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THE CASE FOR SEISMIC COMMUNICATION AMONG MAMMOTHS IN PALAEOLITHIC ART

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Abstract. Seismic communication through infrasound occurs in both genera of extant proboscideans. Demonstrating its occurrence in extinct mammoths can rely on evidence from the body fossil record, trace fossil record and rock art record. Upper Palaeolithic rock art of mammoths in six western European caves suggests that the artists depicted mammoth communication through sound and probably through infrasound over a period of 20,000 years. Substantial correlations exist with the African rock art of elephants. The rock art record, buttressed by the fossil record, suggests that seismic communication among proboscideans was not confined to extant species but also existed in mammoths.

Introduction

The three extant representatives of the order Proboscidea and family Elephantidae are the African bush elephant (*Loxodonta africana*), the African forest elephant (*L. cyclotis*) and the Asian elephant (*Elephas maximus*). Extinct families of proboscideans include mastodons (Mammutidae), gomphotheres (Gomphotheriidae) and stegodonts (Stegodontidae). The Elephantidae family also contains extinct genera, e.g. *Mammuthus* (mammoths) and *Palaeoloxodon* (including straight-tusked elephants).

All three extant species of elephant have the ability to use percussion and/or 'rumbling' to enable long-distance (kilometre-scale) seismic subsurface communication (Payne et al. 1986; Poole et al. 1988). Infrasound refers to very low frequencies, less than 20 Hz, that are inaudible to the human ear. Low-frequency infrasonic elephant rumbling originates in the larynx, whereupon vibrations travel to the ground through the limbs (Payne et al. 1986). The vocalisations then 'couple' with the ground. The resulting seismic waves travel along and below the Earth's surface with a different velocity to that of communication through the air and can travel farther than high-frequency sounds, enabling interactions over relatively large areas (Gunther et al. 2004; O'Connell-Rodwell 2007; O'Connell-Rodwell et al. 2000).

Poole (1997: 50) stated:

> The rumbles are the most numerous (30 known) and complex class of calls. All the rumbles contain components below the level of human hearing, with some being totally infrasonic. Elephant rumbles are harmonic sounds, i.e. they contain frequencies that are multiples of the lowest or fundamental frequency. While the fundamental frequency is typically inaudible to human ears, at least some of the upper harmonics are usually within the audible range. Some calls are extraordinarily powerful, and elephants can hear the lowest frequencies up to 10 km away. At dawn and dusk, when atmospheric conditions are optimum, calls can be heard over at least 285 sq km ... Elephants are also able to pick up these powerful signals through the ground over double these distances.

Achrati (2024: 316) evocatively described elephant rumbles:

> The rumbles dominate the elephant's acoustic repertoire. Rumbling is used for communicating over long distances, as well as for greeting, bonding, threatening, soliciting a mate, soothing, or giving reassurance. … They may be emitted as a soft fluttering whisper or an explosive throaty resonance with high sound pressure levels.

The distance seismic waves travel and their velocity are related to the nature of the substrate, and sandy terrain has been modelled as allowing for the farthest propagation (Mortimer et al. 2018). In this respect, heavy-bodied proboscideans are at an advantage, as lighter animals cannot generate low-frequency seismic surface waves through vocalisation (O'Connell-Rodwell 2007).

Elephants often align themselves in the direction of the origin of the seismic communication or perpendicularly to such signals (O'Connell 2007; O'Connell-Rodwell et al. 2006). Furthermore, they adopt certain freezing postures when 'transmitting' or 'receiving', placing more weight on the forefeet, or lifting one leg off the ground to 'triangulate' (O'Connell-Rodwell 2007; Mumby 2020). When elephants place more weight on the forefeet, the trunk is often placed on the ground with its tip directed posteriorly.

The fact that both extant genera utilise infrasound to enable long-distance seismic communication suggests that ancestral or related species (for example, the last common ancestor of elephants and mammoths) developed this capacity, especially given that *Mammuthus* was more closely related to *Elephas* than to *Loxodonta* (Shoshani et al. 2007). This would seem more likely than the alternative, that all three extant species independently developed such ability. We are not alone in pondering such issues: Shoshani (1998) stated that an important question with regard to extinct proboscideans lay in determining whether they could produce and hear infrasonic calls.

How could such evidence be sought? We are part of a research team that recently described possible trace fossil evidence of elephant subsurface seismic communication on South Africa's Cape south coast, as well as evidence in the rock art record in southern Africa, which suggested that the San were aware of elephant seismicity and depicted this in their art (Helm et al. 2023). Our team concluded that to be comprehensive, an understanding of elephant seismicity would require the integration of research on (a) extant elephant populations, (b) 'ancestral knowledge' (represented predominantly by rock art), and (c) the trace fossil record.

Achrati (2024) summarised humankind's attempts to depict and record sound, focusing on curved lines as a means of visualising sound. Associations of such lines with rock art of elephants in Algeria were regarded as phonographic depictions of elephant calls.

Applying these concepts to an extinct genus such as *Mammuthus* requires replacing information from extant proboscideans with findings from the body fossil record. The trace fossil record remains a viable avenue of investigation. The rock art record would not be useful for species that became extinct prior to hominins developing their artistic abilities. However, it could be investigated in cases where humans and proboscideans co-existed in a time and place that rock art flourished. For example, the *Mammuthus* lineage begins in the Pliocene and ends in the Holocene around 4000 years ago when the last mammoths went extinct; mammoths thus co-existed with humans in North America, Eurasia and Africa during the Pleistocene.

Informed speculation becomes possible. Elephants may be able to sense distant thunderstorms through infrasound and respond with movements to the area of origin in times of drought (Garstang et al. 2014). Likewise, elephant awareness of precursors to tsunamis following earthquakes has been linked to infrasound (Garstang 2009). Noting the mountain ranges and alpine environments that characterised part of the mammoth distribution range, we can speculate that the ability to respond to infrasound might have created an adaptive advantage with respect to avalanche awareness and avoidance.

Short of attempting de-extinction through genetics (Gill 2013), it may never be possible to know the nature of mammoth vocalisations. However, thanks to innovative technology, it is possible to listen to the *kind* of sounds that woolly mammoths might have produced: *https://www.npr.org/2011/07/23/138644143/helping-mammoths-roar-again*. The question arises as to whether they and other extinct proboscideans rumbled and indulged in long-distance seismic communication. What does appear certain is that larger species of mammoth would have generated seismic waves through percussion (walking, running, foot-stomping etc.) in a way that lighter creatures could not, as the amplitude and propagation distance of such waves are directly related to mass (O'Connell-Rodwell 2007).

We suggest that exploring complementary lines of evidence through the proboscidean body fossil record, trace fossil record and rock art record will at least allow for assessment of probabilities. The purpose of this article is to briefly summarise the mammoth body fossil record and trace fossil record in this regard and to follow this with examples from the mammoth rock art record (in conjunction with that of elephants) to address the question of whether mammoths were capable of seismic communication.

The mammoth fossil record

The body fossil record

The proboscidean lineage extends back to the Palaeocene (Shoshani 1998). The body fossil record of mammoths extends from the Pliocene to the Holocene and includes mummified specimens in which soft tissues are preserved (Haynes 1993; Lister 2014). This creates opportunities for investigating whether mammoths were capable of infrasonic communication, either through the 'receiving mechanism', e.g. the inner ear or specialised receptors, or the 'transmitting mechanism' involving the hyoid apparatus or larynx.

Schmitt (2016) noted that extant elephants are among the few mammals that are able to communicate through infrasound and suggested that studying the cochlear morphology of proboscideans could shed light on the evolution of low-frequency hearing. While acknowledged as preliminary, the resulting studies, which investigated anatomical features in the cochlea, suggested that early proboscideans were not able to hear low frequencies. In contrast, all deinotheres and elephantimorphs (including mastodons, gomphotheres, stegodonts and all members of the Elephantidae) seem to have been adapted to low-frequency hearing (Schmitt 2016). It was concluded that the modern morphotype seen in extant elephant species, which is linked with low-frequency hearing, was probably generalised in elephantimorphs.

The hyoid apparatus, which is involved with sound production, was investigated through examination of comparative anatomy between extant species and examples in the body fossil record. The results supported the conclusion that the *Mammuthus* genus is more closely related to *Elephas* than to *Loxodonta* (Shoshani et al. 2007).

Fisher et al. (2012) dissected and CT-scanned a well-preserved mammoth baby carcass (Lyuba) and identified a small, posteriorly protruding region ventral to the trachea, which they inferred to be the remains of the pharyngeal pouch. This was the first occasion that this feature was identified in a mammoth. In elephants, it has a role in water storage but is thought to aid in sound production when empty (Shoshani et al. 2007).

