Supplementary Information

Contents

S1. DESCRIPTION OF THE SELECTED SITES

S1.1. SANTIMAMIÑE

Location

ETRS89 / UTM ZONE 30N **X:** 529452 **Y:** 4799371 **Z:** 160

The cave of Santimamiñe is located in the municipality of in Kortezubi (Bizkaia), in the Aptian-Albian massive reef limestones of the Ereñozar mountain, in its southern side, 160 meters above current sea level. It's placed in the valley of river Oka, in the estuary of Urdaibai, 6 km from the modern shoreline.

Brief topographic description

It is formed along a joint that dips 45° (similar to its appearance in the entrance), with a 365m long main gallery, with an average width is between 3.5 and 4 metres (although at some points it also covers measures of up to 10 metres) and an average height of 6-7 metres (although at some point it reaches a height of about 40 metres) (Maeztu and Aranzabal, 2011).
The area of the cave which was used by the ancient humans (named as the archaeological area) covers the first 120 meters of the cave. In this field we shall first find the entrance of the cave, with the habitat site from the Lower Magdalenian to the Roman period (Aranzadi et al., 1931; López-Quintana, 2011), although there are some evidence of older occupations (Aranzadi and Barandiarán, 1935; Ruiz Idarraga, 1987), and then the decorated area (with paintings and engravings from the Magdalenian period, see below). The decorated area is divided into several sectors: the vestibule itself, the so-called "Salon" (the first interior hall of the main gallery), the set of the "Old Hall of the Paintings" (with an "Antechamber" and the main "Chamber") and the "New Hall of the Paintings" (the last decorated section of the main gallery). Although it is few meters in length, it has a very abrupt topography, which greatly increases the difficulty of walking through it. Although we can find the first paintings in the entrance room itself (red dots and stains), the most important areas are located in the deep parts of the cavern (in the dark rooms). Above all, in a lateral gallery about sixty meters from the entrance (despite it is geologically part of the Main Gallery, which was separated by formations -see above-) we shall find the main set of cave figures ("Old Hall of the Paintings"). Along the Main Gallery there are also a few more isolated rock art (in the room opposite the "Old Room of Paintings", called the "Salon"). The last figures are in the "New Hall of the Paintings," after a steep and dangerous path, nowadays achievable thanks to stairs and walkways.
From the "New Hall of the Paintings", after a vertical climb of 6.5 meters, the gallery continues 240 meters further into the depths. No archaeological remains have been found in these areas. However, through these deep areas of the cavern we will find the largest volumes of Santimamiñe (the "Great-Hall" and the "White-Hall") and spectacular geological formations, like the "Fried-Egg".

The cave art

Based on the latest inventories of Palaeolithic cave art carried out in Santimamiñe (Aranzadi et al., 1925; González Sainz & Ruiz Idarraga, 2010; González Sainz, 2016/17; Garate, 2017), we have developed a database of graphic elements (we have added some new images identified in our project, apart from some re-interpretations).
The rock art in the cave consists of 75 individualised graphic units (GU's), of which 30 represent bison, together with 8 animals hard to identify, 8 horses, 4 ibex, 1 bear, 1 deer, several simple signs (dots, paired marks, etc.) and unvoluntary traces (stains, marks, etc.). They are placed in 5 different sectors: A or the "Vestibule", B or the "Sallon", C or the "Antichamber", D or the "Chamber" and E or the "New Hall of the

Paintings". The paintings were created mostly with black pigment made from charcoal, although shallow engraving was also used (sometimes combined with the paintings) as well as red pigment based on iron oxide (González Sainz and Ruiz Idarraga, 2010). The engravings are mostly fine and superficial, although there are cases that go deeper. The stroke is single or repeated.
An attempt was made to date the paintings, obtaining a date that was too recent (907-671 cal. BP) (Moure & González, 2000), produced by insufficient pretreatment to ensure the elimination of modern carbon pollution and at the same time preserve the sample, too small (H. Valladas, Personal Communication). However, because of the similarity with other dated portable and rock art, it can be firmly attributed to a time between the Middle Magdalenian and the first phase of the Upper Magdalenian (ca. 17.5-14.5 ka). On the other hand, in 2022 several charcoal fragments were found in the vicinity of the main panel by M. Medina-Alcaide and I. Intxaurbe, likely to date a possible ancient human frequentation in the room, perhaps linked to the production of rock art.

S1.2. LUMENTXA

Location

ETRS89 / UTM ZONE 30N **X:** 540408 **Y:** 4800919 **Z:** 88

The cave os Lumentxa is located in Ispaster (Bizkaia), near Lekeitio, on the south side of the hill of the same name, on the western bank of the Lea Valley, very close (less than 1 km) to the current coastline. It opens in organogenic Aptian-Albian micritic limestone, 88 metres above sea level.

Brief topographic description

The cave has two entrances, one facing south and one facing northeast. The habitat site in the main entrance hall contains occupation layers with materials from Lower Magdalenian period to Roman age (Aranzadi and Barandiarán, 1935; Arribas Pastor and Berganza Gochi, 2018). It has a development of about 50 m and consists of a main gallery. At the end of this gallery, there are some old ceiling collapses, creating some side passages and pseudo cave levels. The main part of the rock art set of the cave is placed in these last sectors of the cave. Unfortunately, the cave has been intensively used since historic times (at least XVIII century), and it's full of graffiti, soot marks and broken speleothems.

The cave art

Based on the latest inventories of Palaeolithic cave art carried out in Lumentxa (Garate et al., 2013a), we have developed a database of graphic elements (we have added some new images identified in our project). The rock art in the cave consists of 31 individualised graphic units (GU's), of which 2 represent bison, 1 horse, 3 simple signs (dots) and unvoluntary or very simple traces (stains, finger flutings, etc.). They are placed in 3 different sectors: B, C and D. The paintings were created mostly with red pigment made with iron oxides (hematite) (C. Chanteraud, Personal Communication), although multiple thing engraving technique was also used in the deepest part of the cave, along with some finger engravings in soft surfaces (very eroded limestone surface). On this sense, there is a large stain of ochre covering the soil of a huge rock, close to the main panel and other simple GUs (stains, points, etc.). A flint blade was also found inserted in a fissure of the entrance. These remains (and especially the ochre stain) seem to be related with the graphic activity of the cave. There are also some charcoals covering the ground in areas with difficult access, as well as a wall made with rocks covered with a stalagmite. In any case, is difficult to connect these other remains with the graphic activity, due to the intense use of the cave throughout history.

Owing to the similarity of the ensemble to other portable and parietal art dated directly and contextually, it can be firmly attributed to a time between the Middle Magdalenian and the first phase of the Upper Magdalenian (ca. 17.5-14.5 ka). In the habitat site, red ochre pieces were found in Upper Magdalenian levels, one of them with three engraved horses (Aranzadi and Barandiarán, 1934), one of them using the border of the piece to represent the back of the animals, as the two bison do in the main panel of the cave.

S1.3. ATXURRA

Location

ETRS89 / UTM ZONE 30N **X:** 541048 **Y:** 4797129 **Z:** 55

The cave system formed in Aptian-Albian reef limestone (Lower Cretaceous), in the southern slope of the mountain "Gazteluko Atxa" or "Gerika", in Berriatua (Biscay), 55 meters above current sea level, in the valley formed by the stream of Zulueta, a tributary of the Lea, 3 km from the current coast.

Brief topographic description

It consists of two subhorizontal passages (cave levels) at different heights, the lower one called Armiña and the upper one called Atxurra. The cave has two entrances which lead access to two horizontal levels; the lower one is called Armiña (it was artificially opened by roadworks in 1882), and the upper one is called Atxurra. Both are part of the same endokarstic system; the total topographical development of the cave system is 1085 meters (A.D.E.S., Personal Communication). After the upper-level entrance, the only access point to the cave in the past, there is a small vestibule with at least 2 meters of sedimentary deposit developed during at least the last Pleistocene (Gravettian, Lower and Upper Magdalenian) to Holocene (Neolithic/Calcolithic) (Barandiarán, 1961a; Rios-Garaizar et al., 2019; Aranbarri et al, 2023). After crossing this space and going through a small window, we reach the inner sectors of the cave. At this point, 17 meters deep from the entrance, there is a very pronounced ramp which has a length of 15.03 meters by an average wide of 1 meter and descends vertically 10 meters, connecting with the lower level of the cave. If we cross the shaft going around of it, we will enter an area with low ceilings that end in several crawlways. After this point, the sizes of the gallery increase, crossing several large spaces with the floor filled with cave bears nests. After other passages opened in stratified limestone, we will reach the point where this level reconnects with the lower level. If we continue towards the interior, it would be the point where the decorated areas begin.

Nowadays, accessing the system is done by using the lower level's artificial entrance (Armiña), where there are at least two colluvial cones of matrix-supported heterogeneous clastic sediments filling the passage from the outside. Close to this point, there is evidence of a sporadic human occupation dated in the Upper Magdalenian cultural period, suggesting that this entrance was isolated from the outdoor, with humans likely entering from the upper level's entrance through the endokarst (Rios-Garaizar et al., 2020). This cave-level is formed by a large passage with regular dimensions of 4 by 4 meters and a relatively horizontal floor (except for the last part, where we can find a series of bear dens), which is stable for its extension of about 200 meters. In its final stretch, it connects with the upper level (Atxurra) through a steep ramp caused by a roof collapse (at a distance of 203 meters from the entrances).

The areas with rock art and archaeological remains also begin here (in the upper level), 10 meters before the union between Armiña and Atxurra with a first depiction hidden in a small phreatic tunnel located in the lower part of the right wall (Sector A). Between this point and up to a depth of 365 meters from the entrance, the decorated sectors will follow one another. There are 15 sectors with archaeological remains (rock art or superficial evidences like flint pieces or charcoals) in the right wall, and 10 in the left wall. They are normally found on elevated shelves above the easiest transit area (which runs through the lowest area of

the gallery), some with difficult access (Sector C, Sector H, Sector F' and G'), although there are also some areas on both sides of the main road towards the interior (Sector G' floor, I floor or J' floor). Some of the sectors, such as sector D (the "Hall of at the Bison") or J (the "Cornice of the Horses") have the capacity to accommodate quite a few people at a time.
Thirty meters after the last archaeological sectors (K' and J'), but in the middle section of the upper level, there is a vertical speleothem formation, covering almost the entire passage. This has been partially broken at a height of 3 meters by cavers to allow further exploration of the cave deeper into the mountain, through a narrow passage. The passage continues 600 meters having the same morphologies as before, but there is also a stational lake. No rock art evidences (or other archaeological remains) have been found in the cave portion beyond this gravitationally formed speleothem.

The cave art

The cave art of the cave was found in 2015 (Garate et al., 2020a), and a complete inventory has not been published yet. However, there are some partial inventories (Intxaurbe et al., 2020; Garate et al., 2023). The GUs of the cave were found in 18 sectors, among them 7 also contained superficial archaeological remains (scattered charcoals, fixed fires, a probable grease lamp and/or flint pieces), and there are also 5 additional sectors with only archaeological remains (mainly scattered charcoals). The sectors with rock art are A, C floor, C or the "Alcove of the Bear Claw marks", D floor, D or the "Hall of the Bison", D', F, G, E', H, F', G', G' floor, I floor, J or the "Ledge of the Horses", J floor, J' floor and K'.
The rock art in the cave consists of 256 individualised graphic units (GU's), of which 48 represent bison, 34 ibex, 25 zoomorphic figures hard to identify, 11 horses, 4 hinds, 3 probable stylized feminine figures (FFS), 2 deers, 2 bears and 2 aurochs. There are also 4 isolated arrows and three complex signs (meander form engravings and a probable claviform) and involuntary or very simple traces (113 isolated or non-figurative lines and 5 stains of red pigment). The paintings were created mostly with black pigment made from charcoal, although shallow engraving was also used (sometimes combined with the paintings) as well as red pigment probably made by iron oxide. The engravings are mostly fine and superficial, although there are cases that go deeper. Finger engraving could be seen in one of the GUs, and scraping was also used, combining sometimes with other techniques (thin engraving, black painting, etc.).
Owing to the similarity of the ensemble to other portable and parietal art dated directly and contextually, especially because of the presence of some ibex in frontal view, it can be firmly attributed to the Final/Upper Magdalenian (ca. 15-13.5 ka). This chronological proposal coincides with the contextual dates obtained for one of the phases of use in the cave (14.7-13.9 ka), obtained from dating several scattered charcoals and a fixed fire beneath the panels. One of the most representative samples was found attached to one of the flint tools (a blade) that was found under the main panel of the cave (Sector J) and whose traces of use confirm that it was probably used to make some figures of the same panel (Garate et al., 2023).

S1.4. EKAIN

Location

ETRS89 / UTM ZONE 30N **X:** 558775 **Y:** 4787273 **Z:** 90

The cave of Ekain is located in the reef limestones with rudists and corals from the lower Aptian-Albian of the eastern slope of the hill of Ekain, inside the municipality of Deba (Gipuzkoa), at 90 meters above sea level, in the union of the valleys formed by the Sastarrain and Goltzibar streams (tributaries of Urola), at a distance of 6.6 km from the current coastline.

Brief topographic description

It is a network of horizontal galleries (although it is possible to find some subsidence and sudden changes in level creating several wells and cornices) of about 420 meters of development, and a general upward trend, which allows to gain differences in level of up to 17 meters with respect to the entrance (Galán, 1992). The direction of the galleries is rather variable, and because of the changes in gradient, as well as the numerous forms of erosion and paragenesis (roof channels, pendants, etc.), the cave seems to be a large maze of passages. In any case, we could distinguish the cave topographically, describing it as a large central room ("Erdialde") from which numerous branches branch off in various directions. One of them allows access to the vestibule and the main entrance, where a prehistoric site was located, with levels from the transition moments between the middle and upper Palaeolithic (Châtelperronian), the Aurignacian, lower, middle and upper Magdalenian (these last two with elements of portable art), Azilian, Mesolithic and Neolithic (Altuna, 1984; 2019; Rios-Garaizar, 2011).

Regarding to the deep areas of the cave with archaeological remains, the access used by the Magdalenian societies surely started from the same vestibule, through a passage located at a lower level. This required crawling for about 10 meters (called by us Sector A), where we have recently located a small unpublished stain of red pigment on its southern side. Once passed, the cave continues through an ascending phreatic tube called "Erdibide" or Sector B, whose floor is formed by a stalagmitic flowstone, and where the first figurative representations are located, among which a bison painted in red stands out. A little further on, the tube through which we are accessing would join transversely with a larger descending gallery. Inside "Erdialde", on its north wall there is a very narrow conduit that if we follow it will allow us to reconnect with the gallery that cuts it transversally. If we continue ascending this last gallery, we will find ourselves again at a crossroads of galleries, called Sector C, which contains a relatively flat low ceiling where there is a panel that contains a figure of a horse's head, a back line of a bison in black and an unpublished large bison painted in red. The gallery that starts orthogonally from there is "Ahuntzei" or Sector D, with engraved figures of deer and hind, black drawings of ibex and salmon, and dots and spots in red, and which runs parallel to the access tube or "Erdibide". If instead of entering "Ahuntzei" we continued ascending, we would enter the "Erdialde" room or Sector E, whose west side stands out for containing several bear nests in the clay of the soil, as well as marks produced by the rubbing of torches, charcoals on the ground, a painting of a horse in black and several shapeless stains in red, among which a simple sign (dot) and an indeterminate figure can be distinguished. If we cross it, maintaining the direction of the gallery through which we entered the room, we will enter a sector that runs in a southerly direction called Sector F, and whose roof descends progressively forming a crawlway, whose roof is full of remains of red pigment and torch marks. However, if instead of advancing to Sector F we follow a "path" outlined by a stalagmitic flowstone that formed the floor of several previous sectors (B, C and D), we will turn 90º to enter a new ascending gallery whose first section, still inside of the large "Erdibide" room, but distinguished by several side cornices and blocks, is called "Zaldei", with several spectacular panels with polychrome, monochrome (in red and black) and engraved figures of horses, bison, ibex, deer and fish. Several branches depart from there, some of which contain archaeological remains and have been sectored by us as Sector G (with an engraved and painted bison, charcoal and fingerprints in the clay), H (or "Hartzei", with two bears painted in black), I (with several stains of red pigment), J (or "Azkenzaldei" with several figures of horses and probable bison), K (or "La Fontana" with clay engravings of horses). This gallery would end in a bend called Sector L, with several figures engraved in the clay, and a couple of stains in red and black, where there would be a clogged access to the outside, practicable for several small animals that accumulate waste and organic material there.

Outside of the sectors with archaeological materials, the cave presents other areas of geological and paleontological interest. The maze of galleries that is accessed by descending from the gallery that cut orthogonally the passage called "Erdibide" stands out, and that allows access to a lower sector from where it is possible to reach two semi-blocked entrances that connect with the outside. Another entrance to the interior of the Ekain cave, today artificially filled, allowed connection with an exterior cave through a very narrow passage that started from a bear nest located in "Ahuntzei".

The cave art

The group of rock art known today in Ekain is the result of numerous reviews and specific visits that have added new discoveries (Altuna & Apellaniz, 1978; González Sainz et al., 1999; Altuna & Mariezkurrena, 2008; Fano et al., 2012; Garate et al., 2015a; Ochoa et al., 2018; 2019). In the visits carried out within the framework of the project directed by M. Arriolabengoa, we have located numerous unpublished evidence, some of them figurative (such as a large bison painted in red in Sector C, or an indeterminate animal motif in a vertical position on the main panel Ek.E.VI). That is why for our study we have made a provisional inventory. The GUs of the cave were found in 12 sectors, among them 3 also contained superficial archaeological remains (scattered charcoals, fingerprints, a flint blade, and a big ochre stain): A, B, C, D, E, F, G, H, I, J, K and L. The rock art in the cave consists of 180 individualised graphic units (GU's), of which 44 represent horses, 18 bison, 6 ibex, 4 indeterminable zoomorphic figures, 3 hinds, 2 bears, 1 deer, 1 reindeer, 1 salmon and 1 fish. There are also 9 dots and a set of finger flutings. Regarding to the involuntary or very simple traces, there are 57 stains of red or black colour and 32 isolated or non-figurative lines. The paintings were created mostly with black pigment made from charcoal, although manganese pigment was used in some cases (Chalmin et al., 2002). Shallow engraving was also used (sometimes combined with the paintings), as well as finger engravings in soft surfaces, or scraping on some altered surfaces. The engravings are mostly fine and superficial.

Regarding to the chronology, we can propose two different moments for the decoration of the cave. A large part of the rock art of Ekain fits very well with some dated parietal or portable art of the Cantabrian and Pyrenean region, which attribute it to a phase that It would go from the middle Magdalenian to the beginning of the upper Magdalenian (17.5-14.5 ka). On the other hand, the goats in frontal view of the "Ahuntzei" gallery fit better with the advanced and final moments of the Magdalenian (15-13.5 ka). Several direct dates for the representations were obtained in the cave. Excluding those that are discardable due to insufficient treatment to eliminate modern contamination (H. Valladas, Personal Communication), given priority for the sake of conservation of the sample, one of the horses (Ek.E.VI.26) was dated in the Upper Magdalenian (15.161-14.275 ka), while the humic fraction gave a date for the beginning of the Middle Magdalenian (18.202-17.071 ka) (González Sainz, 2005). We are waiting to know if the results of the new sampling carried out on the horse Ek.E.VI.20, in the same panel (Ochoa et al., 2021), provide more information on this issue. In the visits carried out within the framework of the project directed by M. Arriolabengoa, we located several scattered charcoals on the surface of Sector E, some of them associated with a torch-mark existing there. In this room, in its central area, we located a large stain of ochre on the surface (similar to the one existing in Lumentxa), with some remains of scattered charcoal, unfortunately very poorly preserved due to the constant trampling of visitors, who have covered it with clay. On the other hand, in Sector G, M. Medina-Alcaide discovered charcoal adhered to the wall, and there are known traces produced by the introduction of fingers into a clay fill, covered by a stalagmitic flow. These remains add to a flint blade on a cornice that exists in Sector B (Altuna, 1997), whose use-traces were compatible with its use as a tool for engraving stone surfaces (J. Rios-Garaizar, Personal Communication). As no other post-Palaeolithic uses or visits are known in the cave (for example, funerary uses during the Holocene), it is very likely that these remains are contemporary with the graphic activity, so their dating could also help shed light on the chronology of the rock art.

S1.5. ALTXERRI

Location

ETRS89 / UTM ZONE 30N **X:** 570214 **Y:** 4791021 **Z:** 25

The Altxerri cave (Aia, Gipuzkoa) is on the eastern slope of Mount Beobetagaña, above the valley of the Altxerri river, a tributary of the Oria. The cavern develops in calcareous breccia and micritic limestone from the Maastrichtian – Danian period, alternating with bands of reddish and grey marl, 2.5 km from the current shoreline and 25 meters above sea level.

