituals in the Arcadian Mountains: The Case of the Sanctuary of Zeus on Mt. Lykaion,” in *Beyond the Polis: Rituals, Rites, and Cults in Early and Archaic Greece*

(12th–6th Centuries BC) (Études d’archéologie 15), ed. I. S. Lemos and A. Tsingarida, Brussels, pp. 133–146.

World Meteorological Organization. [1953–1956] 1969. *World Distribution of Thunderstorm Days: Part 2. Tables of Marine Data and*

World Maps (World Meteorological Organization 21), repr. Geneva. Zolotnikova, O. A. 2013. *Zeus in Early Greek Mythology and Religion: From Prehistoric Times to the Early Archaic Period* (BAR-IS 2492), Oxford.

Mary E. Voyatzis

UNIVERSITY OF ARIZONA
SCHOOL OF ANTHROPOLOGY AND
DEPARTMENT OF RELIGIOUS
STUDIES AND CLASSICS
mev@arizona.edu

David Gilman Romano

UNIVERSITY OF ARIZONA
SCHOOL OF ANTHROPOLOGY
dgromano@arizona.edu

George H. Davis

UNIVERSITY OF ARIZONA
DEPARTMENT OF GEOSCIENCES
gdavis@arizona.edu

Pamela Jordan

UNIVERSITY OF AMSTERDAM
AMSTERDAM SCHOOL FOR HERITAGE,
MEMORY AND MATERIAL CULTURE
p.f.jordan@uva.nl

Ryan K. Said

VAISALA INC.
LOUISVILLE, COLORADO
ryan.said@vaisala.com

Kenneth L. Cummins

UNIVERSITY OF ARIZONA
DEPARTMENT OF HYDROLOGY
AND ATMOSPHERIC SCIENCES
kcummins@arizona.edu

Susan Beck

UNIVERSITY OF ARIZONA
DEPARTMENT OF GEOSCIENCES
slbeck@arizona.edu