Shoshani (1998) noted that modifications for water storage (e.g. to the hyoid apparatus and pharyngeal pouch) allowed for lower-frequency sounds to be produced and may have facilitated the development of infrasonic calls in elephants. Comparing features of the hyoid apparatus and auditory characters in extant and extinct proboscideans, Shoshani (1998) concluded that the development of infrasonic communication may have evolved by the Early Miocene (24–20 Ma). Further evidence might lie in the external naris, which is particularly wide and deep in mammoths and extant elephants and can already be identified in Miocene gomphotheres (Shoshani and Tassy 1996). Shoshani (1998) thought that a wide and deep external naris conveyed the ability to create deeper vocalisations. Such findings led Gill (2013) to claim with respect to mammoths: 'we do know from modifications in their hyoid bones, tongue, and voice box that they would have been capable of low frequency communication'.

Other studies have demonstrated the capacity to dissect and analyse mammoth skeletal material and soft tissue (e.g. Grigoriev et al. 2017; Maschenko et al. 2017). However, they have not provided specific details on the possibility of seismic communication. Extant elephants have a cartilaginous fat pad located in the heel and well-developed cutaneous Pacinian corpuscles (pressure receptors) (O'Connell-Rodwell 2007). Identification of such features in examples from the body fossil record in which soft tissues are preserved and comparing them with those of extant elephants potentially offers a further line of research. In combination, these findings strongly suggest that it would not be surprising if mammoths had the capacity for low-frequency seismic communication.

The trace fossil record

Proboscidean tracks have been reported from numerous sites in the Americas (e.g. Aramayo et al. 2015; Campos-Medina et al. 2022; Fisher 1994), Europe and the Mediterranean (e.g. Milàn et al. 2007, 2015; Muñiz et al. 2019; Neto De Carvalho 2009), Asia (e.g. Matsukata and Shibata 2015), and Africa (e.g. Musiba et al. 2008; Roach et al. 2016). This may partly be due to their size, depth and characteristic appearance, which combine to make identification straightforward. For example, in a comprehensive inventory of Cenozoic vertebrate tracksites, McDonald et al. (2007) provided 52 references for traces of Proboscidea, and numerous finds have subsequently been reported. For example, Helm et al. (2021) reported on 35 elephant tracksites from South Africa's Cape south coast, all identified since 2008. Altamura and Serangeli (2023) reviewed fossil proboscidean tracks at Palaeolithic sites globally. For mammoths alone, tracksites have been reported from diverse locations in the contiguous United States (Bennett et al. 2019; Hunt and Lucas 2007; Lucas et al. 2007; Retallack et al. 2018), Canada (McNeil et al. 2005, 2007), Alaska (Lea 1996), Korea (Kim et al. 2009) and Sardinia (Pillolo and Zoboli 2017).

Many of the above-mentioned tracksites are preserved in aeolianites. Given the suitability of sand as a propagating medium for seismic communication, the possibility exists at many proboscidean tracksites of finding ichnological evidence of seismic communication. Given the findings interpreted by Helm et al. (2023) as possibly representing a trace fossil signature of seismic communication between elephants, a combination of concentric ring features within an elephant track could be sought, combined with parallel, linear groove-and-ridge features that might occur on a stratigraphically lower surface. Evidence of both features at the same site, which may require the fortuitous exposure of more than one surface, might be rare. The presence of concentric ring features alone would not constitute compelling evidence, as Graversen et al. (2007) have reported such features in theropod dinosaur undertracks; they could simply represent the intersection of the surface with closely spaced laminae that had been deformed by the weight of the trackmaker. Therefore, the relevant ichnological evidence might not be readily apparent, and a dedicated search is required.

One example is provided from a Miocene proboscidean tracksite, Mleisa 1, in the United Arab Emirates (Bibi et al. 2012: Fig. S3c). It contains a proboscidean track with ring features in the peripheral portion of the track, with a suggestion of associated linear features. While other explanations can account for these features, they could be evaluated in the context of possible proboscidean seismic communication. All fossilised proboscidean ichnological sites could be re-examined and re-interpreted similarly.

Complementary lines of evidence from the trace fossil record are also helpful. Bibi et al. (2012) reported the presence of complex social structure in Late Miocene proboscideans from Mleisa 1. The 'exceptionally long trackways' of a herd of at least 13 proboscideans of varying size were crossed by a trackway of a single large individual (probably a male), leading the authors to infer the presence of both herding and solitary behaviour, and features consistent with those of an extant elephant family unit.

If complex social structures in proboscideans extend back to the Late Miocene, then it is not unreasonable to suspect that similar behaviour might have occurred in mammoths. Moreover, the observation that modern observers can appreciate and value the artistic portrayals of mammoths in Palaeolithic European rock art suggests that their behaviour was

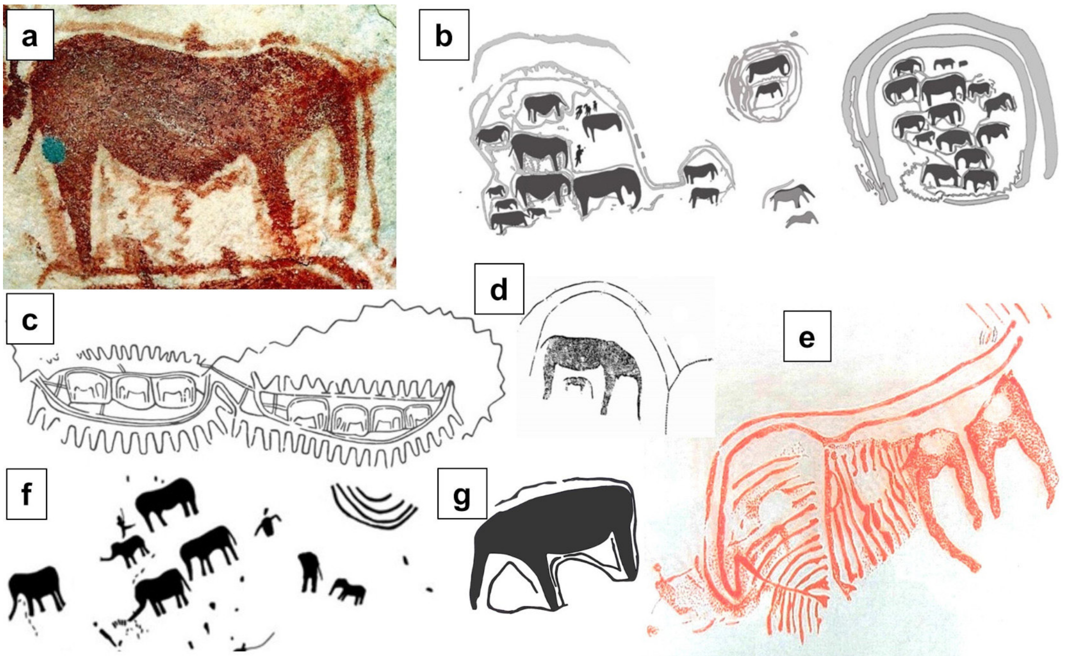


Figure 1. *Rock art from South Africa: (a) zigzag lines link multiple parts of the elephant body to the ground; (b) fine lines and concentric circular lines surround elephant pods; (c) rock art with sinusoidal lines suggesting communication through vibration of discrete elephant pods; six elephants are depicted in head-to-head postures; (d) lines partially encircle a mother and baby elephant; (e) head-to head position, with multiple human figures, and an elephant trackway superimposed on the elephants; (f) sub-parallel lines ahead of an elephant's trunk, in association with lines connecting elephant trunks to the ground, human figures, and concentric rings; (g) elephant image with purported 'sound lines'.*

broadly similar to that of extant elephants. Extending this inference, sound likely played an important role in mammoth communication and behaviour. Of course, this does not prove that they utilised infrasound or seismic communication—to explore the latter concept further, we turn to the rock art record.

The proboscidean rock art record

The evidence for seismic communication in the rock art record of extant elephants is first reviewed, from South Africa (where more than 200 elephant paintings from the Cederberg region were considered, as well as the Little Karoo, the Langeberg and the Outeniqua Mountains) and northern Africa. This is followed by an examination of possible evidence from the European mammoth rock art record. We have also examined the North American proboscidean art record (Malotki and Wallace 2011; Purdy et al. 2011) but have not found evidence to suggest mammoth seismic communication. We follow an ethological approach (*sensu* Azéma 2008), incorporating observations of animal behaviour as it occurs in a natural environment and focussing on parallel behavioural aspects of mammoths and elephants as depicted in rock art.

Our analysis is based on rock art images of 56 'mammoths' and 60 'elephants'. Specifically, we examined the behaviours evident in paintings and engravings of mammoths in France and Spain from the Aurignacian to the Magdalenian, spanning ~20,000 years. We compared these apparent behaviours with those noted in African rock art of elephants and records of behavioural patterns of the extant African savanna elephant (*Loxodonta africana*) associated with seismic communication. These included the body parts used, the postures adopted and associated behavioural patterns.