Brief topographic description

The cave of Altxerri is a speleological network of 2.5 km developed in at least three levels (Galán, 2011). The conduits are highly conditioned by the stratification of the narrow bands of box rock (calcarenites, marls and sandstones). This gives a "squared" appearance to many of the galleries. In other sectors, the folding of strata has favoured structural weaknesses that have caused sporadic collapses. In fact, it is curious how the morphologies of the intermediate floor (through which the system is currently accessed) are repeated 16 meters higher (on the upper floor) but displaced from the lower axis by about 20 meters due to a dip of 45º. It seems that the anticline present in the stratification favoured both the width of the spaces (through collapses) and the connection between the floors. Given the unique structural characteristic of the massif into which the cave opens, water flows relatively easily through various points of the system, favouring the washing and deposition of fine materials. These are normally associated with open (semi) vertical conduits between the different levels, in whose most horizontal and lowest areas there are deposits of clay and silt. Other areas present lower infiltration water activity, with more sporadic active speleothems. There are also old generations of speleothems, mainly dome shaped formations, and ground flowstones.
In the areas closest to the artificial hole opened in 1956 which actually is the only access-point to the system, there would be the archaeological zone, which would occupy approximately the first 120 meters of the cave. In this area, the galleries are arranged in at least 3 main levels, with some sub-levels, connected to each other through vertical wells and/or very steep ramps, favoured by the geological structure on which the cave is based (especially by the stratification and the folding of stone supports) and the fillings of allochthonous materials that are preserved forming hanging floors. Through the current entrance we will reach an intermediate fossil level of the cave. In this area we can find the vestibule of the cave, which, based on the quantity and typology of the evidence located, does not seem to have been used as a habitat. A little further on there is a gallery that borders two sinkholes. Once past the second, the classical decorated sector would begin, composed of several groups of engravings and paintings, in addition to a set of two bison located in the lower part of a 6-meter well (which was called "Grupo de La Sima"). The stylistic conventions present in these first sectors are typical of the last phases of the Magdalenian. Shortly after passing the initial room of the cavern, a chimney develops in favour of the stratification of the lithology and an anticlinal fold. This initial climb of 12 meters allows us to reach a higher level located at a height of +22 meters with respect to the current artificial entrance. In this upper sector, made up of two or three superimposed sub-levels and interconnected through vertical steps, there is another archaeological set, with superficial archaeological remains (burned bones, bones, charcoal, ochre, flint) and paintings (exclusively made in reddish or purple pigments). The radiocarbon dating and the stylistic parallels of the figures attribute this group to the Aurignacian period (González Sainz et al., 2013). In any case, it seems obvious to think that the two sets described (the lower and the upper) acted as two independent cave-sites, each with its respective entrances, currently collapsed. That is why it was decided to name the upper sector as Altxerri B (with an Aurignacian frequentation), independent of the lower level called Altxerri A (frequented -at least- during the Magdalenian).

Starting from the "Grupo de La Sima", a low pass leaves us at the head of two galleries. Continuing towards the entrance, but at a lower level, we could reach a section of the active section of the cavern, which ends in a siphon located near (but 21 meters below) the current entrance, right in contact with the red insoluble sandstones. If we continue in the opposite direction, a low pass leaves us at the head of a 12-meter vertical through which we reach the active zone again (but in a section upstream). From here, we can go up to a deep development of the cavern, made up of a maze of active and fossils galleries located at different heights. Despite the geological and biological interest of these sectors, no elements of prehistoric anthropic origin are known in them, so it does not seem that they were frequented by human societies in the past.

The cave art

Starting from the latest inventory of Palaeolithic rock art carried out in Altxerri (Ruiz-Redondo, 2014), and limiting ourselves to the sector with Magdalenian art named as "Altxerri A", we have prepared a database of graphic elements to which we have added some new identified motif in the latest projects carried out in the cave (protection and geomorphological study led by D. Garate, and study of the archaeological context, led by M.Á. Medina-Alcaide). Among the discoveries would be two possible stylized female figures, and several spots of red paint, unpublished until now in the part with Magdalenian art. The GUs of the cave were found in 5 sectors, among them 4 also contained superficial archaeological remains (scattered charcoals, two flint pieces, bones, and some probable chips of ochre): B, C, D, E and F. The rock art in the cave consists of 166 individualised graphic units (GU's), of which 70 represent bison, 8 indeterminable zoomorphic figures, 7 reindeers, 5 ibex, 5 bison, 3 chamois, 2 anthropomorphic (1 male and 1 ambiguous), 2 stylized female figures (FFS), 2 aurochs, 2 hind, 2 saiga antelope[1], 2 flounders, 1 salmon, 1 undeterminable fish, 1 bird, 1 bear, 1 snake, 1 fox and 1 deer. There are also 12 complex signs: 4 sets of paired strokes, 2 arrows, 2 cross shaped signs, 2 ovoid shape signs, 2 circular or subcircular shaped signs (although an alternative interpretation for one of them could interpretate it as the anus of a male anthropomorphic figure). Regarding to the involuntary or very simple traces, there are 21 isolated or non-figurative lines and 15 stains of red or black colour. The paintings were created mostly with black pigment made from charcoal, although shallow engraving was also used (sometimes combined with the paintings) as well as red pigment probably made by iron oxide. The engravings are mostly fine and superficial, although there are cases that go deeper. Finger engraving could be seen in some of the GUs, and scraping was also used, combining sometimes with other techniques (thin engraving, black painting, etc.). Two engravings also contain some abrasion in the groove to give it volume.

Owing to the similarity of the ensemble to other portable and parietal art dated directly and contextually, it can be firmly attributed to a time between the Middle Magdalenian and the final Upper Magdalenian (ca. 16.5-13.5 ka). There is no guide fossil, such as goats in frontal view, that determines their belonging to a specific phase. However, the radical schematization when drawing some animals, almost "expressionist" (for example, bison that are reduced to an amalgam of lines that represent the abundance of fur), seems more typical of the final phases of the Magdalenian, with stylistically very close specimens present in the

[1] Regarding this interpretation, the two figures, located immediately next to each other, were originally identified as a chamois and a bovid by J. M. de Barandiarán (1964a), who already noted the unusual arrangement of the horns. Subsequently, J. Altuna and J. M. Apellaniz (1976) reinterpreted them as two representations of the saiga antelope (*Saiga tatarica*). This interpretation was rejected by A. Ruiz-Redondo in his re-examination of the cave, who argues that "*the long neck in an upright position rules out its identification as a saiga or any other bovid*" (Ruiz-Redondo, 2014).

However, we believe that J. Altuna and J. M. Apellaniz are also correct in stating that "*the shape of the horns—short, unbranched, and subvertical—excludes cervids, large bovids, the chamois, and the ibex*." Furthermore, this interpretation is consistent with the convex profile of the snout, which is likewise unusual and distinctive. Nor can it be ruled out, as these authors suggest, that the figure represents a "*male saiga in its typical vertical jumping posture*." It also seems relevant that the adjacent figure, if interpreted as a head, displays the same anomalous inclination of the snout.

We agree with A. Ruiz-Redondo that these authors may have overinterpreted certain motifs, as in the case of the wolverine; however, in this particular instance, we consider that there is sufficient evidence, at least, to propose this hypothesis. In any case, since it is not a determining representation, we will do another analysis considering it as "undefined".

Atxurra cave, dated in the Final Magdalenian (14.7-13.9 ka). On the contrary, Altxerri contains figures of cold fauna that are not known in Atxurra, such as reindeer, which become the second most important theme of the cave, in terms of the number of representations. Therefore, it cannot be ruled out that it contains art that was made at an earlier time (perhaps at the end of the middle Magdalenian). Therefore, it is not ruled out that it contains art that was made at an earlier time (perhaps at the end of the Middle Magdalenian), or even later as could have been a cold oscillation within the Greenland Interstadial 1 (Older Dryas or Dryas II? Between 14-13.5 ka). The discovery of several scattered charcoals within the project led by M.Á. Medina-Alcaide, some discovered under an eroded stalagmitic flowstone, opens the possibility of being able to date a phase of human frequentation that could be linked to the execution of the art. These remains would be added to those located by J.M. Barandiarán (1964a), including the ephemeral occupation layers located at -30 and -80 depth in the vestibule, which contained some charcoals and two fragments of flint in each level (a sheet in the first and a tiny flake in the second).

S1.6. AITZBITARTE IV

Location

ETRS89 / UTM ZONE 30N **X:** 589641 **Y:** 4790572 **Z:** 223

The cave of Aitzbitarte IV is opened in the western slope of the hill of the same name (Errenteria, Gipuzkoa), above the valley of the river Landarbaso, a tributary of the Urumea. The cavern develops in bioclastic calcarenites, together with smaller areas of massive micritic limestones, limestones with silidifications, and schistose limestones, from the Upper Albian, 8.3 km from the current shoreline and 223 meters above sea level.

Brief topographic description

The cave of Aitzbitarte IV has 280 meters of development, which forms a cave-system with the nearby Aitzbitarte V, developed in at least two levels and some sub-levels with 54 meters of unevenness. The cavern has several branches that allow access to other sub-floors of the system. On the left side of the entrance hall, it is possible to access to a lower hall where there start some short galleries that end a few meters from a branch that also starts on the left of the entrance to Aitzbitarte III. The same thing happens at the bottom of the cave, where some fissures and vertical sinkholes allow access to semi-active galleries located at the level where the main gallery of Aitzbitarte III opens (Manteca et al., 1997). Other branches, however, start in intermediate sections of the main gallery and access another upper level of caves in the system, where the sector of animals modelled in clay, and the chimney that connects with Aitzbitarte V, are located.
It is the largest of the caves in the massif, with a main entrance 19 m wide by 9 meters high, which gives way to a descending vestibule (Sector A), with a floor full of blocks and whose sediment was emptied resulting from ancient or uncontrolled excavations, as well as space conditioning for military or industrial purposes (mushroom cultivation). In this area there were levels of habitat attributable to at least the Aurignacian (with doubts), Solutrean, Badegoulian, lower, middle and upper Magdalenian, Azilian, Chalcolithic/Bronze Age and Iron Age (Barandiarán, 1961b; 1963a; 1963b; 1964b; 1965; Barandiarán Maestu, 1967; Utrilla, 1981; 1986; Straus, 1983).

Going inside, we access a large gallery, with the floor occasionally covered with large blocks, and at one point we can observe the presence of a wall that partially closes the gallery, perhaps related to a mycological exploitation that took place in this cavity (Manteca et al. 1997). From this point on, the soil

sediment becomes a uniform and compact clay layer, linked to its conditioning for mushroom cultivation at the beginning of the 20th century.
Starting from this gallery, crossed successively by orthogonal fissures (which were filled during the works in the cave for mushroom cultivation), it is possible to access two vertical chimneys. These take us to two floors located at a height of 20 and 25 meters from the gallery floor. Sector B, or the "Chimney of Modelled Clay Animals", is in one of them. On the other you access Aitzbitarte V, an intermediate area between the entrance and the decorated sectors of this last cavern.
Further inside, a narrow and short gallery excavated geologically on one of the transverse joints allows us to access the final room of the cave, where stairs carved into the rock allow us to descend to the lower final hall of the cave (Sectors C and D). In our incursions we observed the speed with which the infiltration waters reach this gallery of Aitzbitarte IV, forming notable water streams, that subside to lower cave-levels. In this room, in marginal areas that are difficult to access due to their narrowness, there are several panels with rock art made in red paint.

The cave art

The first evidence of rock art was discovered in 2012, and later, in 2017, an important set of animal figures engraved and modelled in clay was found in a chimney more than 20 meters from the current floor of the gallery. While the research projects have lasted, specific discoveries have been added, especially in a final room of the cave, and a complete inventory has not been published yet. However, there are some partial inventories (Garate et al., 2013b; 2020b). The GUs of the cave were found in 4 sectors (in one of them we have also distinguished 4 sub-sectors). The sectors with rock art are A (the vestibule), B (the "Chimney of Modelled Clay Animals", with its 4 sub-sectors: B.A; B.B; B.C and B.D), C and D (the last two located in the last hall of the cave).
The rock art in the cave consists of 59 individualised graphic units (GU's), of which 10 represent bison, 3 horses, 2 reindeers, 2 zoomorphic figures hard to identify, 2 vulvas and 1 ibex. There are also four signs (1 rectangular shaped sign and 3 dots), 3 series of finger flutings and involuntary or very simple traces (13 isolated or non-figurative lines and 19 stains of red pigment). The paintings were probably made by iron oxide. In some places where the wall had a layer of alteration that produces a decalcification clay, finger engravings were used, as well as extractions and modelling using the hands to create volume. In harder walls there are some engravings which are mostly fine and superficial, although there are cases that go deeper, especially when the support is softer. Scraping was also used in some cases, and some figures were made combining sometimes several techniques.
An attempt was made to date contextually the engravings of the Sector B (the "Chimney of Modelled Clay Animals"), trying to date one of the two bones and animal teeth which were found inserted on fissures where the chimney starts, with no success. However, because of the similarity with other dated portable and rock art, it can be firmly attributed to a time between the Middle Magdalenian and the first phase of the Upper Magdalenian (ca. 17.5-14.5 ka). For example, the way to represent the closed eye or the foreleg of bison, could be found in other directly dated representations in the Middle Magdalenian (e.g., Covaciella, 17.3-16.9 ka). Representations executed on clay are frequent in other groups mainly located in the Pyrenees (Tuc d'Audoubert, Montespan, Bedeilhac, Erberua, Oxocelhaya, Fontanet, Labouiche and Etxeberri), although they are also known in the Cantabrian Sea (La Garma and El Castillo) and Dordogne (e.g., Les Combarelles and La Calevie). In the cases in which the groups have been contextually dated (Tuc d'Audoubert, Etxeberri, Fontanet and La Garma), the dates are from the Middle Magdalenian.
Regarding to the rock art painted in red that appears in the final room, it has raised many doubts since its discovery in 2012, especially on its chronology. In the Cantabrian region, caves decorated in red paint are common and belong to a chronology prior to the Magdalenian (mainly Aurignacian and Gravettian, perhaps Solutrean). That is why at first the figures seemed to belong to that time frame. However, there are also known caves almost exclusively decorated in this color (red) that belong to the Magdalenian, such as Lumentxa. The discovery of a group of three animals (a horse, a bison, and an animal that is difficult to

determine, perhaps an ibex) in 2020 shed light on this question: The way of representing the bison, with a sinuous "S"-shaped horn and two legs in perspective, seemed more typical of late chronologies of the Palaeolithic (Magdalenian). We believe that the initial doubts must be understood by the painful conservation of the set of red paintings, which prevents a correct interpretation of the figures, in a could have also occurred in the cave of Morgota (Garate et al., 2015b).

S1.7. AITZBITARTE V

Location

ETRS89 / UTM ZONE 30N **X:** 589666 **Y:** 4790584 **Z:** 251

The cave of Aitzbitarte V is opened in the western slope of the hill of the same name (Errenteria, Gipuzkoa), above the valley of the river Landarbaso, a tributary of the Urumea. The cavern develops in bioclastic calcarenites, together with smaller areas of massive micritic limestones, limestones with silidifications, and schistose limestones, from the Upper Albian, 8.3 km from the current shoreline and 251 meters above sea level.

Brief topographic description

The cave of Aitzbitarte V has 95 meters of development, which forms a cave-system with the nearby Aitzbitarte IV, developed in at least two levels and some sub-levels with 54 meters of unevenness. It was originally described as a single meandriform conduit of about 25 m in development, about 3 m in width and about 2.20 in height (Manteca et al., 1997). In its deepest part, some obstructed crawlways were observed. The surveys carried out within the karstic system showed that these blocked passaged were very close to the end of what is known as the “Gallery of the Bears”, which was accessed through a vertical chimney of about 25 meters from Aitzbitarte IV. In the entrance hall of this cave, there were found some remains of lithic industry, pottery, remains of macrofauna, molluscs and a fragment of human skull (Altuna et al., 1995). Later, within the framework of the opening of the blocked crawlway carried out by the Felix Ugarte Elkartea speleological group in 2015, abundant prehistoric pottery fragments were found, some of them probably from the Bronze Age, as well as a sheet of large flint blade obtained by pressure flaking. Ceramic remains have also been found on the other side of the crawlway and even at the foot of the chimney that connects with Aitzbitarte IV.

It has been observed that this originally blocked crawlway that allowed the connection between the entrance and the deep sectors bifurcates into two ways, allowing access to two differentiated sectors that meet again farther. On the one hand, the left branch connects with the upper part of the vertical chimney that connects Aitzbitarte IV and V. On the other hand, the branch on the right connects directly with the “Gallery of the Bears”, allowing easier and more direct access to the decorated area of it.

This gallery was named as that because of the multitude of cave-bear nests that are preserved on the floor of the cave, as well as to the numerous claw marks which could be observed in its walls. The first section of the gallery after the well maintains minimum dimensions of 2 m wide and 3 m high, and a total development of about 60 meters.

In the final section, a small climb allows access to an interconnected sector through ledges and phreatic tubes. The first sector (Sector A) would be composed of a ledge that connects the “Gallery of the Bears” with the deepest areas using a hanged passage. The Sector B is a narrow hallway accessible by a phreatic tube under Sector A. A final climb allows to reach the Sector C, a narrow passage which connects with the final hall of the cave, Sector D.

The cave art

The rock art in this cave was initially located in 2015, limited to Sector B, which contained 4 bison engraved in Magdalenian style, and some lines that were difficult to interpret (Garate et al., 2016). In 2017, new evidence was found in Sectors A and D, with parallels in Gravettian art, which turned Aitzbitarte V into a diachronic or long-traditional complex. Finally, in 2020, more engravings were found in Sectors C and D, all of them assignable to the first graphic cycle of the cave, although one of the figures in the last sector (two sinuous horns in the shape of an "S") present technical parallels (the use of a similar tool) and stylistics (sinuous horns and in correct perspective) with the Magdalenian bison of Sector B (Garate et al., 2020c).
The rock art in the cave consists of 18 individualised graphic units (GU's), of which 11 represent bison and 1 zoomorphic figure hard to identify. There are also two signs (1 ogee shaped sign), 1 series of finger flutings and involuntary or very simple traces (3 isolated or non-figurative lines and a red stain). The paintings were probably made by iron oxide. The engravings are mostly fine and superficial, although there are cases that go deeper. Finger engraving could be seen in one of the GUs.
As we have previously indicated, some of the graphics in sectors A, C and D have parallels in terms of theme -mainly bison- and style -absence of perspective- in the movable and parietal art of Gravettian chronology (30-23 ka) in the area. of the French south/west (Isturitz, Gargas, Cussac, etc.), or style -absence of perspective- of a larger territory that covers the Mediterranean (Cosquer, El Parpalló, etc.) and greater chronological (also Solutrean) (Garate et al., 2020d). The whole of sector B, and perhaps a representation of sector D, presents a greater affinity with the Magdalenian style. Furthermore, the detail of the lines to represent the frontal line of the bison has only been found in specimens from the Middle Magdalenian (17.5-15) (Rivero, 2010).

S1.8. ALKERDI 1

Location

ETRS89 / UTM ZONE 30N **X:** 619828 **Y:** 4792224 **Z:** 155

The cave of Alkerdi 1 is opened in the western slope of a small hill (Urdazubi-Urdax, Nafarroa/Navarra), above a sinkhole where the Urtxume stream enters, in the valley of the Urdazuri or La Nivelle river. The cave develops in red limestones with rudists from the Albian/Turonian, 17.1 km from the current shoreline and 155 meters above sea level.

Brief topographic description

The Alkerdi 1 cave is part of a complex speleological network, which is characterized by the development of more than 5 km in 5 different cave-levels and 80 meters of elevation gain. The cave is situated on the 4th cave-level and has a known development of ca. 160 m and 5 m vertically.
The spacious entrance porch (11 x 5 meters) allows access to the vestibule. Actually, it is a rather uncomfortable space with low ceilings, and the excavations carried out there have only documented a sporadic level of occupation dating back to the Gravettian (Barandiarán Maestu et al., 2010).
In a sector located at the back of the vestibule that D. Garate and O. Rivero (2015a) called Sector C, I. Barandiarán Maestu (1974) pointed out the existence of two anomalous engravings due to their morphology, which have not been recognized again.
At the back of the hall, in its left area, a gallery begins, at first with a slope produced by the colluvium of sediment that rushes towards a central subsidence, called Sector C, which contains an engraving on its left wall. At the end of this gallery, in a bend there is a stalagmitic formation (a flowstone) in the shape of a dome (Sector A or "Stalagmitic Mogote") with a set of animal engravings.

If, instead of advancing through the gallery on the left, we continue towards the right of the vestibule, we will cross a rather irregular sector with meanders that start from the ceiling. Subsequently, a room with a low ceiling opens, and on one of its walls there is a gallery that reduces in size until it becomes a very narrow meandering duct, called the “Gallery of the Bison” or Sector D, which contains the largest set of engravings. This gallery opens again to the second room of the cave after a very narrow passage.

The cave art

The rock art of this cave is mainly made up of two main sectors, which not only seem spatially distant, but also belong to different ways to make the figures (and perhaps chronological moments): Sector A or the “Stalagmitic Mogote” and Sector D or the “Gallery of the Bison”.

Based on the inventory that was carried out based on the last study of the cave's rock art (Garate & Rivero, 2015b), the cave contains 31 individualised graphic units (GU’s), of which 14 represent bison, 4 zoomorphic figures hard to identify, 3 horses, 1 deer and 1 aurochs. There are also one signs (1 series of two dots), and involuntary or very simple traces (6 isolated or non-figurative lines and 1 stain in black pigment). The paintings were probably made by iron oxide and charcoal. The engravings are mostly fine and superficial, although there are cases that go deeper. Some figures were made with a combination of several techniques.