We have used a 'line drawing and mass block-in' technique to reproduce the rock art images herein, thus attempting to replicate, *alla prima*, the technique used by Palaeolithic artists. The elephant images have been drawn from photographs of elephants in the wild in Kenya, Botswana and South Africa, drawing on the research of behavioural specialists Iain Douglas-Hamilton, Beth Mortimer, Cynthia Moss, Caitlin O'Connell Rodwell, Katy Payne and Joyce Poole. Attention was paid to the compositions, relative sizes, and proportions of the elephants, and their inferred behaviour and associated sounds. To preserve authenticity, the elephants were carefully traced as single-line drawings from photographs, then 'massed in' using a soft pencil and the 'fallen straw' cross-hatching technique.

South Africa

Evidence from South Africa was presented by Helm et al. (2023), following earlier work by Paterson (2007), Rust (2008), and Paterson and Parkington (2015). Ten San rock art sites in the Western Cape Province were considered. It was inferred that San artists were aware of elephant seismicity and depicted it in their art. In summary, this evidence included phenomena such as:

- zig-zag lines connecting various elephant body

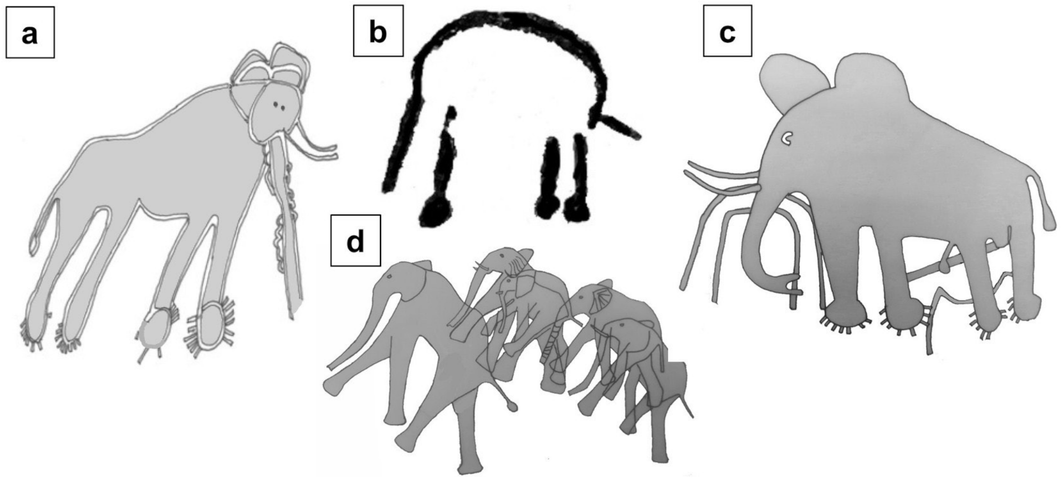


Figure 2. *(a) Rock engraving from northern Africa, showing lines radiating from bulbous feet and adornments on the trunk; (b) rock painting from the Biedouw Valley, Cederberg, in South Africa, showing bulbous feet; (c) a bull elephant from Iwellene, Niger, in a forward-leaning posture, showing bulbous, spiky feet, an open trunk tip (pointing posteriorly), raised ears and a prominent penis, with associated lines (reproduced with permission from a photo by David Coulson); (d) superimposition of elephant images at the Tadrart Rouge site in Algeria; see text for details.*

parts (e.g. abdomen, groin, throat, trunk and feet) with the ground (Fig. 1a);

- fine lines (sometimes concentric) surrounding elephant pods (Fig. 1b);
- pods of elephants surrounded by and connected by lines which include sinusoidal forms, often with a high amplitude-to-wavelength ratio (Fig. 1c);
- encircling lines around a mother and baby elephant (Fig. 1d);
- head-to-head communication postures (Fig. 1c, 1e);
- sub-parallel lines ahead of an elephant's trunk, in association with lines connecting elephant trunks to the ground (Fig. 1f);
- human figures in association with the elephants, sometimes in postures suggesting touching or appreciation of vibration in accordance with the concept of *n/om*, the source of inspired energy for the San (Fig. 1e, 1f).

Algeria

Similar findings were presented from rock engravings at the Garet et Taleb and Chériha sites in the Qsur mountains in Algeria (Achrati 2023, 2024). Elephant rumbling was inferred from sinusoidal lines surrounding the trunk and pecked depressions adjacent to the trunk. In one case, at Mouchgueg, lines were noted to radiate from the bases of all four feet, two of which were 'bulbous', and the trunk was adorned with extra markings (Fig. 2a). Achrati (2024: 318) referred to the feet as seemingly being 'caught in spiky traps', whereas we consider that the radiating lines from the feet may represent vibrations from rumbling. These features can be contrasted with a depiction of bulbous feet in a rock painting of an elephant from the Biedouw Valley, Cederberg, in South Africa (Fig. 2b), an engraving from Niger (Fig. 2d), and a painting from Chauvet Cave (Fig. 10a).

An engraving of elephants at the Tadrart Rouge site in Algeria (Fig. 2c) shows considerable superimposition, with multiple examples of trunks and legs overlapping and touching each other. Similar depictions are evident in some of the western European cave art (described below), and such 'overlapping' images may represent close proximity at a birthing scene or when elephants (or mammoths) are protecting their young or each other.

In this case, the intentional superimposition of the elephants creates a three-dimensional effect, and the engraving appears realistic: the elephants appear to be excited or fearful as they all run in the same direction, all 'in step', with heads raised, ears spread out and tails horizontal. This appears to be a female family unit with the matriarch in the lead, and the other two females each have younger ones running close to them. It seems that the artist intentionally superimposed these younger elephants on top of their mothers to illustrate this closeness. In such a situation, elephants are usually silent as they try to get out of danger. There are no features to suggest vocalisation, although the percussion effect of the scene must have been considerable.

With regard to northern African rock art involving elephants, Coulson and Campbell (2001: 180) noted 'a ritual in which people obtain some form of power from elephants' and related this to a similar theme in southern African rock art. The many petroglyphs of elephants in northern Africa suggest a special connection between humans and elephants—a similar relationship can be postulated between humans and mammoths in western Europe, as detailed below.

Niger

An example from Iwellene in Niger, about 300 km south of the Algerian border, forms part of David Coulson's collection (*https://www.britishmuseum.org/collection/object/E_2013-2034-9909*, British Museum

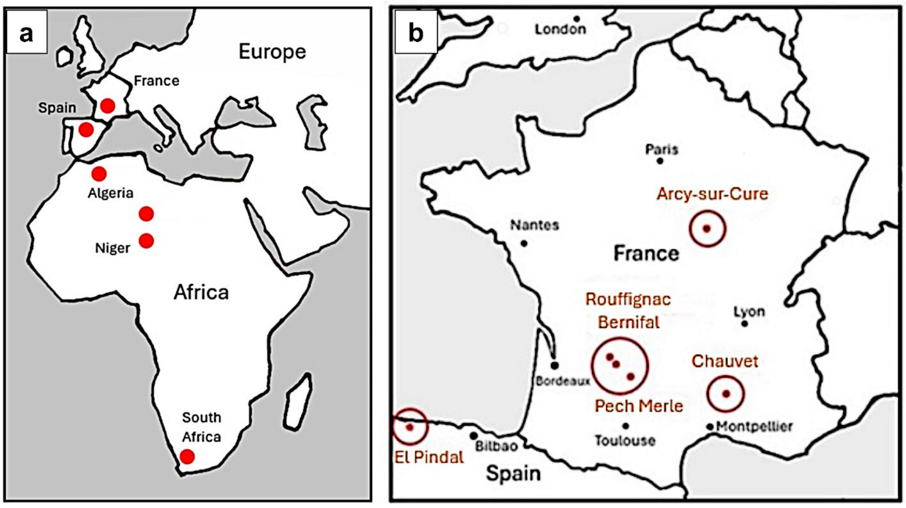


Figure 3. *(a) Map of Africa and Europe, showing countries mentioned in the text; (b) map of western Europe, indicating the sites of caves mentioned in the text.*

number 2013,2034.9909) and is shown in Figure 2d. A bull elephant is depicted in a forward-leaning posture; the feet are bulbous and are adorned with 'spikes', the tip of an open trunk is pointing posteriorly, ears are raised, a penis is prominent, and lines of various shapes are associated with the engraving. Both these lines and the spiky, bulbous feet suggest an association with sound in what appears to be remarkable convergence between rock art in Niger, Algeria, South Africa and western Europe (cf. Figs 2a, 2b, and 10a).

Evidence of mammoth seismicity in European rock art

In introducing this topic, we identify assumptions or acknowledgements:

- it is assumed that if there is evidence of seismic communication in mammoths, it would take a form similar to that seen in extant elephants, e.g. the adoption of certain postures;
- it is assumed that depictions of elephants and mammoths in the rock art record are reasonably accurate and were created by perceptive artists, i.e. that the postures and behaviours depicted are representations of what had been seen, heard or sensed by the artists at the time (see Azéma and Rivère 2012);
- in doing so, we are following the example of Plassard (2023: 20), who inferred the depiction of musth (as discussed further below) in 19 mammoths in Rouffignac Cave in France, and commented on the 'naturalistic mastery of the artists' and their ability 'to show more subtle anatomical details' such as a two-lobed trunk tip, the suggestion of a double eyelid, and the use of a double line to indicate the diameter of the tusks, all suggesting that the artist knew the species well;
- it is acknowledged that this is an area in which absolute certainty is elusive and in which speculation, when present, needs to be identified, and unequivocal conclusions are unlikely to emerge.

We present evidence from six western European caves: El Pindal, Rouffignac, Chauvet, Pech Merle, Bernifal and Arcy-sur-Cure. The 'mammoth' images range in age from the Aurignacian period to the Magdalenian period. Forty-two mammoth images (three-quarters of the total) are from Rouffignac Cave, which has the largest concentration of mammoth art (157 images) in western Europe. Figure 3 shows the areas in which the rock art described here from Africa and Europe occurs.

El Pindal Cave: The first example is a painting in red ochre of a mammoth in El Pindal Cave in the Pimiango region of northern Spain. The rock art in the 360-m deep cave was discovered in 1908, and the first copy of the mammoth image was published soon thereafter by Abbé Breuil (Del Rio et al. 1911). The image, seemingly containing an appropriately placed heart (an interpretation now discarded), has become emblematic of El Pindal Cave. Situated towards the end of the cave, it is one of the few depictions of a mammoth in the region. González Sainz and Cacho Toca (2003) noted the convex form of the skull, cervical depression and short tail. These authors interpreted the absence of markings indicating coats or tusks and the presence of only one leg for each pair of legs as representing archaic stylistic conventions from the Solutrean or earlier. Both González Sainz and Cacho Toca (2003) and Bacon et al. (2023: Fig. 1h) drew attention to two sets of five parallel or sub-parallel lines immediately ahead of the mammoth image (Fig. 4a), which had also been recorded by Breuil (Del Rio et al. 1911).

From our perspective, important features are the forward-leaning posture (potentially a 'freezing posture'), with the weight firmly placed on the forefeet and the end of the trunk resting on the ground, pointing backwards. The head appears level with the shoulders and points downwards, and the front legs are depicted leaning forward. Figure 4b illustrates a similar posture in the African elephant, with the trunk curled back beside the front feet. In extant elephants, in the context of seismic communication, this is understood to be a typical sensing pose.

Bacon et al. (2023) interpreted the parallel or sub-parallel lines as communication units that denoted numbers of lunar months, recording calendar time from spring onwards. As an alternative interpretation, we question whether these lines, placed immediately ahead of the mammoth image, may represent vibration or seismic communication. However, we acknowledge that the El Pindal cave contains numerous abstract motifs and geometric patterns in addition to parietal art of animals. We also note that the notion of such lines representing a phenological calendar has been rebutted (Garcia-Bustos et al. 2023; Nowell et al. 2024).

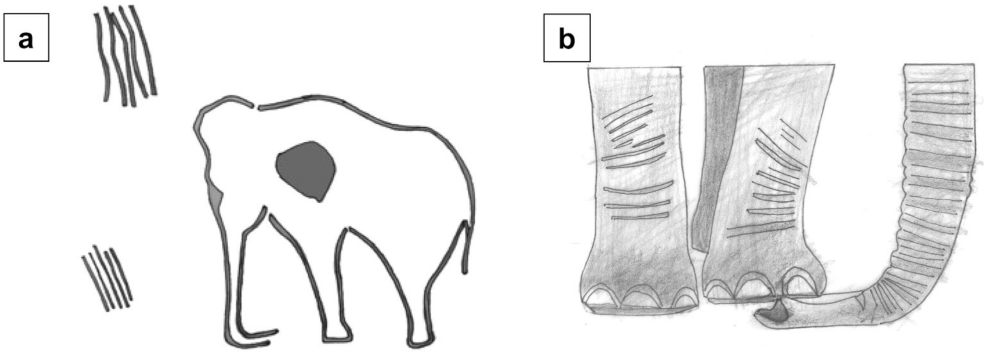


Figure 4. *(a) The El Pindal Cave mammoth with sub-parallel lines ahead of it; (b) a similar posture in* Loxodonta africana.

Rouffignac Cave, in the Dordogne region of southwestern France, is also known as the 'Cave of 100 Mammoths', with around 157 depictions of mammoths (mostly charcoal drawings). These comprise approximately 62% of the animal images in the cave and represent 30% of mammoth images in Palaeolithic art (Plassard and Plassard 1995). The cave art is also notable for an area of 500 m^2 of serpentine, meandering, 'macaroni' lines and finger flutings (Van Gelder 2010; Plassard and Plassard 1995: 13, 19). The most spectacular paintings are found about 700 m into the cave. The art style has been attributed to the Magdalenian, about 13,000 years ago (Leroi-Gourhan 1988).

The degree of accuracy of the mammoth depictions is evidenced by the portrayal in some images of the 'anal flap'. This was used to bolster the claims for authenticity for the corpus of art at Rouffignac, as its presence in mammoths would not have been known to more recent, 'post-mammoth' artists (Plassard and Plassard 1995). We also note the comment (Plassard and Plassard 1995: 14) that: 'Engraving, like a piece of sculpture, is final. The artist cannot erase it or correct it … the premeditated gesture is of vital importance'. The final, skilful result thus needed to be obtained at the first attempt.

Early researchers (Nougier and Robert 1958; Barrière 1982) interpreted the serpentine, meandering lines as representing snakes. More recent analyses (e.g. Van Gelder 2010) did not support this interpretation, and it was suggested that children, held aloft, were responsible for many of the finger flutings on ceilings (Sharpe and Van Gelder 2006). It was acknowledged that the meaning behind the flutings remained unknown, although the possibility of an ancient form of writing was raised (Van Gelder 2010). Clottes and Lewis-Williams (1998) favoured a shamanistic explanation, related to entoptic images. In interpreting the flutings, Von Petzinger (2016) suggested rites of passage and shamanic visions and that some areas may have been decorated in seclusion.

Bacon et al. (2023) did not analyse markings at Rouffignac Cave but contended that lines and dots in European caves constituted a proto-writing system and phenological calendar related to the 'bonne saison' (a French term for the time at the end of winter and beginning of spring). However, in an exploratory study, Thackeray (2023) examined images of nine mammoths from Rouffignac Cave, using catalogue numbers from Barrière (1982), to show that the numbers of linear markings within the bodies of mammoths were randomly variable. The possibility was raised that these kinds of lines might potentially represent symbolic wounds.

One of the most intriguing of the Rouffignac mammoth images is what Barrière (1982) referred to as 'Mammoth 107'. Located on the 'Great Ceiling', it is the most complete depiction of a mammoth in the cave. In this image, the mammoth is depicted in a forward-leaning posture (although not as much as in the El Pindal Cave image), with the tip of the trunk again curved and pointing backwards. Of note is the depiction of two 'fingers' at the end of the trunk, as in *L. africana* (see also Fig. 6a). In Figure 5 'the 'Mammoth

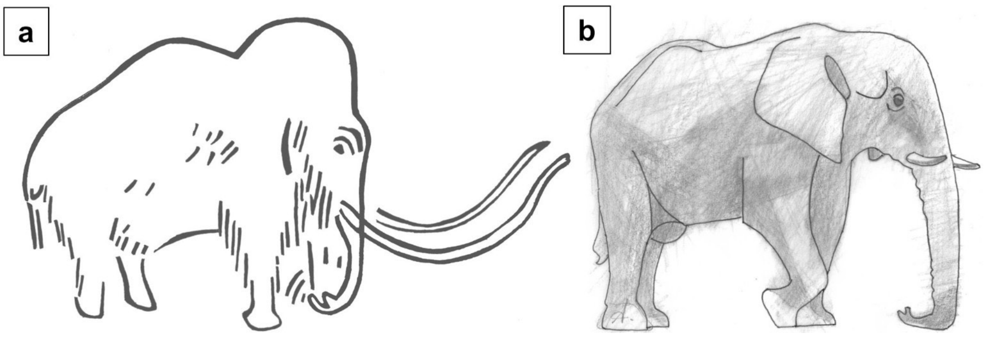


Figure 5. *(a) 'Mammoth 107' from the Great Ceiling in Rouffignac Cave; the 'fingers' at the tip of the trunk are 'open', and three concentric arcs behind the trunk tip might potentially depict sound. The longer vertical lines behind the eye could represent secretion from the temporal gland, suggesting that the mammoth may be in musth (see discussion below); (b) a 'triangulation' posture in a young* L. africana *bull with a streaming temporal gland, showing the 'fingers' at the end of the trunk.*