Regarding its chronology, the (re)discovery of the "Gallery of the Bison" and its study already pointed to the differences in style between sectors A and D. The bison in the first sector have a hump and lack of signage of the fur, something more typical of the central area of the Cantabrian Sea such as in Hornos de la Peña (Garate & Rivero, 2015a). On the contrary, the bison of Sector D mark their fur profusely, being a characteristic more typical of the Pyrenees, with examples in Trois Frères, Niaux or Marsoulas. In fact, this cave has another similarity with the bison of Alkerdi 1, and it is the way of representing the bison's horns in perspective, with the distant horn located behind the horn in the foreground, when it is usual to see just the contrary. This characteristic is not only exclusive to Marsoulas, but is also observed in the Dordogne area (Rouffignac or Font-de-Gaume) and the Cantabrian Region (Altamira). All these representations (especially in the case of Altamira, Font-de-Gaume and Marsoulas) have been dated to recent times of the Lower Magdalenian, or early Middle Magdalenian. This assessment has been confirmed by the contextual dating of a long bone, probably bovid, with cut marks located just below the figures of Sector D, in a place with complicated access and close spatial relationship, in 18.425-18.12 ka.

As for the second set (Sector A), the chronology that was traditionally assigned to it in the Lower Magdalenian (e.g., Barandiarán Maestu et al., 2010), was based on the presence of a deer with a "striated" head. Although this characteristic, traditionally attributed to the lower Magdalenian of the Cantabrian Region, does not seem exclusive to these chronologies (Rivero et al., 2019), with more recent known examples in Atxurra or Altxerri, nor regional (e.g., Marsoulas, Fritz et al., 2016), the way of representing the bison, as we have previously mentioned, is more typical of the Cantabrian Region. The contextual dating obtained in the Hornos de la Peña cave, with figures of that style (bison with rounded hump without representing the fur), also covers a chronological period similar to that of Sector D (18.646-18.036 ka) (Medina-Alcaide, 2020).

In summary, and without excluding the possibility that the art of Alkerdi 1 was also made in more recent phases of the Magdalenian, we believe that there is sufficient evidence to propose that it contains the oldest artistic group that we have included in our study.

S1.9. ETXEBERRIKO KARBIA

Location

ETRS89 / UTM ZONE 30N **X:** 669350 **Y:** 4776457 **Z:** 448

Etxeberriko Karbia opens in the Upper Aptian Urgonian limestones of the "Ascune" series (Vanara, 2000), on the eastern slope of Hardegainxardeka (or "Axkoargibela" mountain) (852 meters), located in the municipality of Gamere-Zihiga (Zuberoa), at an altitude of 448 meters above sea level and 66 kilometres from the current shoreline.

Brief topographic description

Etxeberriko karbia has the shape of a large rectilinear canyon of approximately 240 meters of longitudinal development, with a height that sometimes reaches 30 meters, but a width of less than 10 meters, with few exceptions. This gallery is filled in some points by collapses and detrital and lithochemical sedimentation, which forms large, steep slopes, and basins that fill with infiltration water at various points, forming temporary lakes. It presents a known topographic development of 541 meters and a cumulative difference in altitude of 63.5 meters, +12 and -51.5 meters with respect to the entrance level. On both sides of the gallery is possible to see terracing in the form of horizontal notches, as well as hanging horizontal floors.
Firstly, there would be the entrance hall of the cave (Sector A), whose floor is covered with large fallen blocks, and soon a steep ascent begins until reaching the "Gallery of the *Gour*-s" (Sector B). At the top of this gallery, just after a protection fence placed there, the conduit begins to descend towards the "Gallery of the Lakes" (Sector D). The first two lakes were full of water for at least a good part of the last century. The temporary water current that feeds them begins right at the point where the fence is located and coincides with a place where excavations were carried out that confirmed the existence of occupation layers from the Neolithic to the Roman era (Ebrard, 2013). Currently, the water course has been diverted so that it flows towards the "Gallery of the *Gour*-s" first, reaching the vestibule afterwards, where the stream disappears between the blocks. The third lake is fed by infiltration waters that fall from a large flowstone located there (so it is only possible to find it half empty in the summer), and these end up in a lower network accessible through vertical sinkholes of between 7 and 10 meters located shortly after. If we continue along a risky elevated passage over these vertical jumps, but surmountable using the opposition technique (exerting pressure on both walls) and secured with a rope, we will reach the foot of a stalagmitic flowstone. If we climb this obstacle (6 metres), we will reach a ledge from which a very narrow crawlway begins. This ends abruptly in a jump of two vertical meters, which leaves us in the "*Salle des Peintures*" (Sector E), the main sector of the cave, regarding to the rock art and archaeological remains. Descending a steep, almost vertical 7 metres ramp, we will reach the "Room of the Sinkhole" (Sector F), named as this because of the sinkhole of the "Angel", an impressive 16-meter abyss. Near this topographical accident are located the last four decorated sectors: the "Narrowness" (Sector G), the "Decorated Fissure" (Sector H), the "Cornice of the horse engraved in clay" (Sector I) and the "Sinkhole of the Angel" itself (Sector J).
At the bottom of this abyss, we will find a temporary lake called "Sea of the Niphargus". From some ledges located a little further forward, it is possible to reach a narrow window that takes us to a network of vertical shafts 20 meters deep that allow us to reach the last room of the cavern, located just below the "*Salle des Peintures*", but 70 meters below: the "Room of Discs", named after the unique geological formations.

The cave art

Based on the last inventory of Palaeolithic cave art carried out in the cave (Garate & Bourrillon, 2017), we have developed a database of graphic elements (we have added some new images identified in our project, apart from some re-interpretations).

The rock art in the cave consists of 77 individualised graphic units (GU's), of which 15 represent horses, together with 4 animals hard to identify, 3 bison, 1 ibex, several signs (1 rectangular shaped sign, 1 angle shaped sign, 1 possible claviform, 2 paired strokes and 4 points) and unvoluntary or very simple traces (38 stains and 8 isolated or non-figurative lines). They are placed in 6 different sectors: the "*Salle des Peintures*" (Sector E), the main decorated sector of the cave, the "Room of the Sinkhole" (Sector F), the "Narrowness" (Sector G), the "Decorated Fissure" (Sector H), the "Cornice of the horse engraved in clay" (Sector I) and the "Sinkhole of the Angel" (Sector J). The black paintings were created mostly with black pigment made from charcoal, in some cases probably conifer, the red painting made with iron oxides, sometimes mixed with aluminosilicates (clay), and the marron colour was made using the clay of the cave, sometimes mixed with burned bones (Laval et al., 2017). In the case of the engravings, shallow engraving was also used (in a case combined with a black painting). They are mostly fine and superficial, although there are cases that go deeper, when the support is soft. The stroke used to be single. Finger engraving was also used in soft surfaces made with clay.

Because of the similarity with other dated portable and rock art, it can be firmly attributed to a time between the Middle Magdalenian and the first phase of the Upper Magdalenian (ca. 17.5-14.5 ka). For example, the way to represent the closed eye or the foreleg of bison, could be found in other directly dated representations in the Middle Magdalenian (e.g., Covaciella, 17.3-16.9 ka). In the case of the great bison in the painting room (Etx.E.II.08), there is a representation very similar to it in the Tito Bustillo cave, which was dated to 15.275-16.454 ka (Fortea, 2007). Besides, representations executed on clay are frequent in other groups mainly located in the Pyrenees (Tuc d'Audoubert, Montespan, Bedeilhac, Erberua, Oxocelhaya, Fontanet, Labouiche and Etxeberri), although they are also known in the Cantabrian Sea (La Garma and El Castillo) and Dordogne (e.g., Les Combarelles and La Calevie). In the cases in which the groups have been contextually dated (Tuc d'Audoubert, Etxeberri, Fontanet and La Garma), the dates are from the Middle Magdalenian. Finally, the study of the archaeological context yielded a series of radiocarbon dating coinciding with the estimated chronology for the parietal art, based on the technical and stylistic characteristics that we have mentioned above (Garate & Bourrillon, 2012). An indeterminate burned bone fragment from level I of the survey returned a date of 14,893 to 13,967 cal BP (Beta-284730). Another indeterminable burnt bone fragment from level II from the same survey offered a slightly older date of 15,117 to 14,767 cal BP (Beta-284731) and the Littorina obtusata shell fragment mentioned above, a date 2,500 years older than 18,066 to 17,503 cal BP (Beta-284733). In summary, we can assume that the Etxeberri parietal complex is assigned to the Middle Magdalenian, without multiple phases being excludable within that chronoculture.

S2. DETAILED ESTIMATIONS OF PRESERVATION BIAS AND RECONSTRUCTED LOSS BY SITE

S2.1. SANTIMAMIÑE

The cave of Santimamiñe is characterised by the presence of numerous speleothems that partially obscure the original wall surfaces, as well as by erosional and paragenetic morphologies affecting different sectors of the cavity. Detrital sediment deposits and remnants of allochthonous sandstone terraces are also present along the gallery. Together, these processes have modified the original topography of the cave, creating alternations between constrictions and enlargements (in some cases up to twenty metres wide), as well as vertical drops, pronounced slopes, and multiple side passages. Most of these features were already present during the Magdalenian, and only limited later changes can be identified, such as the development of Holocene formations on cave floors (e.g., gours and flowstones) and local lithochemical reconstructions. Although it cannot be ruled out that some of the formations sealing the entrance to the former "Chamber of Paintings" developed during the Holocene, the general morphology of the passage would have been broadly similar to its present configuration (Intxaurbe et al., 2023a).

At present, access to the cave is facilitated by modern installations, including stairs, railings, artificial pathways, and flattened surfaces. In its original state, however, access would have required speleological equipment for vertical progression and safety (e.g., ropes, anchors, ladders). These modern alterations were therefore removed from the three-dimensional model in order to reconstruct a configuration as close as possible to the Palaeolithic cave.

Regarding conservation, Santimamiñe presents a relatively fragile state of preservation, resulting from both anthropogenic and natural taphonomic processes (Garate et al., 2025). Anthropogenic factors are primarily related to its long-term use as a tourist cave and include accidental damage during maintenance works (e.g., graffiti cleaning, paint spills from metal structures), as well as direct impacts caused by visitors (e.g., physical contact, additions to figures, or mud covering).

Natural processes have also played a significant role. Many figures were executed on a thin calcite layer covering the cave wall, dated in some areas to approximately 239 ka. This layer is currently undergoing progressive detachment due to the erosion and fragmentation of the underlying calcite crystals, a process further intensified by the circulation of CO_2-saturated water. Additionally, new calcite formations developing through capillary processes may exert pressure on the surface and contribute to this detachment (Hoyos, 1993).

Importantly, several of these processes—such as calcite detachment and the development of vermiculations—have been documented within the last 70 years, raising the possibility that they may have been accelerated or triggered by human activity (Figure S1).

Historical documentation and recent reconstructions (Intxaurbe et al., 2023a; 2023b) allow a partial estimation of the number of figures that may have been lost. In Santimamiñe, these losses mainly affect individual panels, which is particularly significant given the relatively low number of figures present in the cave.

In Sectors A and B, no substantial losses are identified. These areas are characterised by mostly isolated figures and non-figurative motifs, and their state of preservation is generally good, with no evidence of major taphonomic processes affecting the recorded figures.

In Sector C, however, the disappearance of several figures is documented. Thanks to historical photographs, reports, and early studies, it has been possible to reconstruct their original morphology (e.g., S.C.I.02 or S.C.II.06, which no longer exist but have been included in the dataset based on their documented forms). On the ceiling of this sector, a red pigment stain—already identified by C. González Sainz (motifs 3.2.9 and 3.2.10; Figure S2)—may correspond to a more complex composition. In the left-hand figure, faint black lines can be observed, which could hypothetically correspond to part of a limb oriented to the left, while the red pigment might represent the infilling of a polychrome animal. However, this interpretation remains highly uncertain and lies at the limit of what can be considered epistemologically reliable. In the absence of more detailed analysis, and in order to maintain methodological caution, this element has not been included in the present study.

In Sector D, however, significant preservation issues remain, particularly affecting panels D.I, D.II, D.III, D.VI, and D.VII. In some cases, such as panels D.I and D.II, it has been possible to propose a hypothetical reconstruction of the original graphic composition based on DStretch image enhancement and the available historical documentation. In other cases, however—especially where surface detachment has occurred—such reconstruction has proven impossible.

It can therefore be assumed with a high degree of confidence that a portion of the original figures has been irreversibly lost. Nevertheless, this sector constitutes the largest pictorial ensemble within the cave, and the thematic repertoire identified here corresponds to canonical elements of Franco-Cantabrian parietal art (González Sainz y Ruiz Idarraga, 2010). For this reason, we do not consider the assemblage to be significantly biased, at least at the level of thematic association (Figure S3 and S4).

In Sector E, a degree of loss can be assumed for panels E.0 and E.I. In the former, extensive surface detachment has affected most of the panel, which likely explains why the motif was not previously identified. In contrast, although the current state of preservation of panel S.E.II is relatively poor, the available historical documentation allows us to be confident that no significant information has been lost (Intxaurbe et al., 2023b).

Under a deliberately conservative (worst-case) estimation, it can be proposed that up to seven figures may have been lost out of the 56 analysed in the cave (Table S1). For such losses to significantly affect the overall statistical patterns, they would need to correspond to previously undocumented or rare thematic representations. However, this appears unlikely in the context of the assemblage. The least common animal representations identified in the cave—such as bear and deer—are well preserved within the same chamber, suggesting that any loss is more likely to have affected more frequently represented taxa, such as equids or bison.

Panel	Preservation estimated bias	Panel	Preservation estimated bias
S.A.I	No bias	S.D.IV	No bias
S.A.II	No bias	S.D.V	No bias
S.B.I	No bias	S.D.VI	1 figure?
S.B.II	No bias	S.D.VII	1 figure?
S.C.I	No bias	S.D.VIII	No bias
S.C.II	1 figure? (2.3.9)	S.E.0	1 figure?
S.C.III	No bias	S.E.I	1 figure?
S.D.I	1 figure?	S.E.II	No bias
S.D.II	No bias	S.E.III	No bias
S.D.III	1 figure?		

Table S1: Estimation of preservation-related bias in Santimamiñe.

Figure S1 – Top: Representation S.E.II.01 of Santimamiñe cave in 1958 (**Top**) (Arkeologi Museoa) and in 2021 (**Bottom**). If we relied on the current state, we would identify it as a horse protomos, when originally, we know that it was complete).

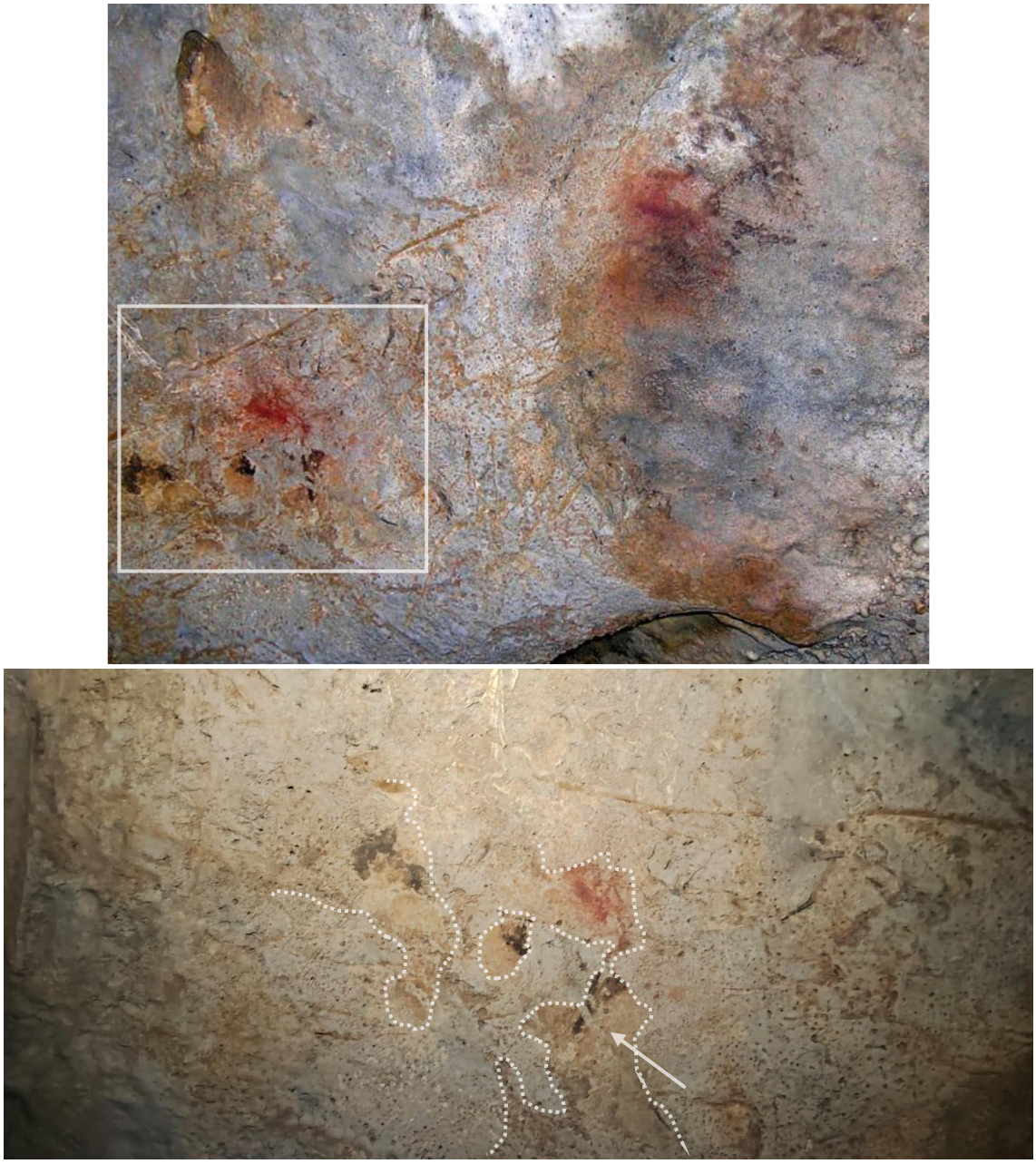


Figure S2 – Top: Representation 3.2.9 figure of Santimamiñe cave in 2008 (**Top**) (César González Sainz) and in 2024 (**Bottom**). We noted the presence of black paint, which could represent a leg (remains of a polychrome figure?). The most is damaged due to flaking (indicated with dashed lines).

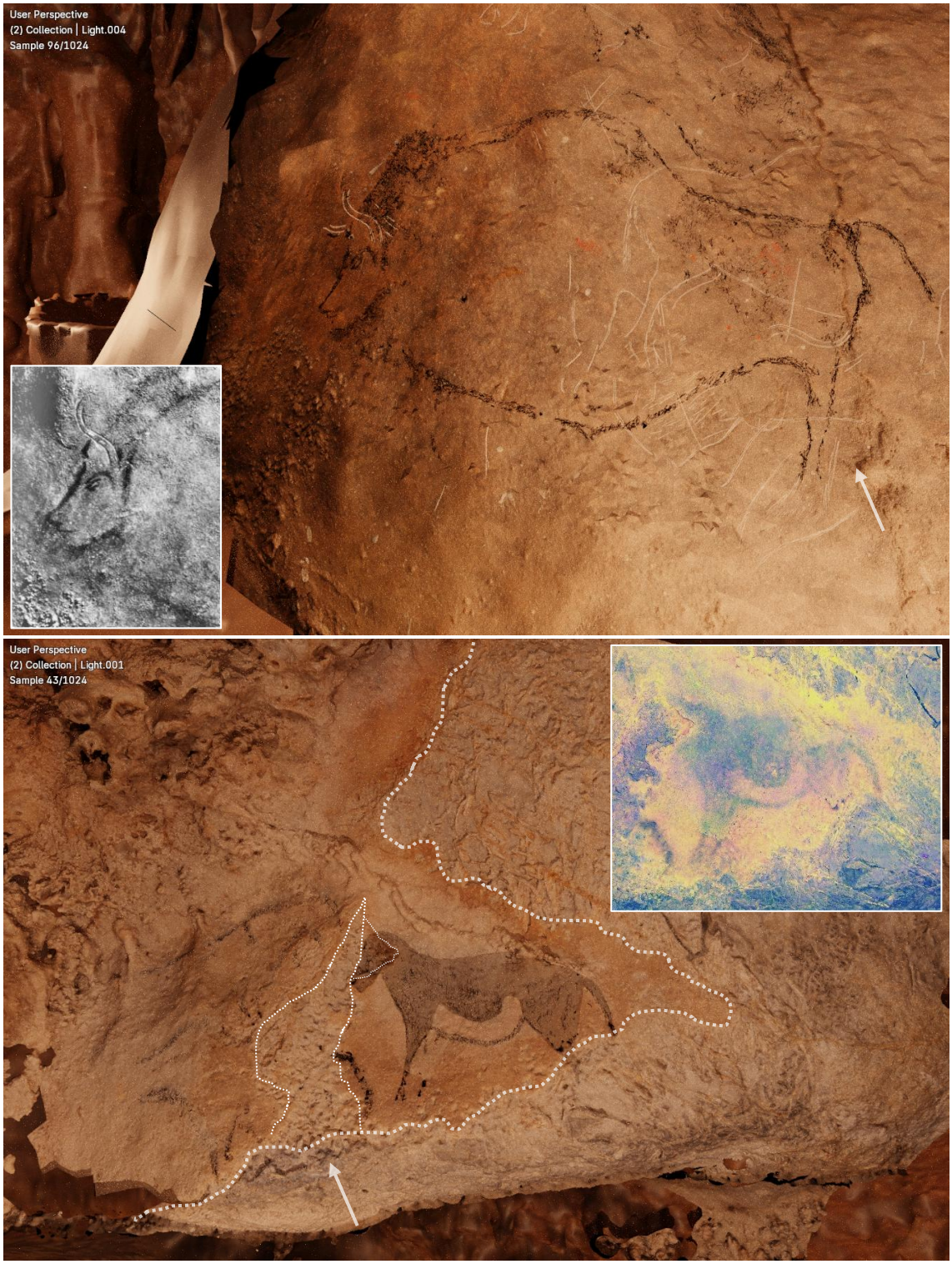


Figure S3 – Examples of reconstructions carried out in Sector D of Santimamiñe. Above: Panel S.D.II. At present, practically all the figures have disappeared; however, we have been able to reconstruct them thanks to historical records (like this photo from J. Vertut, 1955/60), including the thin engravings (indicated by arrows).
Below: Panel S.D.I, one of the most damaged due to flaking (indicated with dashed lines). Thanks to DStretch (*ybk, 7%*), it has been possible to partially reconstruct some figures.?).