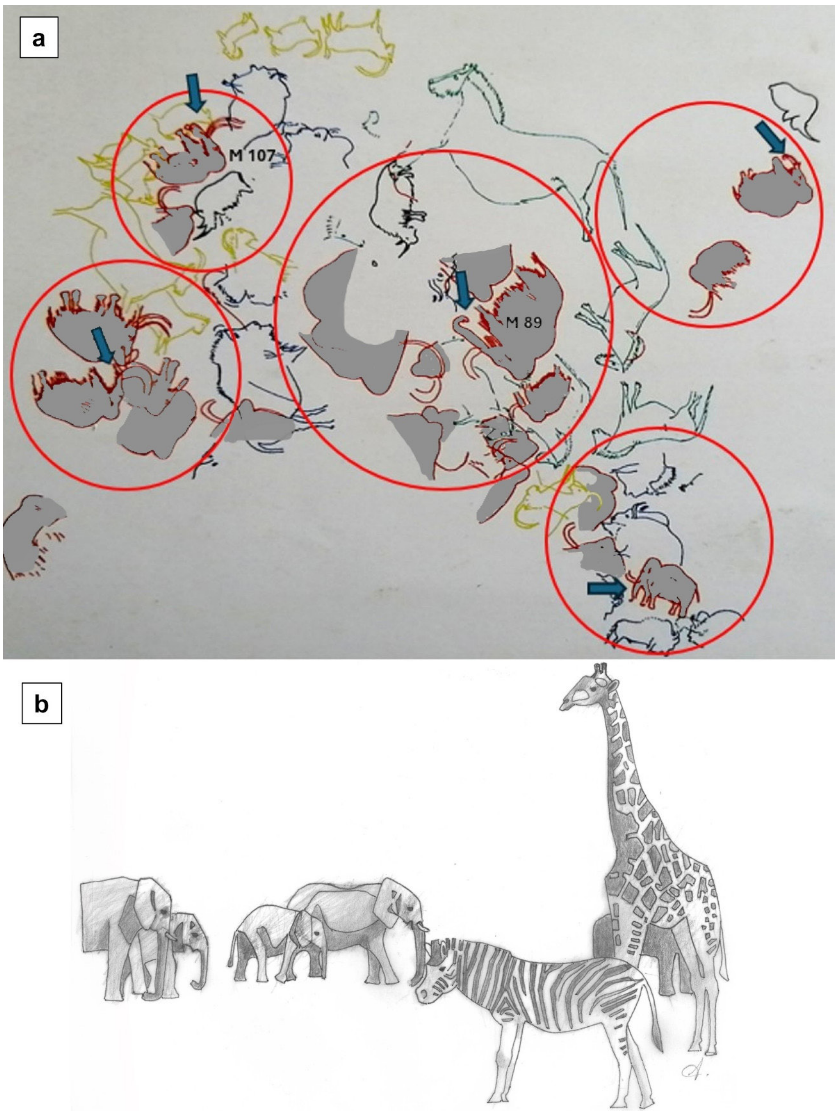


Figure 6. *(a) The Great Ceiling composition in Rouffignac Cave, after Barrière (1992); see text for details. Circles, arrows and shading in grey of mammoths are ours: circles surround mammoth groups, and arrows point to depictions of five mammoths exhibiting possible communication postures, including M 89 and M 107; (b)* L. africana, *plains zebra and giraffe stand harmoniously around a water hole; the elephants have their trunks lowered, perhaps rumbling and communicating independently of the other animals, similar to the scene in Fig. 5A.*

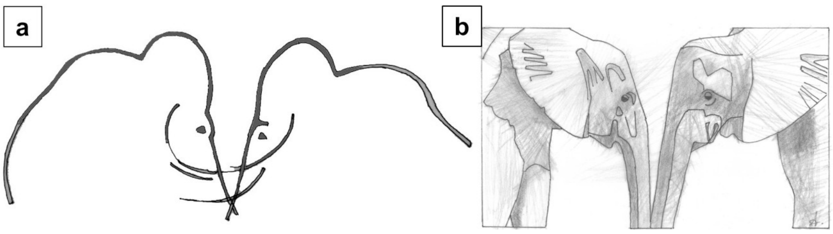


Figure 7. *(a) Mammoths in a head-to-head posture along the Via Sacra in Rouffignac Cave. (b)* L. africana *communicating, possibly though infrasonic rumbling, in a similar head-to-head posture.*

107' image is presented alongside a photograph of an extant elephant in a 'triangulation' posture.

The Great Ceiling composition (Fig. 6a, following Barrière 1992) includes mammoths, ibex, bison, horses and rhino. They are arranged in loosely associated groups of each animal type. There are five groups of mammoths, with 25 mammoths in total. The two central groups of mammoths, containing the largest examples, are facing one another at close quarters. The mammoth in the middle (Mammoth 89, following Barrière 1992) is depicted facing another large mammoth; the distal trunk portion of its trunk is directed posteriorly, and the 'fingers' at the trunk tip are 'open'. Five mammoths (indicated with our blue arrows within circles in Fig. 6a) appear to be standing in the 'communicating pose' with the distal ends of their trunks resting on the ground, and four of these face inwards towards the central group of large mammoths. None of the mammoths are depicted in single file.

This composition can be interpreted as a natural arrangement of animals in the wild, as the artist experienced them without tension or aggression between them. It might have been normal for all the mammoths in such an arrangement to be communicating amongst themselves, perhaps using infrasound, while the other animals were milling around. It would also be natural for herbivores to stand in a large, mixed group like this to protect themselves and deter predators from attack, a protection behaviour that occurs currently with elephants and other herbivores (Mumby 2020).

Plassard and Plassard (1995) noted that the 'standing head-to-head' posture is repeated fifteen times within the cave and commented that while it is usually interpreted as a confrontation, they could determine no signs of aggressivity. In Figure 7, their front cover image (from the Via Sacra) is presented alongside a photograph of extant elephants exhibiting a similar posture; see also Fig. 1c and 1e. Communication via infrasound in elephants can extend over kilometres or can occur at very close range. In fact, one of the initial discoveries of the role of infrasound in elephant communication involved the head-to-head position (Payne 1998).

Figure 8a (modified from Barrière (1992: Fig.

301) further indicates communication between mammoths. Barrière referred to this as 'Mammoths greeting each other in Rouffignac Cave'. Our blue arrows indicate curved, curvilinear or undulating pairs of lines (typically parallel or sub-parallel) superimposed on or connecting the closely spaced group of seven mammoths. In several such cases at Rouffignac Cave, parallel, undulating or sinusoidal lines are portrayed in close proximity to mammoth images or festoon the images. While a coincidental origin for such juxtaposition cannot be excluded, the lines can be interpreted as possibly representing vibration and communication through sound.

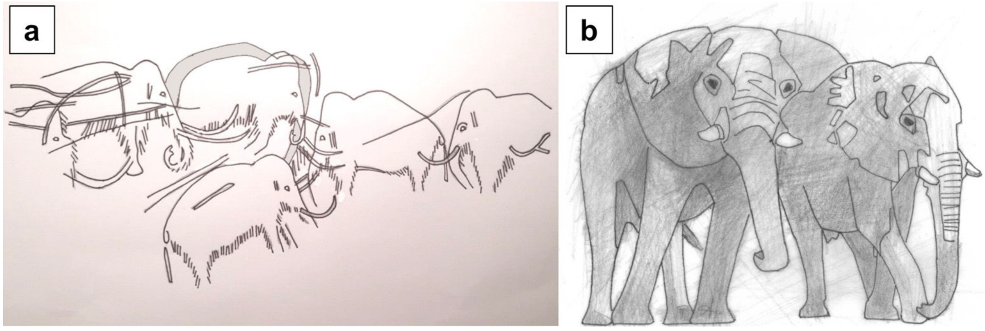


Figure 8. *(a) Images from Salon Rouge in Rouffignac Cave of seven mammoths communicating, with lines festooning them or connecting them; five of the mammoths are facing a pair of mammoths standing very close together and facing in the same direction (one is shown here shaded in dark grey) that may be in consort—see text for details (modified from Barrière (1992: Fig. 301); (b)* L. africana *mating pair in consort.*

Five of the mammoths (all showing temporal gland secretions) face inwards towards the two mammoths in the centre of the composition, which are portrayed standing very close to one another. The composition resembles what occurs in *L. africana* when a male and female go into consort for three to four days while mating. They typically stand very close to one another, with the bull protecting his mate, usually with several male elephants in musth (as discussed further below) milling around the two elephants in consort, waiting for an opportunity to mate while the female is still in oestrus, all accompanied by rumbling and other sounds (Fig. 8b). It is possible, therefore, that Figure 8a represents a pair of mammoths in consort, surrounded by bulls in musth, and that the lines represent infrasound or sound. A similar example from Chauvet Cave is described below.

Two features that distinguish the art of Rouffignac Cave are (a) the large number of mammoth images and (b) the extent of the serpentine ('macaroni') lines and finger flutings. It appears that previous interpretations do not link these two features into a single hypothesis. An explanation could be that the artist(s) would not have had to see a mammoth to feel or hear its infrasound or sound. This could explain how many 'macaroni' lines occur at a distance from mammoth images. Interpreting the lines as sound-related or infrasound-related offers a parsimonious explanation and can be considered in interpreting such art.

In general, echoes are known to be a key feature in the siting of rock art for many ancient artists around the world, including in caves (Devereux 2002). Reznikoff (1995) researched the acoustic dimensions of pre-Historic painted caves and classified resonance patterns, finding a correlation between resonant locations and rock art. With respect to painted caves in France, Reznikoff (2009) reported a direct correlation between the resonance of the location and the number of paintings or signs in that location. In fact, Reznikoff (2009) noted that in Rouffignac Cave, proceeding through the site as in pre-Historic times (i.e. without strong lights) and guided by sound and echoes, the explorer was allegedly 'led' to the area of rock art. Moreover, Waller (1993) reported that a ceiling along the Via Sacra in Rouffignac Cave containing a concentration of images of mammoths, horses and ibexes was found to 'buzz' with echoes, attributing the strong acoustics to a pit located directly underneath the stone ceiling.

Mammoth 107 (Fig. 5a) and other mammoth images at Rouffignac Cave contain several shorter linear markings within the outline of the body. It may be questioned whether the lines relate to the principle of so-called sympathetic hunting magic (e.g. Thackeray 2023). At other Upper Palaeolithic sites, they have been interpreted in terms of proto-writing and a phenological calendar (e.g. Bacon et al. 2023). To such suggestions, we can add the notion (in the case of Mammoth 107) that they may conceivably represent vibration or sound, although they are not as dramatic as the lines ahead of the El Pindal Cave mammoth. We note, too, that the collection of lines on Mammoth 107 (Fig. 5a) occupies approximately the same anatomical position as the 'heart'-shaped image on the El Pindal Cave mammoth (Fig. 4a).

The 'First Mammoths' at Rouffignac Cave, so named because they were the first to be identified in the cave in 1956, also face each other 'head-to-head'. Long, vertical, sub-parallel lines cover much of the mammoth on the right (Fig. 9) and were registered prior to the engraving of the mammoth (Plassard and Plassard 1995). A connection to sound and vibration can again be postulated.

Further insights into the kind of panels that might contain evidence of mammoth seismic communication include birthing. Poole (1997: 11) noted how newborn elephants are welcomed into elephant society by loud roaring and rumbling:

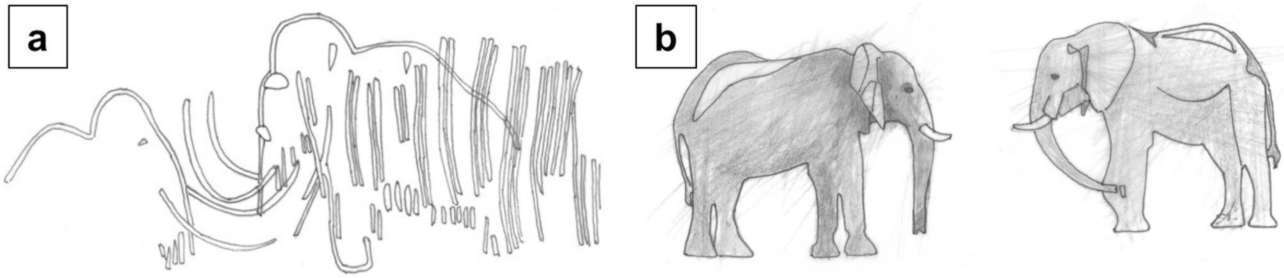


***Figure 9.** (a) The 'First Mammoths' of Rouffignac Cave, facing one another in a possible greeting posture; the larger mammoth on the right has been superimposed on a set of long, sub-parallel vertical lines; (b)* L. africana *in a similar greeting posture.*

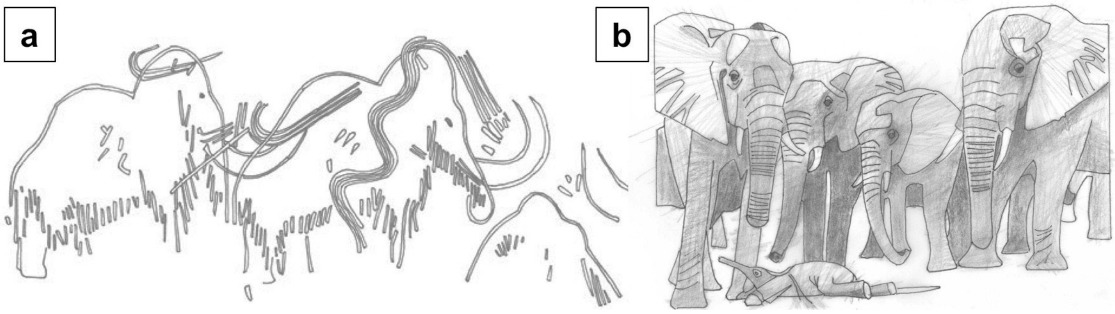


***Figure 10.** (a) A possible birth or newborn scene (with the putative newborn at bottom right) from the 'Frieze of Five Mammoths' in the Via Sacra in Rouffignac Cave; a possible interpretation of the multiple finger flutings on two of the mammoths is that they represent the chorus of sound at the birth scene; (b) a birth scene among* L. africana*, in which the newborn is welcomed into the group with loud vocalisations and rumbling from the older relatives; note the secretion from the temporal gland of the female elephant on the left.*

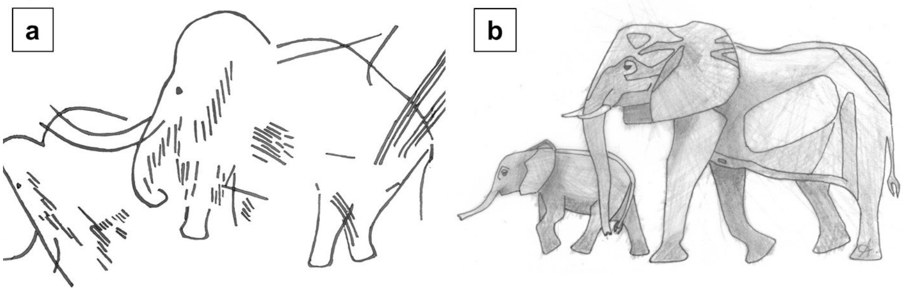


***Figure 11.** (a) 'Mother and calf' from the Grand Fosse site in Rouffignac Cave; (b)* L. africana *mother and calf in a potentially analogous relationship; see text for details.*

> I have witnessed the intense excitement displayed by elephants at the birth of a baby, as 10 or perhaps 20 elephants vocalise in chorus, their calls extraordinary powerful, some well below the level of human hearing, reaching over 106 decibels, and travelling 5 to 10 kilometres. These scenes are typical of elephants during moments of social excitement, greeting, a birth, a meeting, for example.

A frieze of five mammoths along the Via Sacra in Rouffignac Cave (Plassard and Plassard 1995: 8, 9) possibly depicts a birth scene. Two groups of two mammoths are portrayed facing each other while the fifth mammoth fills the empty space between the heads of the front two animals (Fig. 10a). The perfectly central position of this very small mammoth increases the effect of symmetrical composition (Plassard and Plassard 1995: 19). Two of the mammoths have superimposed finger flutings (Fig. 10a), and on the ceiling are meanders and serpentine lines. We postulate that these enigmatic marks might represent mammoth sounds, possibly including infrasound, at the birth of the central mammoth, similar to what has been described in elephants by Poole (1997: 49).

A final example from Rouffignac Cave, from the Grande Fosse site, is a depiction of an adult mammoth, possibly female, with her offspring ahead of her within touching distance (Fig. 11a). Sets of long, parallel lines are present in the rump region, with a larger set of shorter lines in her 'heart' region (cf. Figs. 4a, 5a). Figure 11b shows a potentially analogous scene involving *L. africana*, with the mother able to keep an eye on her calf while walking, while quietly communicating through rumbling. Moss (1988: 161) described such behaviour:

> The calf is rarely more than a few feet from its mother and usually less than a foot from her, often touching her by leaning on her leg or resting its head against some part of her body. Over 90 per cent of the time the newborn's nearest neighbor is its mother.