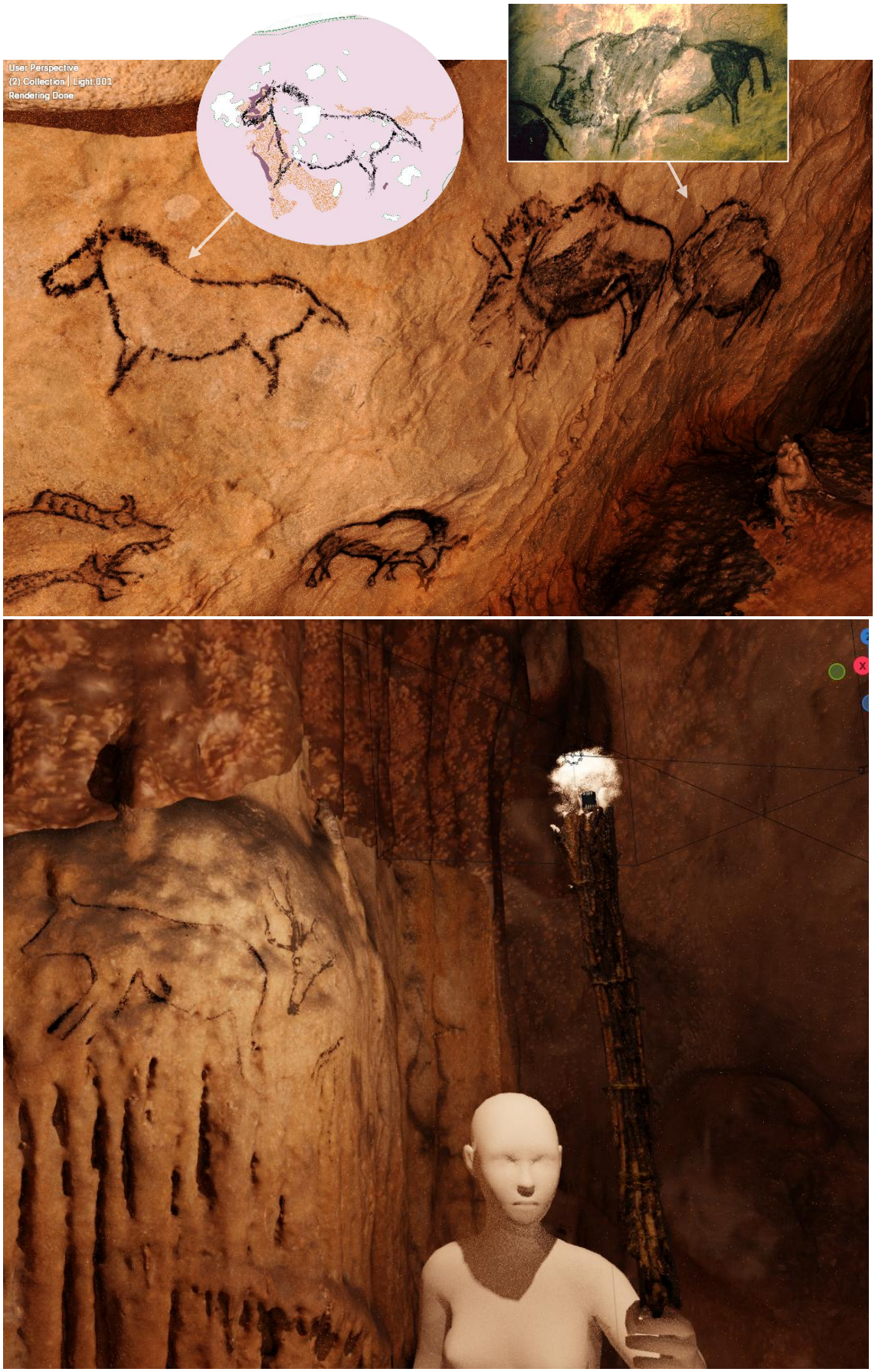


Figure S4 – More examples of reconstructions carried out in Sector D of Santimamiñe. **Above:** Panel S.D.III, where we have been able to reconstruct ancient motifs (S.D.III.06 and 09) thanks to geomorphological study and old photographs such as this one by P. Graziosi (1954). **Below:** Panel S.D.IV, damaged by dust deposits from construction work and modern additions, also reconstructed thanks to old photographs. The animals represented are usually unusual and isolated, so the probability of their reappearing in the chamber would be lower, which leads us to think that, if any motif had disappeared, it would have been a bison or an equid.?).

S2.2. LUMENTXA

Lumentxa is a cave-level in a senile phase, with generations of very old speleothems. New generations of important active speleothems are barely visible. Furthermore, corrosive forms abound in the cave, perhaps due to the existence of two entrances at each end of the passage, and thin thickness between the cave ceiling and the outside, that introduce numerous biofilms and fungi into the gallery. As we have pointed before, there are some blocks in the last part of the gallery. The antiquity of the collapses is proved by the phreatic erosive forms which were formed when a stream crossed again the cavern, after a first vadose phase (paragenesis). In summary, is difficult to assess exactly the form that would have the cave in the past (and particularly during the Magdalenian), but the main changes would be located near the two entrances (colluvial type sedimentation and human-occupation remains). In the other parts of the cave, we can assume a lower ground level in some parts of the gallery (especially due to active flowstones and thin materials introduced by laminar type water streams produced by infiltration, but they would not affect the passage of humans considerably. Nor can we rule out the existence of subsidence in some points of materials that move to lower levels, as would surely happen in the vestibule. The main changes produced by the archaeological excavations have been modified to obtain a model as close as possible to the Palaeolithic appearance of the cave.

As for the cave paintings, all of them were executed using red pigment and a fairly broad stroke, except for a series of incised lines in a horizontal notch at the end of the cave. These appear to have been a form of surface preparation similar to that observed at Altxerri (although no figures were ultimately created there). This, together with the cave's favorable climatic conditions (low CO_2 levels, low humidity, and a general lack of condensation except in areas close to the entrance), has created an environment conducive to the preservation of the parietal art (Garate et al., 2025).

For this reason, despite the cave having been heavily vandalized, the rock art is preserved "quite" well, at least in terms of natural degradation factors. In our work, we carried out a thorough survey of the cave, identifying new parietal motifs, though none were figurative, which are limited to a single panel within the cave (Table S2). Therefore, we believe we are dealing with the entirety of the preserved assemblage. We can state with a high degree of certainty that the cave has not lost any figurative parietal motifs from its original composition (except perhaps for some evidence that may have existed in the main vestibule, which has been more affected by condensation and biological alterations). That is, the disturbances would occur at the "sector" level, so they would not introduce any bias into the statistics (which operate at the panel level).

Panel	Preservation estimated bias
L.C.I	No bias
L.D.II	No bias
L.D.V	No bias

Table S2: Estimation of preservation-related bias in Lumentxa.

S2.3. ATXURRA

The geomorphological study carried out in the cave (Arriolabengoa et al., 2020) identified several phases of sedimentation that occurred in times after the Magdalenian frequentation of the cave. These would correspond to lithochemical formations identified at various points (mainly paving type, such as gours and superficial flowstones), as well as fills of karstic origin, produced by low-power infiltration waters. On the other hand, the access points to the endokarst contributed colluvial sediments, which would be added to those contributed by human occupations in the cave (and the Holocene fills that we mentioned above).

All this allows us to limit the subsequent modifications to the late-glacial human use of the cave, surely linked only to symbolic activities in the case of the deep areas, mainly to the outermost sectors of the two cave floors (Atxurra and Armiña). That is, the ground level would be lower than the current level, and this made it possible to cross the existing low-ceiling passages in numerous points in a simpler way than today. On the other hand, in the decorated area the greatest changes would occur in the lowest points of the gallery, so the sectors with rock art would have hardly noticed any changes since their use in the Magdalenian. All identified changes were edited to obtain a model that was as faithful as possible to the cave known to ancient human groups (Intxaurbe et al., 2022).

As for the cave's rock art, we propose a different interpretation. Thanks to the intensive survey of the cavity, we are confident that all sectors have been identified and controlled (with the exception of a sector that still requires climbing, located between the decorated sectors J and J' at ground level).

Regarding taphonomic issues, it is true that the cave presents processes that are highly damaging to the paintings, such as air currents that produce condensation phenomena (and subsequent biofilm proliferation) similar to those observed at Altxerri (Garate et al., 2025). In any case, this does not affect the engravings, and as with the Gipuzkoan cave, we believe we have a fairly comprehensive understanding of the entire cavity, except perhaps for the areas most affected by natural processes (speleothem formation and biocorrosion), which are limited to the outer sectors (Armiña and the entrance of Atxurra).

In the first of these areas (cave of Armiña), an archaeological context has been identified that could be compatible with the presence of rock art, which has not yet been located—perhaps because it lies beneath stalagmitic formations developed during the Holocene (Rios-Garaizar et al., 2020). In any case, this represents a sector-level issue and does not affect the unit of analysis (the panel).

We have, however, identified another issue: the overwhelming presence of figurative lines (more than 50% of the decorated parietal assemblage: Intxaurbe et al., 2020), which is highly unusual when compared to other decorated ensembles. This leads us to consider two possible causes and effects.

On the one hand, it may be that we are unable to perceive elements that rely on natural forms to complete figures, as we have observed in some sectors, such as sectors C, G, or J. On the other hand, it is possible that the cave was decorated during different periods, as suggested by radiometric dating, including the Late Magdalenian, but also Azilian and even Mesolithic phases (Garate et al., 2023).

The chronologies of the first two cultures have been identified in three sectors that present figurative representations (D, J, and J'), always associated with conifer wood, specifically juniper (*Juniperus sp*.), which only appears in these sectors (together with a fragment in the path to first area of sector C). As for the Mesolithic chronology, this has been identified in a greater number of sectors (A', C, D, and J), always associated with oak wood (*Quercus sp*.), a species that appears exclusively in more decorated areas (Medina-Alcaide, 2020).

This could suggest, as a hypothesis, the existence of a later figurative phase that altered decorative dynamics and makes identification more difficult. In any case, we do not believe that any differences this might produce would be significant at the level of the unit of analysis, except in a few specific cases (Table S3).

Panel	Preservation estimated bias	Panel	Preservation estimated bias
Atr.A.I	No bias	Atr.G.II	No bias
Atr.C.I	No bias	Atr.G.III	No bias
Atr.C.II	No bias	Atr.H.I	No bias
Atr.C.III	No bias	Atr.H.II	No bias
Atr.C.IV	No bias	Atr.F'.I	No bias
Atr.Dsuelo.I	No bias	Atr.F'.II	No bias
Atr.D.I	No bias	Atr.F'.III	No bias
Atr.D.II	No bias	Atr.F'.IV	No bias
Atr.D.III	No bias	Atr.G'.I	1 figure?
Atr.D.IV	No bias	Atr.G'suelo.I	1 figure?
Atr.D.V	No bias	Atr.Isuelo.I	1 figure?
Atr.D.VI	No bias	Atr.J.I	No bias
Atr.D'.II	No bias	Atr.J.II	1 figure?
Atr.F.I	No bias	Atr.J'suelo.I	No bias
Atr.G.I	No bias		

Table S3: Estimation of preservation-related bias in Atxurra.

S2.4. EKAIN

The cavern of Ekain presents several deposits of allochthonous sediments, some of fluvial origin (detrital, pebbles, etc.) and different generations of speleothems. There are numerous active processes in Ekain, among which we highlight the entry of infiltration waters, and several active parietal and surface formations (gours, flowstones, etc.) that hide some surfaces that existed during the Magdalenian.

Besides, the cave has not been modified to facilitate the visits, so it continues to appear like when it was discovered in 1969, excepting for the first crawlway, which was enlarged by digging a trench. However, this conditioning allowed us to know the stratigraphy of this passage, so we know that it was composed of a power of several archaeologically sterile levels interspersed with bones of Ursus Spelaeus, except in the first 10 centimetres, where there could be more recent contributions, perhaps the result of removals caused by animals that entered the cave. Having this in mind, the main changes produced by these archaeological excavations have been modified to obtain a model as close as possible to the Palaeolithic appearance of the cave).

Regarding the cave's rock art, petrographic, mineralogical, and geochemical analyses carried out on various elements of the cave indicate that processes driven by a relatively high level of humidity occur within Ekain Cave (Arriolabengoa et al., 2024). These processes are mainly linked to condensation phenomena which, combined with the presence of microbiologically derived CO_2, can lead to the alteration and deterioration of the rock art.

It is likely that, due to these conditions, part of the original graphic assemblage has been affected and currently shows a poor state of preservation. However, in the absence of more destructive processes such as flaking of the rock surface, water-related processes tend to produce primarily visual and superficial alterations to the artistic elements.

Importantly, a significant portion of the figures remains embedded within the rock support itself, particularly within its outer irregularities, such as crystallizations, fissures, and micro-reliefs. This has enabled the identification of figures that are now barely visible to the naked eye but can be detected using digital image enhancement techniques such as DStretch.

As a result, in recent years numerous previously undocumented pieces of evidence—mainly red paintings—have been identified, significantly expanding the corpus of figurative representations in the cave (Intxaurbe, 2024, p. 320).

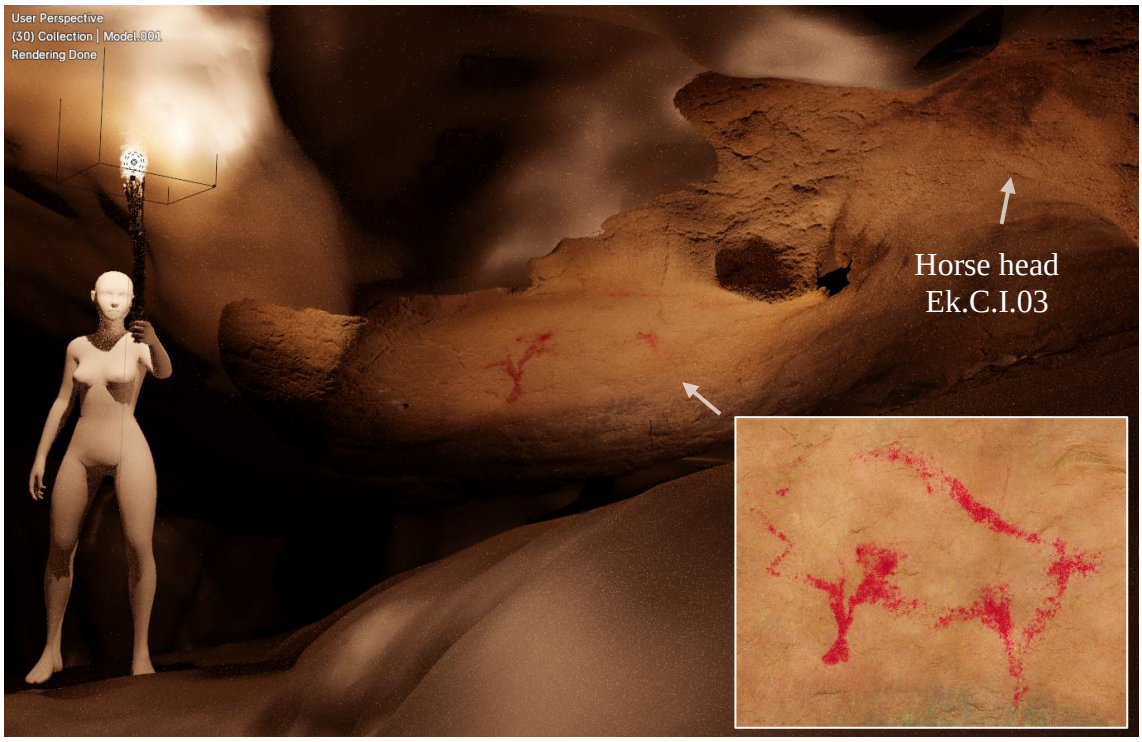


Figure S5 – New representation of a complete bison oriented to the left in panel Ek.C.I (tracing: S. Salazar), where until recently the only known figurative entity was the horse head Ek.C.I.03, located in the upper right part of the image. Thanks to the new discoveries made both in this sector and in Erdibide (Ochoa et al., 2019), we can now assert a more detailed understanding of the Ekain rock art complex.

Overall, based on these observations, we can assert that the loss of the original graphic assemblage has not been substantial enough to significantly affect the statistical results obtained (see Table S4). However, given the lack of thorough surveys conducted to date, we cannot claim a complete understanding of the cave's graphic assemblage, and the presence of isolated figures—mainly small and likely partial representations of bison or horses—within the cavity cannot be ruled out (perhaps in the main sector of the cave, E or Erdialde).

Panel	Preservation estimated bias	Panel	Preservation estimated bias
Ek.B.I	No bias	Ek.E.VI	No bias
Ek.C.I	No bias	Ek.E.VII	No bias
Ek.D.I	No bias	Ek.E.VIII	No bias
Ek.D.II	No bias	Ek.G.I	No bias
Ek.D.III	No bias	Ek.H.I	No bias
Ek.D.IV	No bias	Ek.J.I	No bias
Ek.D.V	No bias	Ek.K.I	No bias
Ek.E.II	No bias	Ek.K.II	No bias
Ek.E.III	No bias	Ek.L.I	No bias
Ek.E.IV	No bias	Ek.L.II	No bias
Ek.E.V	No bias	Ek.L.III	No bias

Table S4: Estimation of preservation-related bias in Ekain.

S2.5. ALTXERRI

Given the specific lithology in which the cave opens, it is extremely difficult to reconstruct with precision the cave's morphology during prehistoric times. Numerous collapses and subsidences have occurred as a result of structural weaknesses in the bedrock, and these events are, in most cases, impossible to date through relative stratigraphy. Nevertheless, in certain instances it is possible to determine whether such features were already present when the decorated galleries of Altxerri Cave were in use. Restricting our observations to Altxerri A—the sector frequented during the Magdalenian—we know, for example, that at least one engraved fragment from the first group of figures detached at a later time. This fragment was found directly above a flint tool (scraper or point), likely used in the production of some of the engravings, as noted by José Miguel de Barandiarán in his personal diary.

In addition, near the vestibule area, sedimentary processes involving fine materials (clays and silts) produced by infiltration water are interspersed with thin laminar deposits of calcium carbonate. These carbonate layers sealed at least two episodes of ephemeral prehistoric occupation, probably dating to the Palaeolithic. Conversely, the collapse located before the decorated sectors must already have existed during the Magdalenian, as its surface contained charcoal remains beneath the most superficial flowstone layer covering it.

The original entrance used by Magdalenian groups remains difficult to reconstruct. The colluvial deposits sealing it are archaeologically sterile, with the exception of a level located approximately 20 cm below the flowstone, where a trench excavated in 1962 under Barandiarán's direction revealed a few charcoal fragments visible in stratigraphy. Two hypotheses can be proposed: either the cave originally had a large entrance, or it was instead small and discreet. Considering the absence of evidence for habitation within Altxerri, as well as indications of other uses prior to the Magdalenian (such as funerary practices and medieval visits), and given the cave's strategic position overlooking the Oria River, the second hypothesis appears more plausible. On this basis, the cave model has been adjusted to approximate as closely as possible its presumed Palaeolithic configuration (Intxaurbe et al., 2023b).

Regarding the conservation of the rock art, the cave's lithology has strongly conditioned the taphonomic processes affecting it. Structural weaknesses have led to the collapse of decorated surfaces themselves. For instance, on the middle level, within the so-called "Group I" engravings, a fragment of wall bearing both engravings and paintings was found on the ground, directly above a level containing a flint artifact. Although the exact timing of this collapse remains unknown, it clearly predates the discovery of the cave art in 1962. Attempts have been made to reconstruct the original form of this support; however, these rely on historical documentation, as none of the original configuration remains today.

Furthermore, collapses, sediment infilling, and the formation of flowstones sealing colluvial deposits contributed to the closure of the prehistoric entrances. This resulted in markedly different microclimatic conditions within the cave. The upper level, isolated from the exterior since at least around 25,000 years ago, exhibits highly stable environmental conditions throughout the year. In contrast, the middle and lower levels—situated between the hydrostatic circulation zone and the current artificial entrance—function as a "wind tunnel," experiencing significant seasonal fluctuations in temperature and humidity (Garate et al., 2025).

Finally, a major source of damage is of recent anthropogenic origin. Although only a short time elapsed between the artificial opening of the cave by quarrying activity in 1956 and the discovery of its rock art in 1962, this interval was sufficient for the accumulation of graffiti, soot deposits, and surface scratches that affected several paintings and engravings.

At the intermediate level, the presence of biofilms has contributed to the micritization of the rock. These microbial formations, common in cave environments, are capable of dissolving calcium carbonate and transforming it into fine clay. Their development appears closely linked to condensation processes, which are intensified by frequent climatic fluctuations at this level. Additionally, extensive areas are affected by water dripping due to the free circulation of water through the rock strata and the formation of speleothems. Some of these zones are currently being monitored and show measurable colorimetric variations throughout the annual cycle (Garate et al., 2025).

In any case, and similarly to what has been observed at Atxurra, paintings appear to have been the most affected. Even so, traces of the most altered paintings can still be identified within the roughness and fissures of the supports, making their reconstruction feasible. With the exception of a few isolated cases—which are not expected to significantly affect the statistical results—the bulk of the preserved assemblage is considered to reliably reflect the original corpus that once existed (Tabla S5).

Panel	Preservation estimated bias	Panel	Preservation estimated bias
Al.C.II	No bias	Al.D.IV	No bias
Al.C.III	No bias	Al.E.I	No bias
Al.C.IV	No bias	Al.E.II	1 figure?
Al.D.II	No bias	Al.F.II	No bias
Al.D.III	No bias	A.F.III	No bias

Table S5: Estimation of preservation-related bias in Altxerri.

S2.6. AITZBITARTE IV

Aitzbitarte IV Cave has undergone numerous alterations throughout its history, which have profoundly modified the morphology it may have had during the Upper Palaeolithic. These transformations are partly the result of natural processes, but above all they are of anthropogenic origin, including military and industrial use of the cave, vandalism, archaeological looting, and cleaning activities carried out without archaeological supervision.

The current ground level along most of the main gallery dates to the early 20th century. During this period, a large portion of the original sediment was removed and used, together with clasts and rock fragments extracted from the cave using explosives, to fill lateral fissures that intersected the gallery orthogonally and posed a hazard for circulation. These interventions also aimed to enlarge the available space for industrial purposes. Subsequently, the floor was covered with organic detritus to facilitate mushroom cultivation. The walls and cultivated areas were disinfected with lime, leaving a visible whitish coating along the gallery. Today, the sediment has been heavily compacted due to the intense visitation the cave experienced until the discovery of the clay-modeled engravings in 2017, after which access was restricted.

At a height varying between approximately 1.5 and 2 meters above the current floor, a lithochemical crust can be observed, containing suspended sediment remains, including bones of Ursus sp., which mark the former floor level of the cave. On the ceilings immediately above this level, black marks and charcoal deposits have been identified and dated to between the 11th and 13th centuries AD, indicating that medieval visitors circulated along this earlier surface (Garate et al., 2012). There is little doubt that the Upper Palaeolithic floor corresponded to this level, as evidenced by the presence of bear remains. This interpretation is supported by radiometric dating obtained in the geomorphological study conducted by M. Arriolabengoa and I. Intxaurbe. It is also important to note that the original pathway through the main gallery was repeatedly interrupted by numerous sinkholes, and that ceiling heights were lower in many areas, making movement through the cave considerably more difficult in its palaeotopographic configuration.

In addition, biocorrosion processes during the Holocene—likely associated with the abundant chiropteran fauna inhabiting the cave—cannot be ruled out. These processes, combined with intensive cleaning using high-pressure water (Kärcher) during the late 20th century, may have led to the destruction of significant archaeological evidence, including parietal art. Indeed, the current appearance of the main decorated sectors resembles that of terminal areas within a more extensive decorated cave (O. Rivero, pers. comm.). Taking these factors into account, and incorporating data from a geophysical survey conducted by V. Bayarri and J. Herrera (GIM Geomatics) to estimate the depth of the original sinkholes, the cave model has been adjusted to approximate its likely appearance during the Magdalenian, when it was visited and decorated.

In any case, as previously noted for the more external sectors of Atxurra, the potential loss of parietal art in more accessible areas—highly likely in the case of this cave—would affect a global understanding of the site but does not compromise our unit of analysis (i.e., the panels). None of the panels examined appear to be incomplete, with the possible exception of panel AitIV.C.I; in this case, any apparent incompleteness is likely due to natural processes, specifically calcite deposition obscuring underlying figures (Garate et al., 2012).

Panel	Preservation estimated bias	Panel	Preservation estimated bias
AitIV.B.AI	No bias	AitIV.B.DII	No bias
AitIV.B.BI	No bias	AitIV.B.DIII	No bias
AitIV.B.BII	No bias	AitIV.C.I	1 figure?
AitIV.B.CI	No bias	AitIV.D.VI	No bias
AitIV.B.CII	No bias	AitIV.D.VII	No bias
AitIV.B.DI	No bias	AitIV.D.IX	No bias

Table S6: Estimation of preservation-related bias in Aitzbitarte IV.

S2.7. AITZBITARTE V

The cave presents two clearly differentiated sectors in terms of the modifications that have occurred since its use in Prehistory. On the one hand, the entrance areas have been significantly affected by post-Palaeolithic activity, which introduced additional sediment into the cavity. In this respect, the crawlway unclogged in 2015 by members of the Félix Ugarte Elkartea—originally sealed by Holocene deposits, probably dating to the Bronze Age—includes an initial bifurcation. Its right branch, currently obstructed by colluvial materials displaced downslope, would have provided a more direct and considerably easier access to the deeper sectors of the cave. However, only the left branch was reopened, meaning that access today requires crossing a difficult passage suspended above a 25-meter-deep shaft that connects to the lower level in order to reach the so-called “Bear’s Gallery.”

On the other hand, the abundance of bear traps and claw marks preserved on the walls of the “Bear’s Gallery” indicates that these deeper sectors have received little to no sedimentary input for approximately 25,000 years. Despite this long-term stability, it is important to highlight the significant alterations caused by recent vandalism—including graffiti, the construction of large hearths, and the accumulation of waste—which are particularly striking given the difficulty of access to this area via a 25-meter vertical chimney. Fortunately, these disturbances have not substantially modified the morphology of the gallery.

Immediately before reaching the final sector of the cave—where panels decorated with Gravettian and Middle Magdalenian rock art are located—a lateral branch opens on the left-hand side of the gallery. This branch leads to a very narrow terminal point filled with alternating detrital deposits and speleothem formations. This infilling lies at the same elevation as the final decorated chamber of the sector containing clay-modelled animals in Aitzbitarte IV, with a separation of approximately 7 meters between both areas. Although this deposit has not been directly dated, its extremely reduced dimensions—even assuming the

removal of the most recent speleothem phases—would have made human passage between the two sectors impossible. This supports the interpretation that Magdalenian groups accessed the decorated areas through the main gallery of Aitzbitarte IV, as is still the case today.

Taking all these factors into account, the 3D model of the cave has been adjusted to approximate as closely as possible the configuration known to human groups during the Magdalenian. Finally, with regard to the rock art, there is strong evidence to suggest that the preserved assemblage has undergone minimal alteration from its original state and, in any case, that any potential losses have not affected the validity of the statistical analyses.

Panel	Preservation estimated bias
AitV.B.I	No bias
AitV.B.II	No bias
AitV.D.III	No bias

Table S7: Estimation of preservation-related bias in Aitzbitarte V.

S2.8. ALKERDI 1

Throughout the galleries of Alkerdi 1, a variety of geomorphological and sedimentary features can be observed, including flat ceilings, ceiling channels (sometimes forming meandriform passages), suspended sediments, and stalagmitic formations such as flowstones—both floor (pavementary) and wall (parietal), some of which remain active. The allostratigraphic units formed after the passage of the Magdalenian groups who decorated the cave correspond to a second unit, composed mainly of several flowstones, some of them still active today (Aranzadi Zientzia Elkartea, 2016).

The vestibule constitutes a relatively uncomfortable space with a low ceiling. Archaeological excavations in this area have only documented occupation levels dated to the Aurignacian and Gravettian, indicating that by the Magdalenian the space was already significantly filled with sediment.

The left-hand branch leading to the so-called “Stalagmitic Mogote” (Sector A) presents a floor composed of detrital and stalagmitic deposits belonging to this second generation. However, these formations are likely to predate the Magdalenian, as suggested by the presence of a flowstone at the end of the gallery that was used as a support for Palaeolithic rock art.

In the central sector of the cave, the presence of currently active speleothems suggests that these formations were either smaller or absent during the Magdalenian, which would have facilitated movement through this area compared to present-day conditions. A similar situation likely applied to the adjacent chamber and the initial section of Sector D, known as the “Gallery of the Bison.” In contrast, the terminal part of this gallery consists of a detrital substrate with clasts attributable to the second allostratigraphic unit. Nevertheless, the presence of archaeological materials linked to Palaeolithic phases—such as charcoal, ochre, and bone remains, some of which have been dated to periods consistent with the execution of the engravings and paintings—indicates that the cave’s morphology has undergone only limited modification since that time. On this basis, the 3D model of the cave has been adjusted to approximate as closely as possible its configuration during the Magdalenian.

Regarding the rock art, I. Barandiarán (1974) reported the presence of several engravings of notable stylistic and thematic originality—including a cervid with a broad, rounded head and a depiction of a wolf’s head—which have not been relocated in subsequent surveys (Garate & Rivero, 2026). However, this sector is

currently covered by a micritized lithochemical crust, likely resulting from bioalteration processes, and it is therefore possible that these figures remain preserved beneath this layer.

In any case, as observed in other previously discussed examples, any potential loss or concealment of parietal art would affect interpretation at the sector level but does not compromise the integrity of the analytical units employed in this study (i.e., the panels). Accordingly, the preserved assemblage is considered to reliably reflect the original corpus.

Panel	Preservation estimated bias
Alk.A.I	No bias
Alk.B.I	No bias
Alk.D.I	No bias
Alk.D.II	No bias

Table S8: Estimation of preservation-related bias in Alkerdi 1.

S2.9. ETXEBERRIKO KARBIA

A geomorphological study was conducted to identify the main sedimentation and erosion processes affecting the cave and to establish a relative chronology based on stratigraphic relationships.

One of the most distinctive features of the cave is the presence of extensive areas affected by biocorrosion. Although recent deposits of bat guano are observed, the biocorrosion processes themselves are considered to be significantly older, predating the presence of Palaeolithic groups. This interpretation is supported by stratigraphic evidence, as the most affected formations correspond to early generations of speleothems. Furthermore, several decorated surfaces—such as sign E.I.01—were executed on already corroded substrates, confirming that these alterations preceded Magdalenian activity.

Subsidence and collapse phenomena are primarily concentrated in the entrance sectors, where geomorphological instability has been more pronounced. In contrast, in the deeper areas—despite the presence of collapse evidence, such as in the “Hall of the Sinkhole”—these features are often sealed by later speleothem formations, allowing their placement within a relative chronological framework. Due to the difficulty of reconstructing the original configuration of the entrance area during the Magdalenian, spatial analyses have been restricted to sectors located beyond the present-day vestibule.

Among the post-Magdalenian modifications, a prominent feature is the large stalagmitic flowstone covering the slope descending from the “Gallery of the Gour-s.” Sedimentological data obtained from a survey conducted near the intermittent resurgence at the top of this gallery indicate the presence of at least one meter of detrital deposits attributable to the Holocene. These deposits alternate with phases of lithochemical reconstruction forming gour-like structures, associated with intermittent human activity, likely of a funerary nature, dated between the Chalcolithic and the Roman period (Ebrard, 2013).

In the sector of the three intermittent lakes, reconstructing the Palaeolithic morphology is particularly challenging. Recurrent flooding events have deposited fine sediments (silts and clays), while subsequent flowstone formation has sealed these deposits with thin carbonate layers. However, available archaeological evidence—such as possible combustion remains between Lakes II and III and the decorated panel D.I.01–03 near the third lake—suggests that these areas have not undergone substantial morphological changes affecting accessibility since the Magdalenian.

A key geomorphological feature concerns the stalagmitic formation that once obstructed the crawlway leading to the "Salle des Peintures." Stratigraphically, this formation likely belonged to an earlier speleothem generation predating the Magdalenian. Historical accounts indicate that when the terminal sector of the cave was rediscovered in 1934, explorers enlarged part of this narrow passage using hammer blows (J. Labeyrie, pers. comm.), and the scar of the broken stalagmitic column remains visible today. It is therefore plausible that Magdalenian groups initially encountered this passage partially obstructed but identifiable as a continuation of the cave, and deliberately opened it. Use-wear analyses of flint tools recovered from the internal archaeological context support this hypothesis, indicating their use in working or perforating speleothems (Rios-Garaizar et al., 2017).

During the Holocene, renewed speleothem growth and reactivation processes generated new calcite deposits throughout the cave, in some cases forming over previously broken structures. It is possible that water circulation reused the fracture surface of the earlier broken formation, leading to the development of a new stalagmitic column in the same location—likely the one subsequently removed by cavers in the 20th century.

Taking all these factors into account, the 3D model of the cave has been adjusted to approximate as closely as possible its configuration during the Magdalenian.

Finally, significant alterations of recent anthropogenic origin must be emphasized. Following the discovery of the cave art at Etxeberriko Karbia in May 1950, the site experienced increasing human impact, despite its known archaeological importance and restricted access. Numerous inscriptions and graffiti are present, particularly in the "Salle des Peintures" (Sector E) and the "Hall of the Sinkhole" (Sector F), with additional evidence in the "Decorated Fissure" (Sector H). More critically, repeated physical contact has caused extensive damage to decorated surfaces, especially in sectors H and J ("Puits de l'Ange"), where nearly all recorded graphic units exhibit some degree of alteration. In Sector H, the figures are located within a narrow meander approximately 50 cm wide, situated above a 16-meter shaft, making contact with harnesses—necessary for safe movement—virtually unavoidable. Similarly, in Sector J, the decorated surfaces lie along the only access route to Sector I, further increasing the likelihood of friction-related damage. In any case, thanks to the existing information from the period following the discovery and its initial studies, as well as later reports (e.g., Brunet & Vidal, 1978), we are able to reconstruct its form.

Despite these impacts, the available evidence allows us to conclude that the loss of information related to conservation remains quantifiable and does not significantly affect the reliability or statistical validity of the analyses conducted.

Panel	Preservation estimated bias	Panel	Preservation estimated bias
Etx.E.I	No bias	Etx.H.I	No bias
Etx.E.II	1 figure?	Etx.H.II	No bias
Etx.E.III	No bias	Etx.I.I	1 figure?
Etx.F.I	No bias	Etx.J.II	No bias
Etx.G.II	No bias		

Table S6: Estimation of preservation-related bias in Aitzbitarte IV.

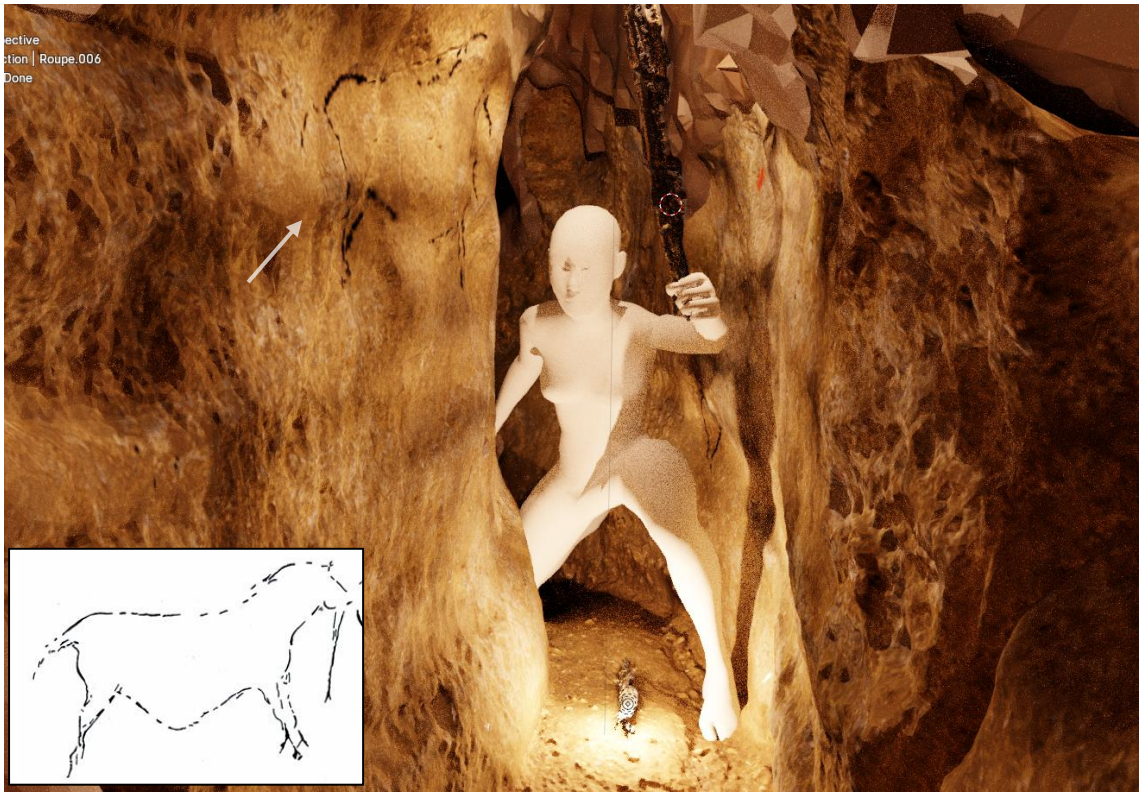


Figure S6 – Reconstruction of Sector H of Etxeberriko Karbia ("Decorated Fissure"). At present, nearly all the figures in this sector are damaged, and some have even disappeared. However, the examination of early photographs and historical tracings—such as those produced by G. Laplace (1950)—has made it possible to reconstruct their original state, thereby allowing the analyses to be carried out reliably.

S3. ADDITIONAL STATISTICAL AND NETWORK ANALYSES

S3.1. Co-occurrence and laterality analysis without "Unknown" figures

The first additional analysis consisted of repeating the statistical and network procedures after removing the "*Unknown*" category, in order to assess whether this group—given its subjective nature—might introduce noise or bias into the results.

The modified code is available in the following repository:

https://github.com/inakiintxaurbe/Rock-Art-Theme-Co-occurrence-Network/blob/main/Supplementary_codes/Script_without_unknown.R

he key modification is summarised in the following code snippet:

```
dat2 <- dat %>%
  transmute(
    GU    = as.character(GU),
    Theme = as.character(Theme)
  ) %>%
filter(Theme != "Unknown")
```

In this case, the `filter()` function removes all entries classified as "*Unknown*". A similar operation is applied in the dataset used for the analysis of figure orientation and inclination:

```
df_fig <- dat %>%
 transmute(
  GU    = as.character(GU),
  Panel  = sub("^([^\\.]+\\.[^\\.]+\\.[^\\.]+).*", "\\1", as.character(GU)),
  Theme  = as.character(Theme),
  Format = as.character(Format),
  Orient = as.character(Orient),
  Incl   = as.character(Incl)
 ) %>%
 filter(
  Format != "NF_F",
  Orient != "NF_O",
  Incl  != "NF_I",
  Theme  != "Unknown"
)
```

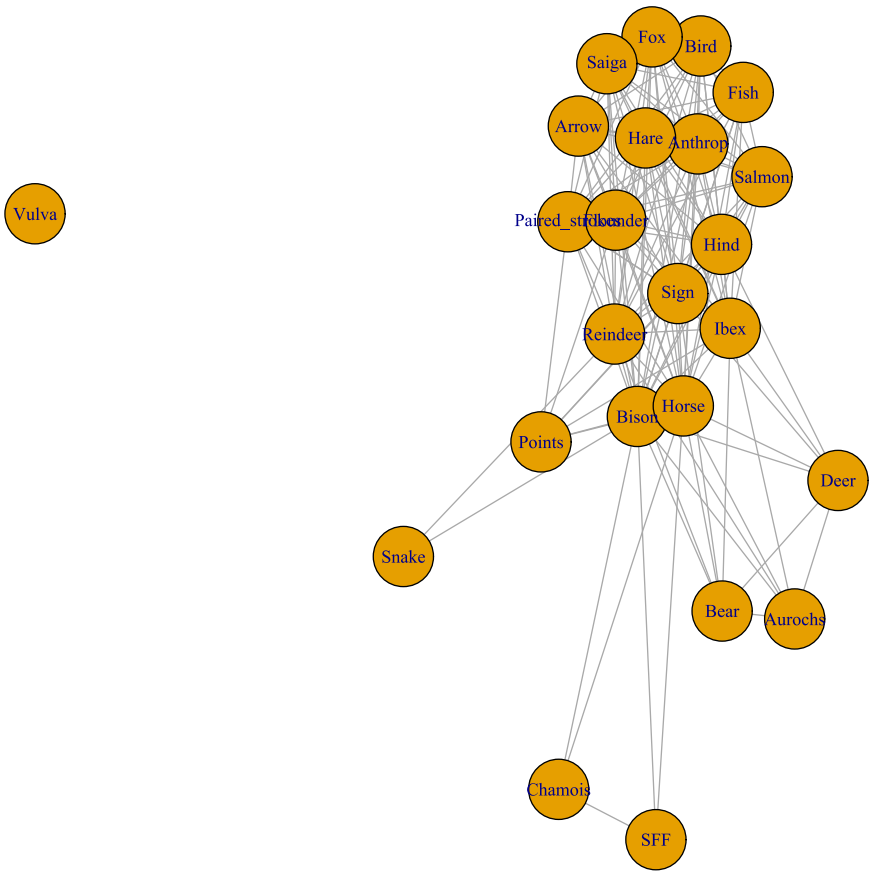
This second filtering step ensures that indeterminate figures are excluded not only from co-occurrence analyses but also from the study of laterality and inclination, so that only well-defined thematic categories are considered.