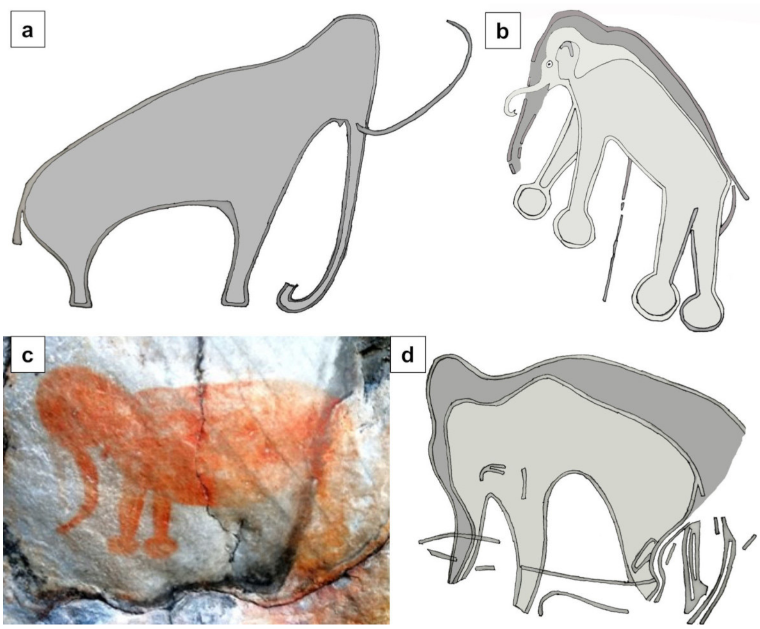


Figure 12. *(a) A mammoth in a forward-leaning posture at Chauvet Cave, probably from the Aurignacian Period; (b) a small mammoth depicted in the Salle du Fond at Chauvet Cave, with bulbous feet and a line connecting abdomen to the ground (cf. Fig. 1a and Fig. 2). The mammoth is depicted close to its mother, surrounded (not shown here) by crouching lions, 'agitated' rhinoceros and bison; (c) rock art from a site near Citrusdal, South Africa, depicting an elephant with bulbous feet (cf. Fig. 2a–c); (d) a pair of mammoths in the Salle Hillaire in Chauvet Cave, possibly in consort (cf. Fig. 8a) with lines in front of, below and behind them.*

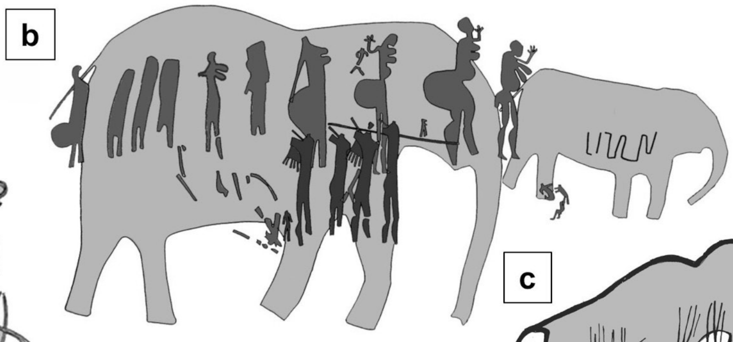
Chauvet Cave: An example from Chauvet Cave in southeastern France, from a section known as 'The Panel of Handprints', shows a mammoth image (Fig. 12a) much like that at El Pindal Cave (Fig. 4a). The mammoth is leaning forward on its front feet in a possible 'freezing posture', with the distal portion of the trunk facing backwards. The cave art in Chauvet Cave has been reported to date to the Aurignacian period, ~32–30 ka (Sadier et al. 2012). To the best of our knowledge, this provides the oldest example depicting an apparent seismic communication posture in a mammoth.

Another example from Chauvet Cave involves the portrayal of a small mammoth with substantially accentuated, bulbous feet and a straight line that joins the underside of the abdomen to the ground (Fig. 12b) (Chauvet et al. 1996: 111, cf. Fig. 1a). This mammoth was drawn close to a larger one, as part of a panel representing a potentially hazardous situation that included images of lions, bears, bison and rhinoceros.

Figure 12c illustrates a similar example of art depicting unusually bulbous elephant feet from South Africa. These images can also be compared with those in Figure 2. While the reason for these depictions cannot be known with certainty, ascribing them to vibration effects that travel down the legs into the ground as part of seismic communication can be added to the postulated explanations. The three images appear to present a convergence of pre-Historic art from South Africa, northern Africa and western Europe.

Finally, in the Salle Hillaire, a pair of mammoths (one larger than the other, possibly a male and female) is depicted standing very close to one another (Fig. 12d). This resembles the mammoths shown in Figure 8a and could also represent a pair in consort.

Pech Merle Cave: in a similar case of convergence of rock art forms from western Europe and South Africa, we note an example from Pech Merle Cave in south-central France, which can also be compared with Figures 1d and 1e. In this work of parietal art, three 'naked dancing' women are superimposed on three mammoths with lines superimposed on them (Fig. 13a). A set of mammoth tusks links the women and mammoths in the composition. These mammoth tusks are depicted in an arrangement similar to that found in the doorways of contemporary dwellings (Iakovleva 2015). This painting suggests a special re-



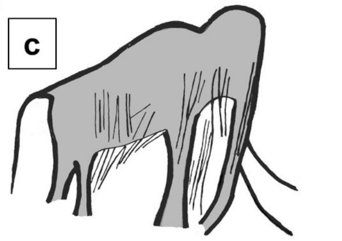


Figure 13. *(a) Mammoth from Pech Merle Cave linked by a pair of tusks and superimposed with images of three 'dancing' female figures; (b) elephant images with superimposed 'dancing' female figures from Salmanslaagte, South Africa; (c) forward-leaning mammoth (part of the 'Black Frieze') at Pech Merle Cave.*

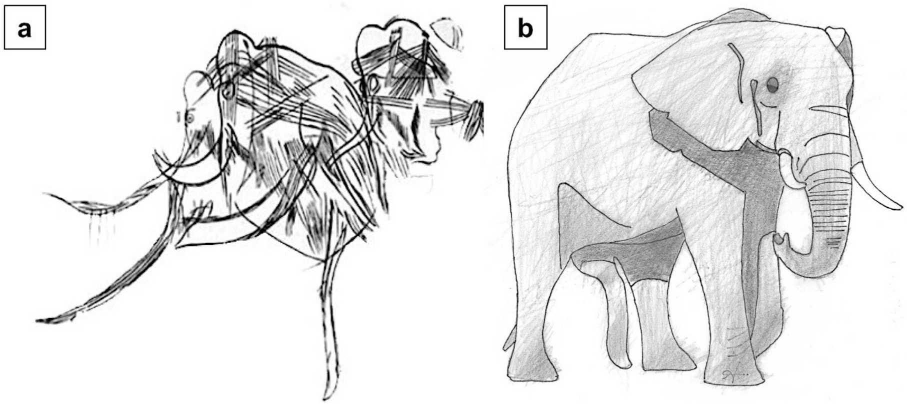


Figure 14. *(a) Three bull mammoths depicted in probable musth in Bernifal Cave; the front bull has what is interpreted as a long, extended penis which is characteristic of musth and the mating season. All three mammoths have tectiforms superimposed on them; (b)* L. africana *in musth, with a streaming temporal gland and a long, extended penis.*

lationship between mammoths, women and perhaps dwellings. The art in Pech Merle Cave is reportedly from the Gravettian and Magdalenian periods.

Figure 13b presents the South African example. A San painting at Salmanslaagte appears to depict a similar scene and relationship, with ten 'naked dancing' women and four 'dancing' men superimposed on top of a pair of elephants. Below these images is a large group of 'singing' people superimposed on a long set of parallel lines that may represent sound.

Also in Pech Merle Cave is the 'Black Frieze', a set of animals, including mammoths, horses, bison and aurochs, facing in different directions. This frieze resembles that of the 'Great Ceiling' at Rouffignac Cave (Fig. 5a), despite a temporal distance of ~12,000 years (Gravettian to Magdalenian). Figure 13c illustrates one of four mammoths, depicted in a forward-leaning posture with the distal end of the trunk pointing posteriorly. This posture is similar to that from El Pindal Cave and represents another possible example of a 'freezing posture'.

Bernifal Cave: Bernifal Cave, in the Dordogne region of southwestern France, is situated within a few kilometres of Rouffignac Cave. It, too, contains rock paintings and engravings attributed to the Magdalenian period. This art is considered here firstly with respect to mammoths in musth, followed by a brief review of 'tectiforms', and a novel postulate that tectiforms may represent sound or infrasound.

Bernifal Cave contains many mammoth images. In one case, an engraving of three bull mammoths depicts them in probable musth (Fig. 14a). One of these engravings exhibits a long protrusion extending from its underside, which is interpreted here as a long, extended penis. This is characteristic of musth and the mating season in elephants; an example from southern Africa of *L. africana* in musth with an extended penis is shown in Figure 14b. All three mammoths have tectiforms superimposed on them.