As a result of this procedure, the corpus is reduced from 500 to 445 figures, representing approximately 89% of the original dataset.

Since all scripts and outputs are fully accessible through the GitHub repository, we do not reproduce the Gephi network files here. Instead, we focus on assessing whether the exclusion of the "Unknown" category

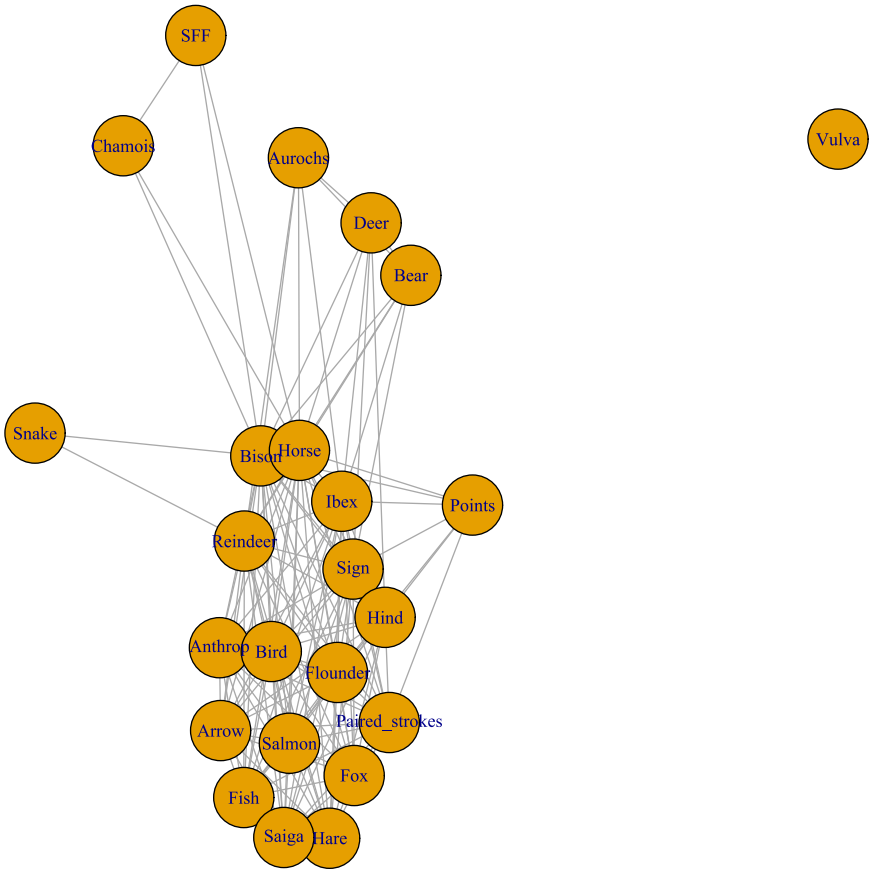
produces any significant structural changes. The figures presented in this section correspond to plots generated directly from the R environment using the following function:

```
plot(g)
# unfiltered co-occurrence network (jaccard-normalised)
```



or extract the corresponding frequency-weighted network, the following code was executed. The first line generates the network object, while the second produces its graphical representation:

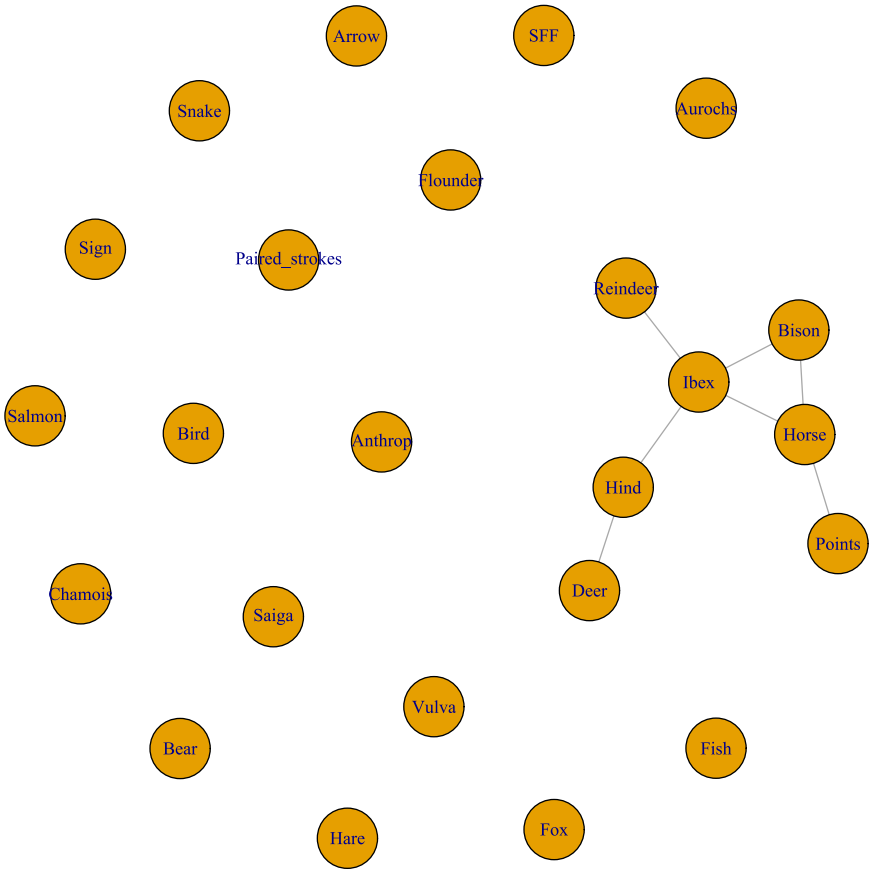
```
g2 <- graph_from_data_frame(edges_tt_weighted, directed = FALSE,
vertices = nodes)
plot(g2)
```



As observed, no substantial changes are detected in the overall network configuration following this modification. We next examine whether applying filtering thresholds—minimum co-occurrence frequency (min_weight = 3) and Jaccard similarity (min_jaccard = 0.12)—produces any notable structural differences.

To visualise the filtered network, the following code was used:

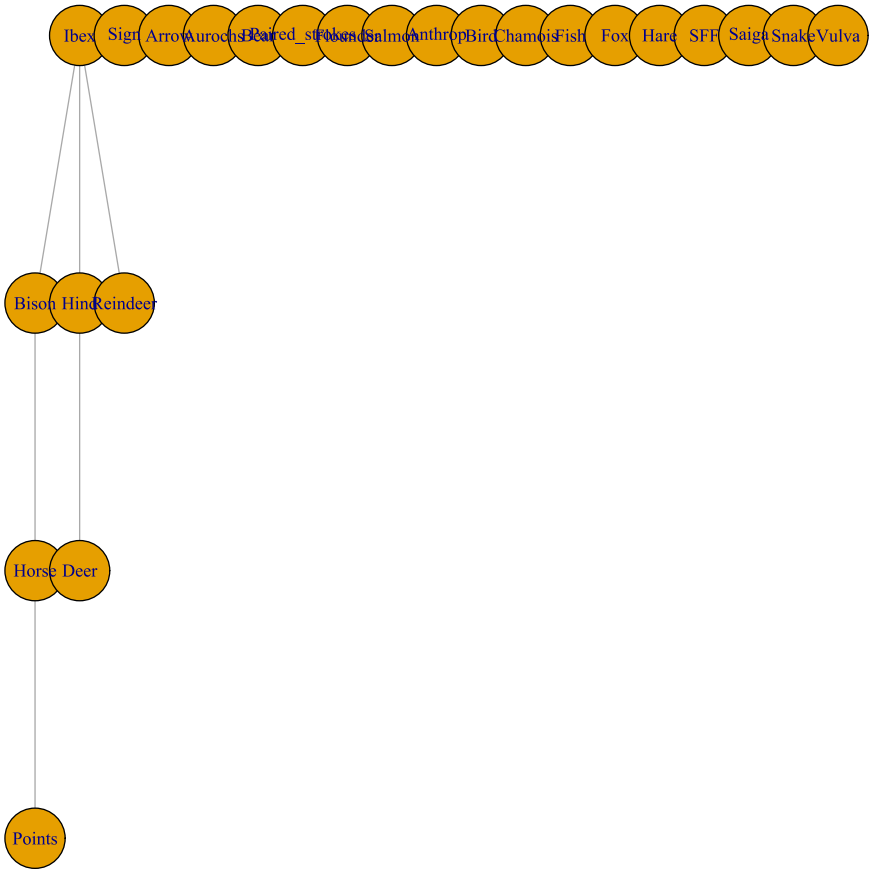
```
plot(g_filt)
```



In this network, no substantial changes are observed. The central structure remains organised around bison, ibex, and horse (with the expected exclusion of the “Unknown” category), together with a set of secondary elements, including points, signs, hind, deer, and reindeer.

To visualise the Minimum Spanning Tree (MST), the following line of code was executed:

```
plot(mst_g)
```



The MST, however, does show some changes. Ibex replaces bison at the top of the hierarchical structure, while reindeer and hind move up in relative position. In this configuration, bison acts as an intermediary node linking to horse representations.

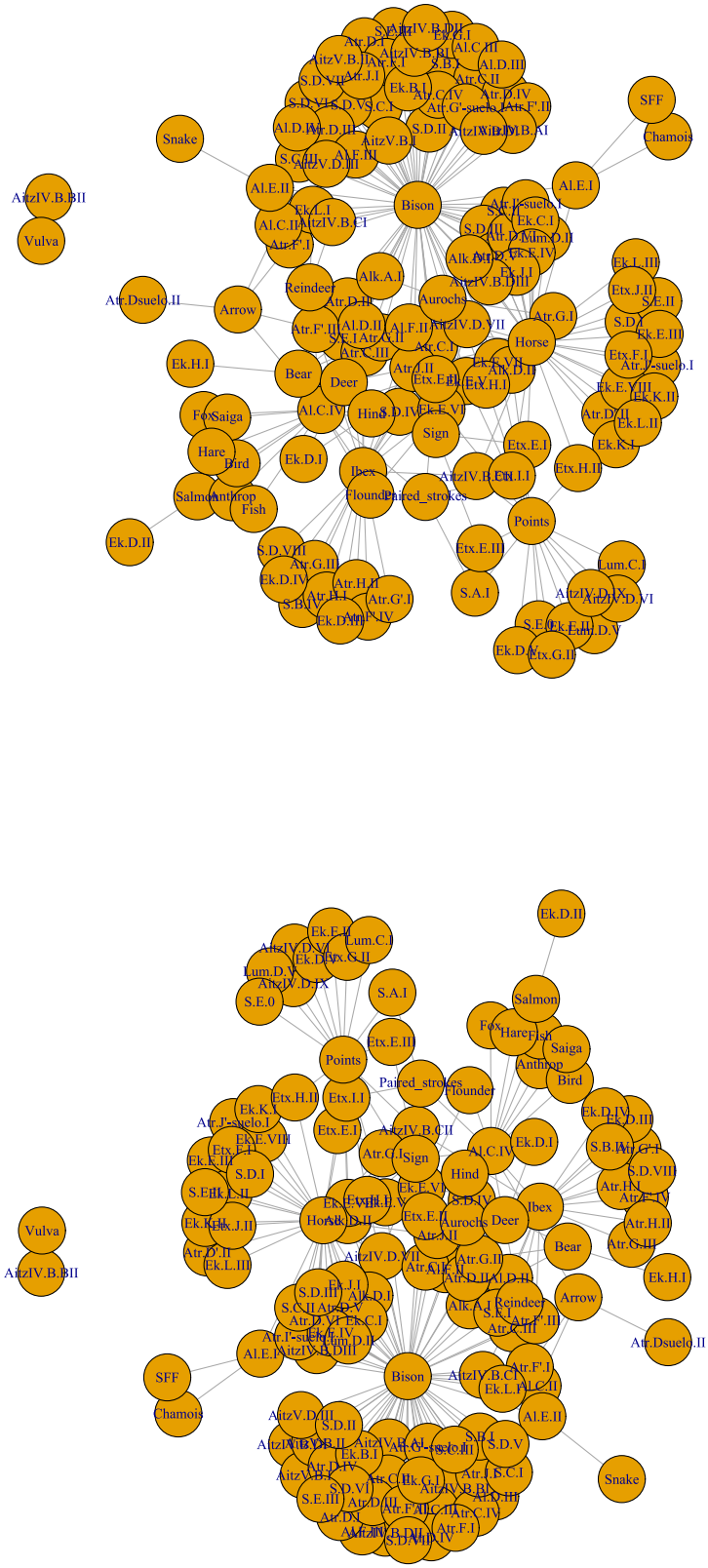
This result is likely influenced by the specific weight of the Atxurra assemblage, which is characterised by an unusually high number of ibex representations (Garate et al., 2020), including sectors almost exclusively devoted to this taxon (Intxaurbe et al., 2020). Comparable configurations—at least in large Late Glacial assemblages—are otherwise only documented in the western Cantabrian region (Asturias), particularly in the caves of El Covarón and El Bosque de Táranu (Ruiz-Redondo & Garate, 2014).

We then proceed to the bipartite analyses, starting with the binary bipartite network (presence/absence):

```
plot(g_bip_1)
```

To generate the count-weighted bipartite network (motif multiplicity), the following command was used:

```
plot(g_bip_2)
```


AitzIV.B.BII
Vulva
Snake
SFF
Chamois
Al.E.I
Al.E.II
Bison
Al.C.II
Atr.F'.I
Reindeer
Alk.A.I
Atr.Dsuelo.II
Arrow
Aurochs
Atr.G.I
Horse
Ek.H.I
Bear
Deer
Fox
Saiga
Hind
Sign
Hare
Bird
Ek.D.I
Ibex
Salmon
Anthrop
Fish
Flounder
Paired_strokes
Points
Ek.D.II
Etx.E.III
S.A.I
Lum.C.I
Etx.G.II

Regarding the laterality analyses, the results are as follows:

Theme	Left	Right	n_total	prop_right	p_binom	direction	p_adj_BH	sig_Binom	sig_BH
Bison	119	82	201	0.4079601990049751	0.0109264285939	Left	0.0731570859981371	*	
Horse	32	58	90	0.6444444444444445	0.0080459281332	Right	0.0731570859981371	*	
Ibex	35	16	51	0.3137254901960784	0.0109735628997	Left	0.0731570859981371	*	
Aurochs	4	0	4	0	0.125	Left	0.625		
Reindeer	7	3	10	0.3	0.3437500000000	Left	1		
Hind	4	5	9	0.5555555555555556	1	Right	1		
Bear	2	4	6	0.6666666666666666	0.6874999999999	Right	1		
Deer	3	2	5	0.4	1	Left	1		
Chamois	2	1	3	0.3333333333333333	1	Left	1		
Flounder	2	1	3	0.3333333333333333	1	Left	1		
Anthrop	1	1	2	0.5	1	Equal	1		
SFF	0	2	2	1	0.5	Right	1		
Saiga	2	0	2	0	0.5	Left	1		
Salmon	1	1	2	0.5	1	Equal	1		
Vulva	2	0	2	0	0.5	Left	1		
Bird	0	1	1	1	1	Right	1		
Fish	1	0	1	0	1	Left	1		
Fox	1	0	1	0	1	Left	1		
Hare	1	0	1	0	1	Left	1		
Snake	0	1	1	1	1	Right	1		

Table S7 – Orientation (left/right) of thematic representations in the analysed corpus. For each theme, the table reports the number of left- and right-oriented figures, total observations (n_total), proportion of right-oriented figures (prop_right), and results of binomial tests (p_binom) assuming a null hypothesis of equal left/right distribution. Direction indicates the dominant orientation. Adjusted p-values (p_adj_BH) were computed using the Benjamini–Hochberg procedure to control for false positives arising from multiple testing. Significant tendencies prior to correction are indicated (*), highlighting orientation biases particularly among the main structuring themes (bison, horse, ibex), while results should be interpreted cautiously given the limited sample size of several categories.

Test	ChiSquare	df	p_value	CramersV
Theme x Orient	35.79242419182876	19	0.011192282773165712	0.3002619519318193

Table S8 – Results of the chi-square test assessing the relationship between theme and left/right orientation for the full corpus.

Theme	Incl	std_resid	Theme	Incl	std_resid
Horse	Horizontal	4.838550481653246	Flounder	Inclined	-0.7692994222832313
Anthrop	Vertical	4.295571113504198	Deer	Vertical	-0.742724948333487
SFF	Vertical	4.295571113504198	Aurochs	Vertical	-0.6634676684614651
Bison	Horizontal	-3.604920127993018	Anthrop	Inclined	-0.6273347424306627
Horse	Vertical	-3.5607223499828904	Saiga	Inclined	-0.6273347424306627
Flounder	Vertical	3.320483809311503	SFF	Inclined	-0.6273347424306627
Fish	Vertical	3.033589903508334	Vulva	Inclined	-0.6273347424306627
Snake	Vertical	3.033589903508334	Hare	Horizontal	0.6004141022910527
Reindeer	Inclined	2.9106857279294154	Chamois	Vertical	-0.5738502299696394
Horse	Inclined	-2.8298158811637824	Bear	Horizontal	0.5473953391635159
Bison	Inclined	2.466211683603889	Horse	Inverted	-0.5421253648038937
Anthrop	Horizontal	-2.3643321054798996	Ibex	Vertical	-0.5090291715880234
Salmon	Horizontal	-2.3643321054798996	Hind	Horizontal	-0.47370412624612135
SFF	Horizontal	-2.3643321054798996	Saiga	Vertical	-0.4679532777281109
Bird	Inclined	2.2628721838828016	Vulva	Vertical	-0.4679532777281109

Fox	Inclined	2.2628721838828016	Fish	Inclined	-0.4430322046758497
Bison	Vertical	2.10946387166132	Hare	Inclined	-0.4430322046758497
Salmon	Vertical	1.9138089178880437	Snake	Inclined	-0.4430322046758497
Reindeer	Horizontal	-1.7102724758230503	Ibex	Inverted	-0.38441001968404903
Bird	Horizontal	-1.66972302732369	Bird	Vertical	-0.3304748777564944
Fish	Horizontal	-1.66972302732369	Fox	Vertical	-0.3304748777564944
Fox	Horizontal	-1.66972302732369	Hare	Vertical	-0.3304748777564944
Snake	Horizontal	-1.66972302732369	Reindeer	Inverted	-0.16095044356847932
Flounder	Horizontal	-1.5853894113670182	Hind	Inverted	-0.15249410393137558
Ibex	Horizontal	1.5264892154340937	Bear	Inverted	-0.12403233135088752
Hind	Inclined	1.3909292493991996	Deer	Inverted	-0.1130809970527973
Ibex	Inclined	-1.357994580403654	Aurochs	Inverted	-0.10101395628389528
Deer	Horizontal	1.3493991922478459	Chamois	Inverted	-0.08736956569123785
Salmon	Inclined	1.2884490479152841	Flounder	Inverted	-0.08736956569123785
Aurochs	Horizontal	1.205402804784304	Anthrop	Inverted	-0.07124659450090201
Reindeer	Vertical	-1.057135265864668	Saiga	Inverted	-0.07124659450090201
Chamois	Horizontal	1.042583850898979	Salmon	Inverted	-0.07124659450090201
Hind	Vertical	-1.0015933571111946	SFF	Inverted	-0.07124659450090201
Deer	Inclined	-0.9956916349036302	Vulva	Inverted	-0.07124659450090201
Bison	Inverted	0.9887298991168968	Bird	Inverted	-0.05031530011406887
Aurochs	Inclined	-0.8894399050393543	Fish	Inverted	-0.05031530011406887
Saiga	Horizontal	0.8501879146417445	Fox	Inverted	-0.05031530011406887
Vulva	Horizontal	0.8501879146417445	Hare	Inverted	-0.05031530011406887
Bear	Vertical	-0.814654179704998	Snake	Inverted	-0.05031530011406887
Chamois	Inclined	-0.7692994222832313	Bear	Inclined	0.01960214373260917

Table S8 – Standardised residuals from the χ^2 analysis of theme × inclination reveal non-random orientation patterns. Values ≥ |2| indicate over- or under-represented inclination categories for specific themes, highlighting differentiated graphic conventions in the depiction of zoomorphic and anthropomorphic figures.

S3.2. Co-occurrence and laterality analysis without "Unknown", "Saiga" and "Atxurra" figures

The second additional analysis consisted of repeating the statistical and network procedures after removing both the "*Unknown*" category and the Atxurra assemblage, in order to assess whether these factors—given the subjective nature of indeterminate figures and the unusually high number of ibex representations at Atxurra—might introduce noise or bias into the results.

The modified code is available in the following repository:

https://github.com/inakiintxaurbe/Rock-Art-Theme-Co-occurrence-Network/blob/main/Supplementary_codes/Script_without_saiga_unknown_and_Atxurra.R

The key modification is summarised in the following code snippet:

```
dat2 <- dat %>%
  transmute(
    GU    = as.character(GU),
    Theme = as.character(Theme)
  ) %>%
       filter(Theme != "Unknown",
              Theme != "Saiga",
              !grepl("^Atr", GU))
```

In this case, the `filter()` function removes all entries classified as "*Unknown*". A similar operation is applied in the dataset used for the analysis of figure orientation and inclination:

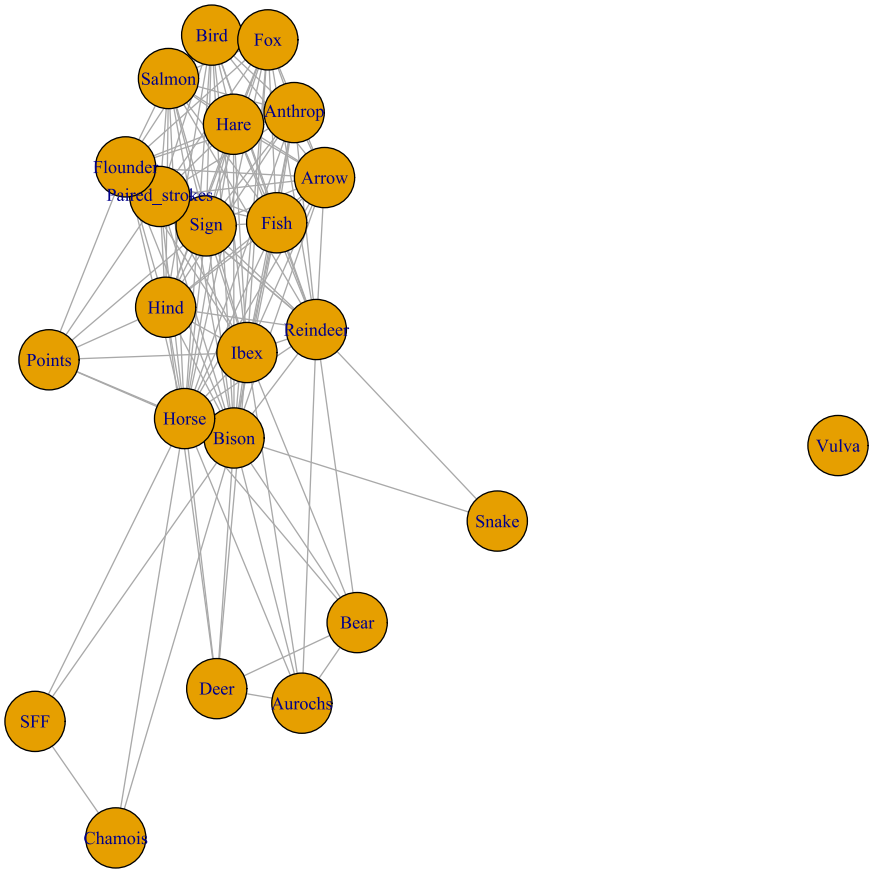
```
df_fig <- dat %>%
 transmute(
  GU    = as.character(GU),
  Panel  = sub("^([^\\.]+\\.[^\\.]+\\.[^\\.]+).*", "\\1", as.character(GU)),
  Theme  = as.character(Theme),
  Format = as.character(Format),
  Orient = as.character(Orient),
  Incl   = as.character(Incl)
 ) %>%
 filter(
  Format != "NF_F",
  Orient != "NF_O",
  Incl  != "NF_I",
  Theme != "Unknown",
  Theme  != "Saiga",
  ! grepl("^Atr", GU)
)
```

This second filtering step ensures that indeterminate figures are excluded not only from co-occurrence analyses but also from the study of laterality and inclination, so that only well-defined thematic categories are considered.

As a result of this procedure, the corpus is reduced from 500 to 336 figures, representing approximately 67.2% of the original dataset.

Since all scripts and outputs are fully accessible through the GitHub repository, we do not reproduce the Gephi network files here. Instead, we focus on assessing whether the exclusion of the "Unknown" category produces any significant structural changes. The figures presented in this section correspond to plots generated directly from the R environment using the following function:

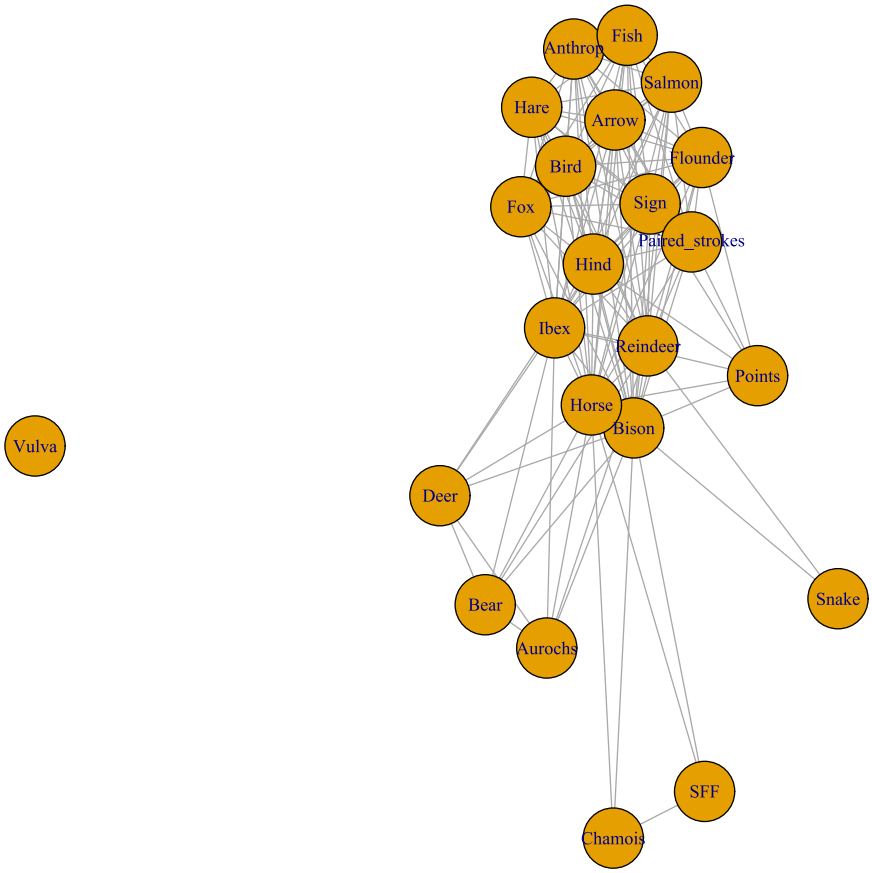
```
plot(g)
# unfiltered co-occurrence network (jaccard-normalised)
```



or extract the corresponding frequency-weighted network, the following code was executed. The first line generates the network object, while the second produces its graphical representation:

```
g2 <- graph_from_data_frame(edges_tt_weighted, directed = FALSE,
vertices = nodes)
```

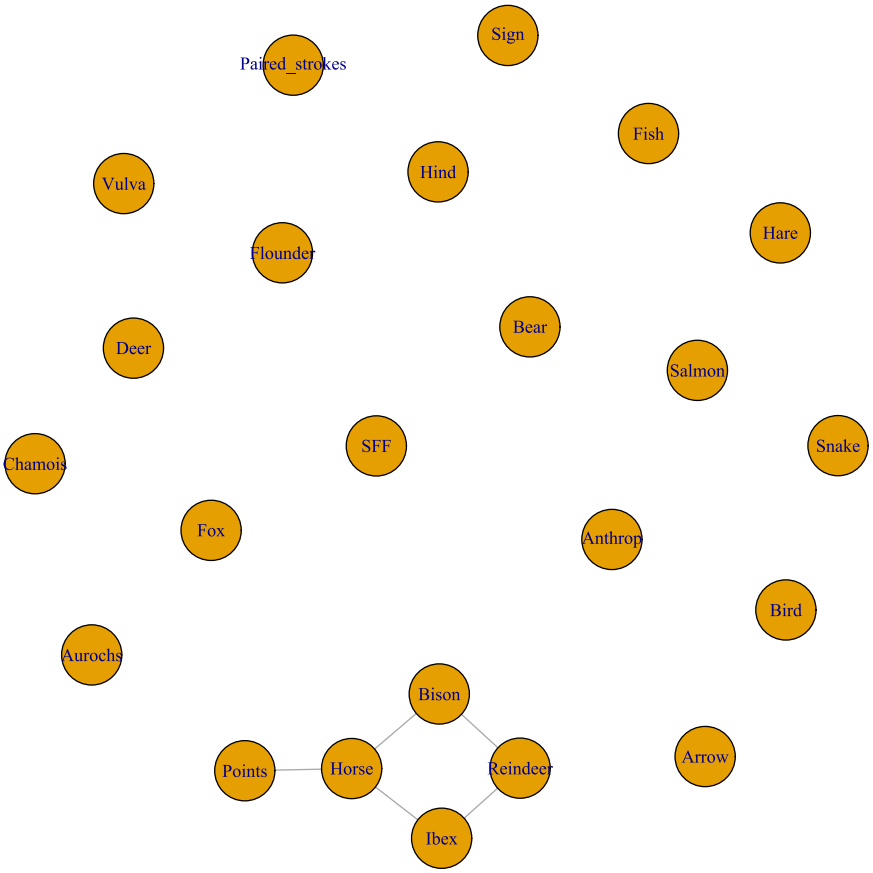
```
plot(g2)
```



As observed, no substantial changes are detected in the overall network configuration following this modification. We next examine whether applying filtering thresholds—minimum co-occurrence frequency (min_weight = 3) and Jaccard similarity (min_jaccard = 0.12)—produces any notable structural differences.

To visualise the filtered network, the following code was used:

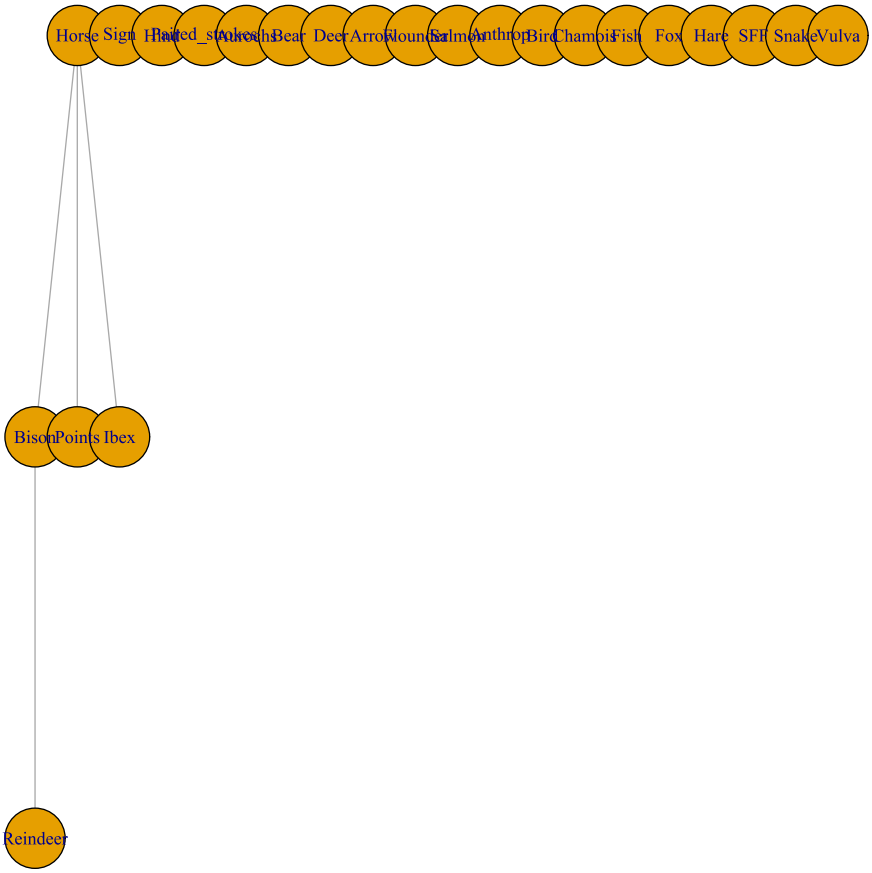
```
plot(g_filt)
```



In this network, no substantial changes are observed. The central structure remains organised around bison, ibex, and horse (with the addition of reindeer figure), together with a secondary element, the points.

To visualise the Minimum Spanning Tree (MST), the following line of code was executed:

```
plot(mst_g)
```



The MST shows some structural changes. First, horse emerges as the primary organising node at the top of the hierarchical structure. Additionally, the category of points occupies a second-level position alongside bison and ibex, while reindeer becomes directly associated with bison.

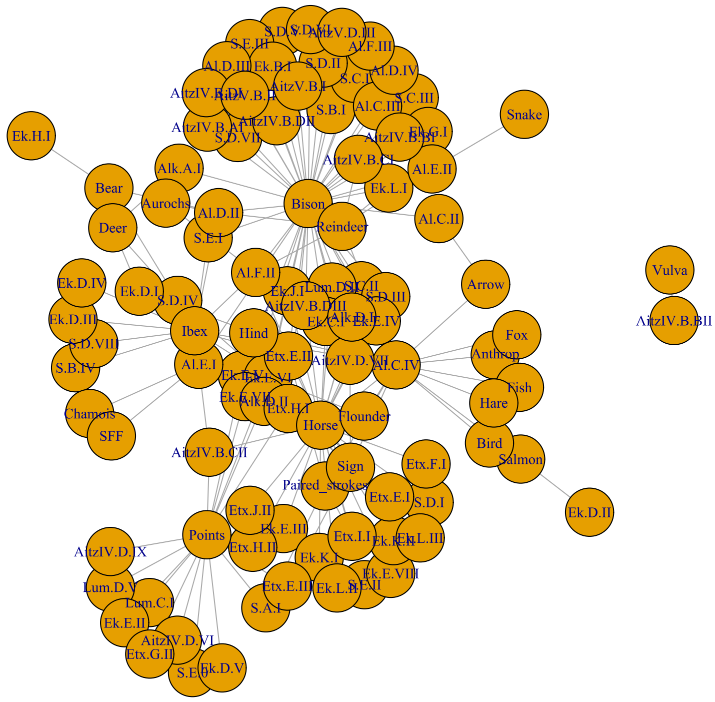
These results may be sensitive to the weight of the Altxerri assemblage, which constitutes the largest corpus of figures within this thematic group, as well as to the substantial reduction in the analysed dataset. The results should therefore be interpreted with caution.

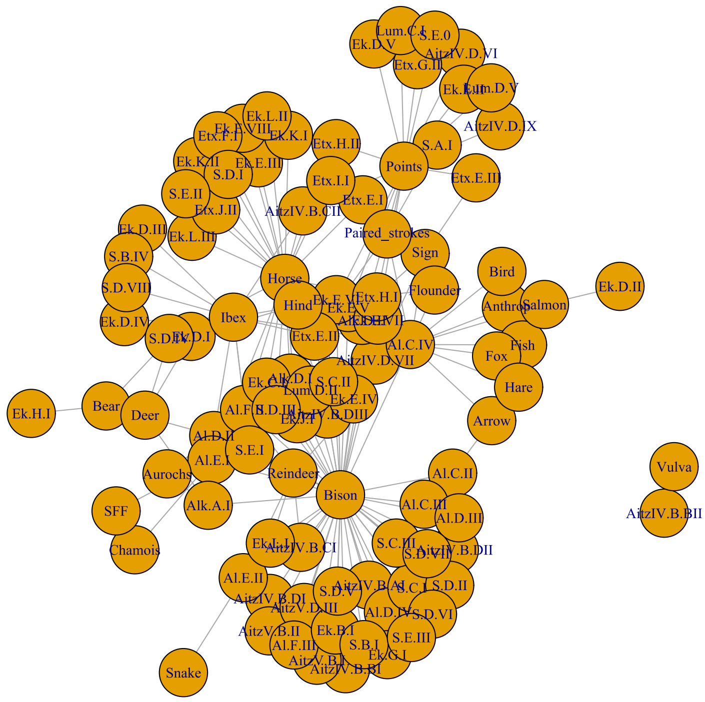
We then proceed to the bipartite analyses, starting with the binary bipartite network (presence/absence):

```
plot(g_bip_1)
```

To generate the count-weighted bipartite network (motif multiplicity), the following command was used:

```
plot(g_bip_2)
```


Ek.H.I
Bear
Aurochs
Deer
Bison
Reindeer
Snake
Arrow
Vulva
AitzIV.B.BII
Ibex
Hind
Horse
Flounder
Fox
Anthrop
Fish
Hare
Bird
Salmon
Ek.D.II
Chamois
SFF
Sign
Paired_strokes
Points
Etx.F.I
S.D.I
S.A.I


Points
S.A.I
Etx.E.III
Paired_strokes
Sign
Bird
Ek.D.II
Salmon
Flounder
Horse
Hind
Ibex
Fish
Fox
Hare
Arrow
Ek.H.I
Bear
Deer
Aurochs
SFF
Chamois
Reindeer
Bison
Vulva
AitzIV.B.BII
Snake

Regarding the laterality analyses, the results are as follows:

Theme	Left	Right	n_total	prop_right	p_binom	direction	p_adj_BH	sig_Binom	sig_BH
Bison	96	59	155	0.380645161290	0.0036930366	Left	0.07016769568439227	*	
Horse	28	50	78	0.641025641025	0.0168530898	Right	0.16010435399872425	*	
Ibex	8	9	17	0.529411764705	1	Right	1		
Reindeer	7	3	10	0.3	0.3437500000	Left	1		
Hind	2	3	5	0.6	1	Right	1		
Bear	2	2	4	0.5	1	Equal	1		
Aurochs	3	0	3	0	0.2500000000	Left	1		
Chamois	2	1	3	0.333333333333	1	Left	1		
Deer	2	1	3	0.333333333333	1	Left	1		
Flounder	2	1	3	0.333333333333	1	Left	1		
Anthrop	1	1	2	0.5	1	Equal	1		
SFF	0	2	2	1	0.5	Right	1		
Salmon	1	1	2	0.5	1	Equal	1		
Vulva	2	0	2	0	0.5	Left	1		
Bird	0	1	1	1	1	Right	1		
Fish	1	0	1	0	1	Left	1		
Fox	1	0	1	0	1	Left	1		
Hare	1	0	1	0	1	Left	1		
Snake	0	1	1	1	1	Right	1		

Table S9 – Orientation (left/right) of thematic representations in the analysed corpus. For each theme, the table reports the number of left- and right-oriented figures, total observations (n_total), proportion of right-oriented figures (prop_right), and results of binomial tests (p_binom) assuming a null hypothesis of equal left/right distribution. Direction indicates the dominant orientation. Adjusted p-values (p_adj_BH) were computed using the Benjamini–Hochberg procedure to control for false positives arising from multiple testing. Significant tendencies prior to correction are indicated (*), highlighting orientation biases particularly among the main structuring themes (bison, horse, ibex), while results should be interpreted cautiously given the limited sample size of several categories.

Test	ChiSquare	df	p_value	CramersV
Theme x Orient	28.12444433020281	18	0.060186506691833425	0.3092917316592842

Table S10 – Results of the chi-square test assessing the relationship between theme and left/right orientation for the full corpus.

Theme	Incl	std_resid	Theme	Incl	std_resid
Horse	Horizontal	5.5291918246565475	Deer	Inclined	-0.8258079455215951
Horse	Vertical	-3.909564579468871	Flounder	Inclined	-0.8258079455215951
Anthrop	Vertical	3.7399253784476643	Bear	Vertical	-0.76408022912408
SFF	Vertical	3.7399253784476643	Hare	Horizontal	0.6760177262529622
Horse	Inclined	-3.181738169516869	Anthrop	Inclined	-0.673113802993834
Bison	Horizontal	-3.1482554914673604	SFF	Inclined	-0.673113802993834
Flounder	Vertical	2.838686933413975	Vulva	Inclined	-0.673113802993834
Fish	Vertical	2.6400098950766755	Aurochs	Vertical	-0.6605749467692896
Snake	Vertical	2.6400098950766755	Chamois	Vertical	-0.6605749467692896
Reindeer	Inclined	2.6284210883799375	Deer	Vertical	-0.6605749467692896
Hind	Inclined	2.4248711305964283	Horse	Inverted	-0.6019498087392198
Bison	Inclined	2.2718284388989867	Vulva	Vertical	-0.5384328365858505
Bird	Inclined	2.1117796279002605	Fish	Inclined	-0.4751504162775586
Fox	Inclined	2.1117796279002605	Hare	Inclined	-0.4751504162775586

Anthrop	Horizontal	-2.1027082001233532	Snake	Inclined	-0.4751504162775586
Salmon	Horizontal	-2.1027082001233532	Bird	Vertical	-0.38007924559469647
SFF	Horizontal	-2.1027082001233532	Fox	Vertical	-0.38007924559469647
Salmon	Vertical	1.6007462709309068	Hare	Vertical	-0.38007924559469647
Bison	Vertical	1.5824711819258344	Bear	Inclined	0.344934609828401
Bird	Horizontal	-1.484299790251069	Bear	Horizontal	0.27327933483185535
Fish	Horizontal	-1.484299790251069	Ibex	Inverted	-0.24815580058494624
Fox	Horizontal	-1.484299790251069	Reindeer	Inverted	-0.18796659964046022
Snake	Horizontal	-1.484299790251069	Ibex	Horizontal	0.1722929770298448
Ibex	Vertical	1.401616568411293	Hind	Inverted	-0.13175767899351867
Hind	Horizontal	-1.396312398139184	Bear	Inverted	-0.11764428964750427
Ibex	Inclined	-1.3695926254887998	Aurochs	Inverted	-0.10170773618982244
Flounder	Horizontal	-1.3281634938746578	Chamois	Inverted	-0.10170773618982244
Reindeer	Horizontal	-1.2980983152961447	Deer	Inverted	-0.10170773618982244
Reindeer	Vertical	-1.2208120168967664	Flounder	Inverted	-0.10170773618982244
Aurochs	Horizontal	1.1749138599660438	Anthrop	Inverted	-0.08290169823612421
Chamois	Horizontal	1.1749138599660438	Salmon	Inverted	-0.08290169823612421
Deer	Horizontal	1.1749138599660438	SFF	Inverted	-0.08290169823612421
Salmon	Inclined	1.159251549600492	Vulva	Inverted	-0.08290169823612421
Vulva	Horizontal	0.9576690812442995	Bird	Inverted	-0.05852023276273804
Bison	Inverted	0.9485962556983886	Fish	Inverted	-0.05852023276273804
Hind	Vertical	-0.8557443617184562	Fox	Inverted	-0.05852023276273804
Aurochs	Inclined	-0.8258079455215951	Hare	Inverted	-0.05852023276273804
Chamois	Inclined	-0.8258079455215951	Snake	Inverted	-0.05852023276273804

Table S11 – Standardised residuals from the χ^2 analysis of theme × inclination reveal non-random orientation patterns. Values ≥ |2| indicate over- or under-represented inclination categories for specific themes, highlighting differentiated graphic conventions in the depiction of zoomorphic and anthropomorphic figures.