So-called 'tectiforms' have a limited spatial and temporal distribution, only being reported from five caves in the Dordogne (Rouffignac, Bernifal, Font-de-Gaume, Combarelles and La Mouthe) and all from the Magdalenian (Capdeville 1986; Desdemaines-Hugon 2010). Capitan and Breuil (1902) first drew attention to their resemblance to a house or tent-like structure, an interpretation that has remained popular. Reportedly, there is only a total of 56 tectiforms (Plassard 2005). They have been noted to have relationships with animals, including mammoths (Vialou 1987; Plassard 2005). Von Petzinger (2016) concluded that the restricted use of the tectiform could mean some sort of clan sign, a marker of a specific group's identity that no one else was allowed to use. Plassard and Plassard (1995: 21–22) acknowledge that the meaning of tectiforms is 'totally unknown'. Desdemaines-Hugon (2010: 18) drily noted with regard to tectiforms that

> the theories depend on current fashion signatures, shamanistic or totemic signs, or considering their restricted geographical distribution, tribal identification. As none of these interpretations can be verified, we must be content with acknowledging their undeniable importance.

Twenty-four mammoths and eleven tectiforms have been reported in Bernifal Cave (Desdemaines-Hugon 2010). The three bull mammoths shown in Figure 14a have an aggressive and determined appearance, and tectiforms are superimposed on them. A nearby bison also has a tectiform superimposed on it.

We suggest that tectiforms may symbolise the special sounds made by mammoths, bison, ibex, horses, reindeer, etc., during the height of the breeding season. This is related to musth in mammoths, whereas in animals such as bison, it is called 'rutting'. Observant Palaeolithic artists would have witnessed these seasonal breeding behaviours and unique sounds for the animals. While tectiforms are frequently associated with mammoths, they are also clearly associated with other animals and could represent the unique sounds of the mating season. In the case of mammoths in musth, this could include infrasound.

Arcy-sur-Cure caves: the caves of Arcy-sur-Cure are located in Burgundy, France. The parietal art they contain also dates back to the Aurignacian period, possibly slightly younger than that in Chauvet Cave. One image (Fig. 15a) of a forward-leaning mammoth in a possible 'freezing posture' can be compared with Figures 4a, 12a and 13c. The depiction of such similar, forward-leaning postures over an extended period suggests that the artists were observing and realistically recording what they encountered. Figure

15b portrays a similar posture in *L. africana*.

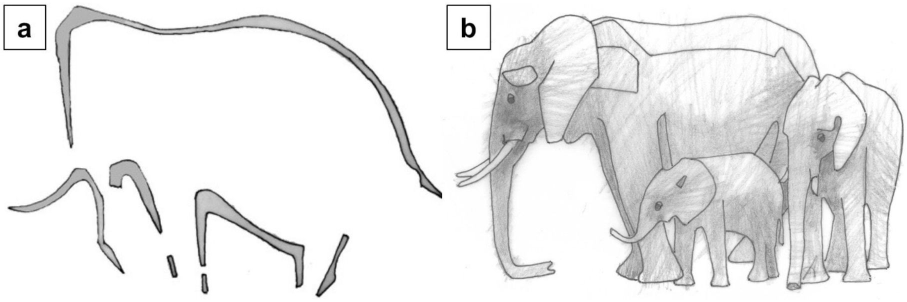


Figure 15. *(a) Forward-leaning mammoth image at Arcy-sur-Cure, cf. Figs 3a and 11a; (b) a similar posture in* L. africana.

Discussion and conclusions

Our approach attempts to bridge the disciplines of traditional palaeontology, ichnology and the rock art record, recognising that each discipline can contribute a unique information set and that these may be complementary to each other. A further line of evidence, given the northern habitats that mammoths inhabited, might lie in assessing the suitability of permafrost as a conducting medium for seismic waves, as has been done for sand. We interpret the evidence from the body fossil record, albeit incomplete, as strongly suggesting that seismic communication through infrasound existed in mammoths, and the trace fossil record has the potential to deliver new evidence in this regard. It should, therefore, not be surprising if evidence is forthcoming in the rock art record to suggest that Palaeolithic artists observed and possibly sensed mammoth behaviour that represented seismic communication and illustrated the resulting postures and associated features in their corpus of art. The concept is evocative of possibly being able to infer the behaviour of an extinct genus through the senses and skills of ancestral humans.

The San in southern Africa know that 'each species has its own characteristic behaviour, which was governed by its *kxodzi* (customs), and each has its particular *kxwisa* (speech, language)' (Liebenberg 1990: 83). This vital connection between animal behaviour and the sounds they make is central to the ability of the San to track and hunt successfully, to protect themselves in times of danger, and thus to their survival. Similar considerations may have applied to Palaeolithic artists in western Europe, and we suggest that the wavy lines made by the artist, around and superimposed on the mammoths, may be directly linked to the individual or group behaviour of the mammoths, witnessed personally by the artist. Furthermore, it appears that the artists responsible possessed a competence for depicting an abstract, non-visual quality as a graphic symbol. This is but one step removed from depicting a visual cue in graphic form, and we suggest that the sound lines associated with the mammoths could conceivably be regarded as a step on the road to the written word.

Commonalities exist between what we encounter in South Africa and what has been recorded in France. We also find rock art concentrations in caves and rockshelters where resonance can be heard or felt (including from natural phenomena such as wind and flowing water). Furthermore, rock art tends to be placed close to dome-shaped rock shelter roofs or other features that promote echoing of sounds, and gong rocks dot the landscape in specific positions (Kleinloog 2019). Morris et al. (2018) noted a strong spatial association between such gong rocks and petroglyphs. At a global level, similar features have been reported from diverse locations, including Europe (Waller 1993; Williams 2012; Díaz-Andreu et al. 2014; Mattioli et al. 2017).

Sound and resonance appear to have been important to pre-Historic artists. At Rouffignac Cave, noting the resonant qualities of the areas of rock art concentration, the preponderance of mammoth images, and the extensive network of serpentine features, it is but a small step to link these phenomena and parsimoniously attribute the lines to a representation of mammoth sound. However, we acknowledge that it is not always possible to know with certainty that the mammoth images and the associated lines (or images of 'dancing' women) were produced simultaneously.

Plassard and Plassard (1995: 22), describing the art in Rouffignac Cave, stated:

> It is easy to describe the art work; it is impossible to understand it. The cave art … is now considered as a many sided phenomenon. A quick look at the situation of the work in the underground cave and galleries shows that the position was not a result of random choice. The layout of the decorated panels indicates that the primitive artists did not work at random or to suit suggestions from their fellows, but that, on the contrary, they knew the topography of the cave like the backs of their hands. Particular spots were selected to comply with what was probably some sort of symbolism in the underground space. Perhaps the artists were depicting a principle or a concept? Perhaps the animal was nothing but a support for some form of symbolism?

We suggest that at least one factor associated with Upper Palaeolithic art related to the symbolic rendition of sound. We acknowledge that the examples we have provided vary: some are more specific to seismic communication through infrasound, and others relate more to sound in general and may have an infrasonic, seismic component. We can speculate that should a Palaeolithic artist have stood close to a stationary rumbling mammoth, a meaningful effect would have resulted, one that was eminently worthy of recording on rock. From our perspective, as we interpret rock art evidence that suggests that mammoth seismicity was a reality, we acknowledge the perspicacity of Upper

Palaeolithic artists.

Clottes (2008: 24) suggested that 'Palaeolithic people had a shamanic religion and created their art within this framework' and that 'shamans thus play the part of the mediators between the world of the living and the world of spirits'. In our interpretations of the images we have studied, we have not discussed the possible role of shamanism, which we do not discount. However, we have consistently found realistically depicted animals with features that potentially could represent depictions of infrasound or sound.

Analysis of the available evidence presented here allows us to postulate that mammoths, like extant elephants, generated seismic waves through rumbling and percussion. Moreover, we infer that Upper Palaeolithic hominins in western Europe, from the Aurignacian to the Magdalenian, probably observed mammoths in postures that are typical of seismic communication and accurately recorded this in their parietal art over a period of 20,000 years. The behaviours depicted are similar to those of *L. africana* encountered today, suggesting that these forms of behaviour have not changed over the past 32,000 years.

Leroi-Gourhan (1965) contended that figurative subjects did not change substantially between the Aurignacian and Magdalenian and that the corpus of western European Palaeolithic art, representing the living world, was maintained with only minor variation. We concur, and we appreciate the artists' abilities to observe proboscidean behaviour in their environment and recall it through painting these animals in superb detail, whether in rockshelters or on boulders in Africa or deep within caves in western Europe. Furthermore, we contend that this ability included the rendition of vocalisations, something that they could not see but could sense (infrasound) or hear (in the acoustic range). The result is a corpus of art that depicts consistent proboscidean behaviour over at least 32,000 years.

We conclude that in all probability, thanks to this rock art record and buttressed by evidence from the fossil record, proboscidean seismic communication is not confined to the genera of *Loxodonta* and *Elephas* but also occurred in *Mammuthus*.

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