S3.3. Co-occurrence and laterality analysis with "Saiga" as "Unknown"s

The third additional analysis consisted of repeating the statistical and network procedures after transforming "Saiga"-s in "Unknown" category, because of the discussion behind their controversial identification (Ruiz-Redondo, 2014).

The modified code is available in the following repository:

https://github.com/inakiintxaurbe/Rock-Art-Theme-Co-occurrence-Network/blob/main/Supplementary_codes/Script_with_Saiga_as_Unknown.R

The key modification is summarised in the following code snippet:

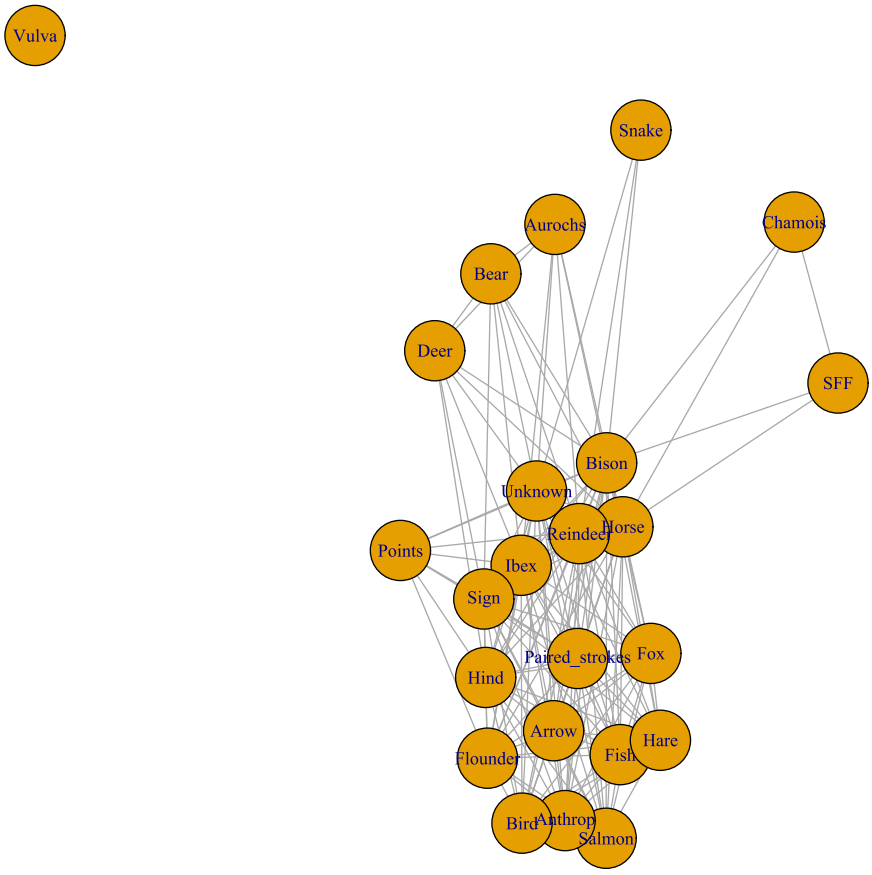
```
dat2 <- dat %>%
  transmute(
    GU    = as.character(GU),
    Theme = as.character(Theme)
  ) %>%
mutate(
    Theme = case_when(
      Theme %in% c("Saiga") ~ "Unknown",
      TRUE ~ Theme))
```

In this case, the `mutate()` function transforms all entries classified as "*Saiga*" in "*Unknown*".

This second filtering step ensures that indeterminate figures are excluded not only from co-occurrence analyses but also from the study of laterality and inclination, so that only well-defined thematic categories are considered.

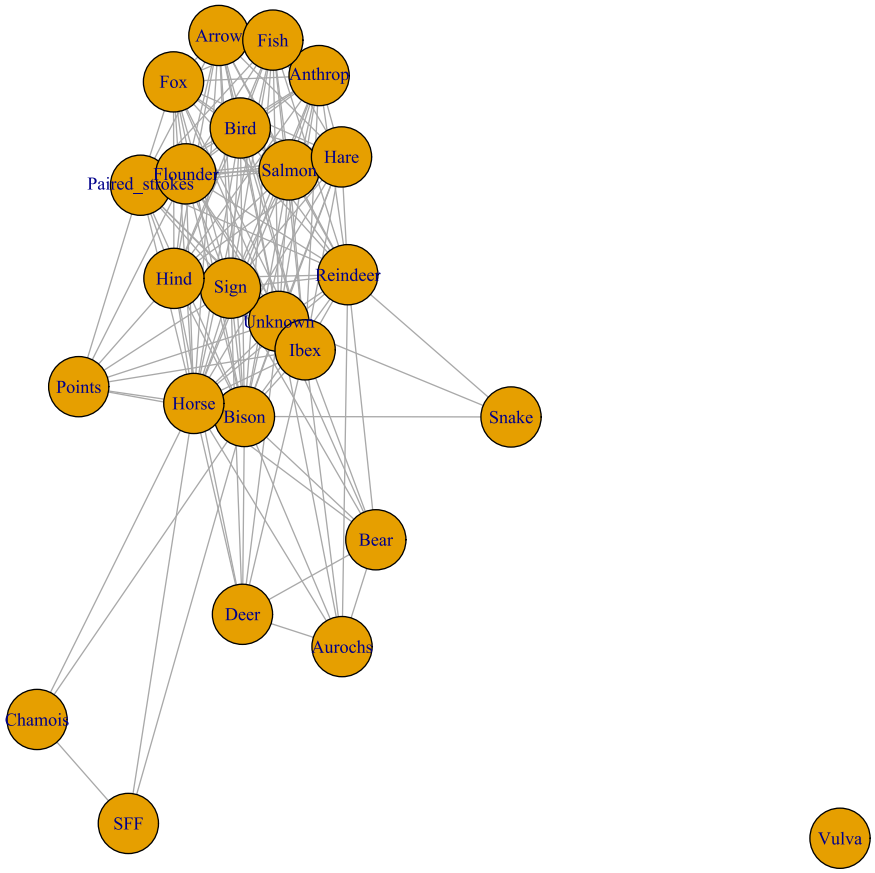
Since all scripts and outputs are fully accessible through the GitHub repository, we do not reproduce the Gephi network files here. Instead, we focus on assessing whether the exclusion of the "Unknown" category produces any significant structural changes. The figures presented in this section correspond to plots generated directly from the R environment using the following function:

```
plot(g)
# unfiltered co-occurrence network (jaccard-normalised)
```



or extract the corresponding frequency-weighted network, the following code was executed. The first line generates the network object, while the second produces its graphical representation:

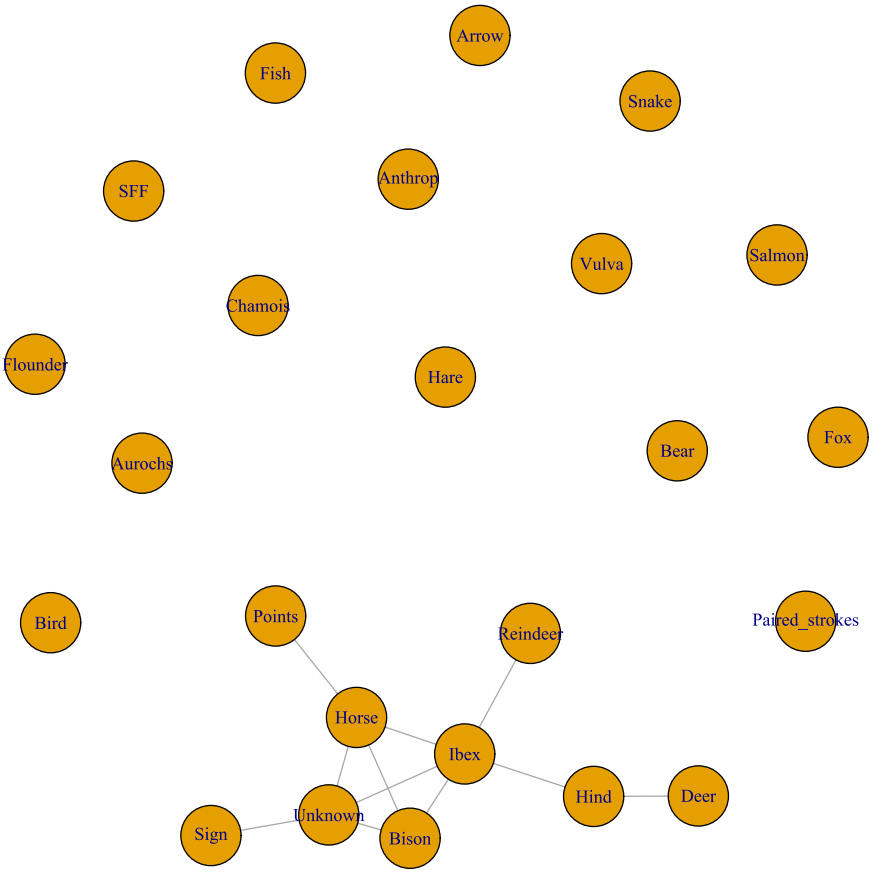
```
g2 <- graph_from_data_frame(edges_tt_weighted, directed = FALSE,
vertices = nodes)
plot(g2)
```



As observed, no substantial changes are detected in the overall network configuration following this modification. We next examine whether applying filtering thresholds—minimum co-occurrence frequency (min_weight = 3) and Jaccard similarity (min_jaccard = 0.12)—produces any notable structural differences.

To visualise the filtered network, the following code was used:

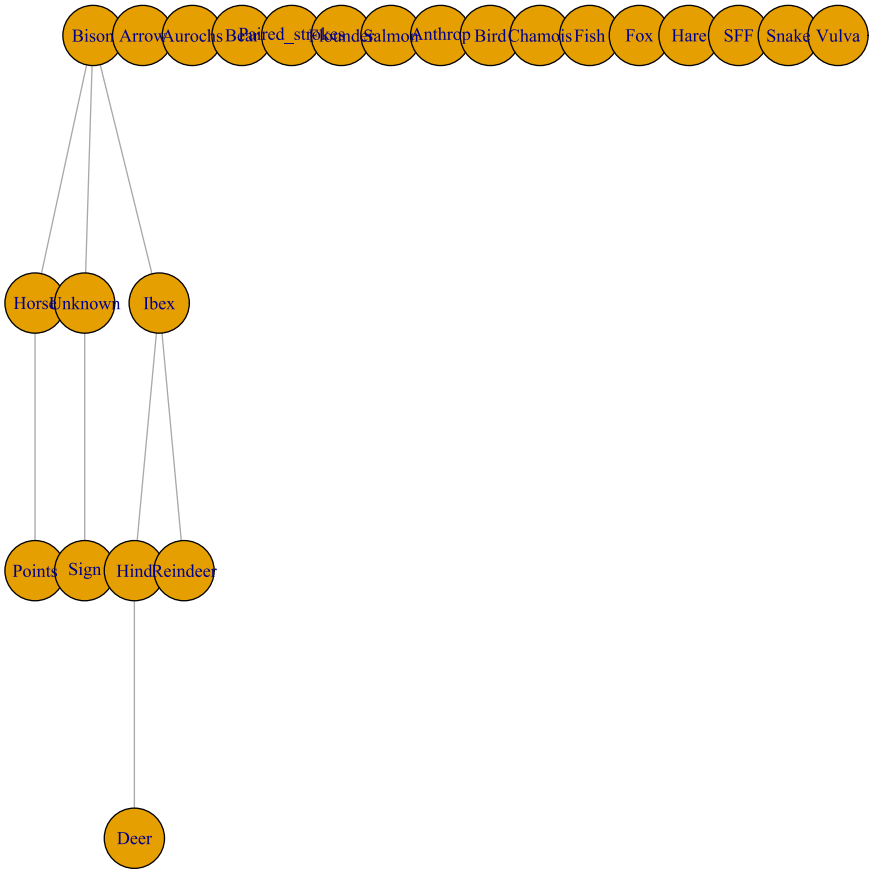
```
plot(g_filt)
```



In this network, no substantial changes are observed.

To visualise the Minimum Spanning Tree (MST), the following line of code was executed:

```
plot(mst_g)
```



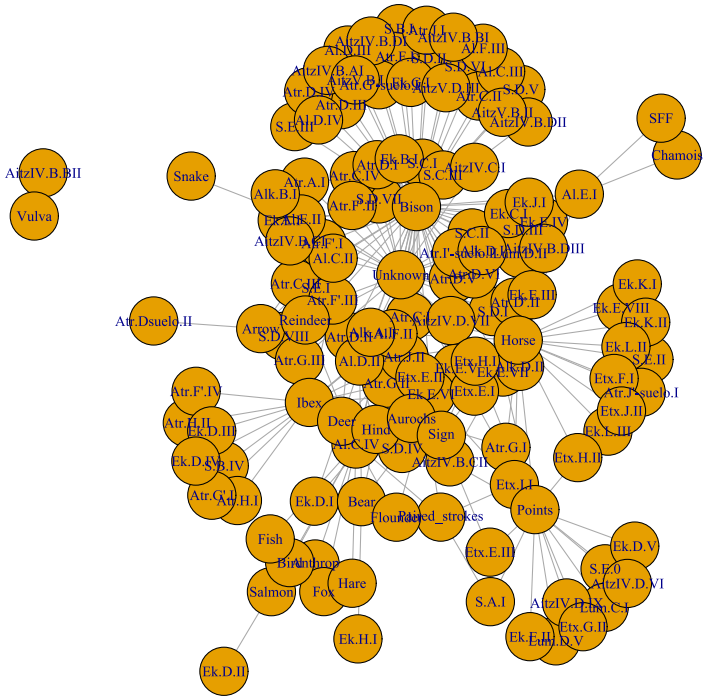
In this MST, no substantial changes are observed.

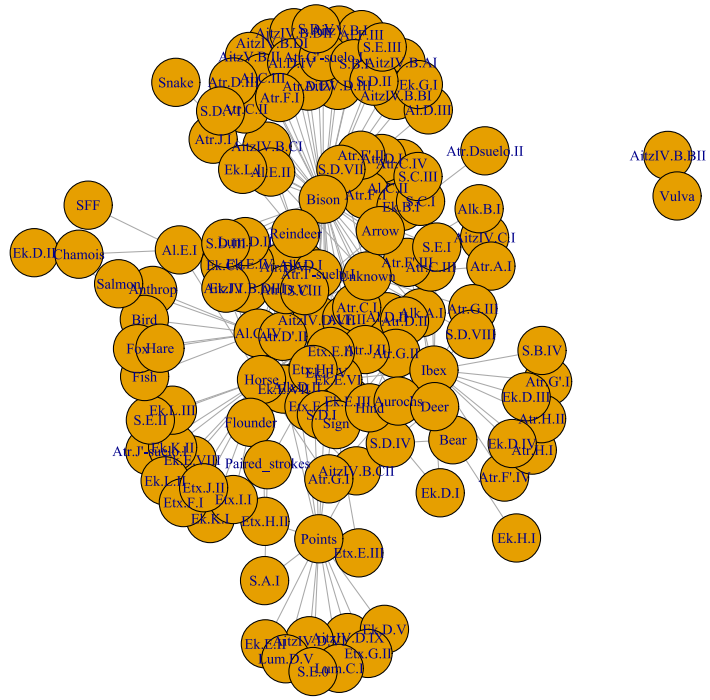
We then proceed to the bipartite analyses, starting with the binary bipartite network (presence/absence):

```
plot(g_bip_1)
```

To generate the count-weighted bipartite network (motif multiplicity), the following command was used:

```
plot(g_bip_2)
```


AitzIV.B.BII
Vulva
Snake
SFF
Chamois
Bison
Horse
Reindeer
Arrow
Ibex
Deer
Aurochs
Hind
Sign
Bear
Flounder
Fish
Bird
Anthrop
Salmon
Fox
Hare
Points
Paired_strokes
Unknown
Atr.Dsuelo.II
Ek.H.I
Ek.D.II


AitzIV.B.BII
Vulva
Atr.Dsuelo.II
SFF
Chamois
Ek.D.II
Snake
Bison
Reindeer
Arrow
Ibex
Deer
Aurochs
Hind
Sign
Bear
Flounder
Fish
Bird
Anthrop
Salmon
Fox
Hare
Points
Paired_strokes
Unknown
Ek.H.I

Regarding the laterality analyses, the results are as follows:

Theme	Left	Right	n_total	prop_right	p_binom	direction	p_adj_BH	sig_Binom	sig_BH
Bison	119	82	201	0.4079601990049	0.010926428593989	Left	0.07681494029804395	*	
Horse	32	58	90	0.6444444444444	0.008045928133225	Right	0.07681494029804395	*	
Ibex	35	16	51	0.3137254901960	0.010973562899720	Left	0.07681494029804395	*	
Aurochs	4	0	4	0	0.125	Left	0.65625		
Unknown	29	26	55	0.4727272727272	0.787706189670044	Left	1		
Reindeer	7	3	10	0.3	0.343750000000000	Left	1		
Hind	4	5	9	0.5555555555555	1	Right	1		
Bear	2	4	6	0.6666666666666	0.687499999999999	Right	1		
Deer	3	2	5	0.4	1	Left	1		
Chamois	2	1	3	0.3333333333333	1	Left	1		
Flounder	2	1	3	0.3333333333333	1	Left	1		
Anthrop	1	1	2	0.5	1	Equal	1		
SFF	0	2	2	1	0.5	Right	1		
Saiga	2	0	2	0	0.5	Left	1		
Salmon	1	1	2	0.5	1	Equal	1		
Vulva	2	0	2	0	0.5	Left	1		
Bird	0	1	1	1	1	Right	1		
Fish	1	0	1	0	1	Left	1		
Fox	1	0	1	0	1	Left	1		
Hare	1	0	1	0	1	Left	1		
Snake	0	1	1	1	1	Right	1		

Table S12 – Orientation (left/right) of thematic representations in the analysed corpus. For each theme, the table reports the number of left- and right-oriented figures, total observations (n_total), proportion of right-oriented figures (prop_right), and results of binomial tests (p_binom) assuming a null hypothesis of equal left/right distribution. Direction indicates the dominant orientation. Adjusted p-values (p_adj_BH) were computed using the Benjamini–Hochberg procedure to control for false positives arising from multiple testing. Significant tendencies prior to correction are indicated (*), highlighting orientation biases particularly among the main structuring themes (bison, horse, ibex), while results should be interpreted cautiously given the limited sample size of several categories.

Test	ChiSquare	df	p_value	CramersV
Theme x Orient	35.86524446641723	20	0.015951566477681638	0.2816875680388624

Table S13 – Results of the chi-square test assessing the relationship between theme and left/right orientation for the full corpus.

Theme	Incl	std_resid	Theme	Incl	std_resid
Horse	Horizontal	4.8132021452144205	Horse	Inverted	-0.7067160064779591
Anthrop	Vertical	4.316002639929543	Aurochs	Vertical	-0.6597151579552
SFF	Vertical	4.316002639929543	Anthrop	Inclined	-0.6321758700558046
Horse	Vertical	-3.481227804428251	Saiga	Inclined	-0.6321758700558046
Flounder	Vertical	3.337692325134339	SFF	Inclined	-0.6321758700558046
Bison	Horizontal	-3.247840501635873	Vulva	Inclined	-0.6321758700558046
Fish	Vertical	3.0484894035604317	Hare	Horizontal	0.6052846142922127
Snake	Vertical	3.0484894035604317	Chamois	Vertical	-0.5706935063701202
Reindeer	Inclined	2.8716646576070692	Bear	Horizontal	0.5626910968825534
Horse	Inclined	-2.828516296216757	Ibex	Inverted	-0.5054647335286906
Anthrop	Horizontal	-2.344224875369118	Ibex	Vertical	-0.4837734303826662
Salmon	Horizontal	-2.344224875369118	Saiga	Vertical	-0.465451265090441

SFF	Horizontal	-2.344224875369118	Vulva	Vertical	-0.465451265090441
Bird	Inclined	2.244507132764737	Hind	Horizontal	-0.4492113066215751
Fox	Inclined	2.244507132764737	Fish	Inclined	-0.4465199866242846
Bison	Inclined	2.2003850804635117	Hare	Inclined	-0.4465199866242846
Bison	Vertical	2.0543399431632907	Snake	Inclined	-0.4465199866242846
Salmon	Vertical	1.9252756874195514	Unknown	Horizontal	-0.41482197071448235
Reindeer	Horizontal	-1.6778019690921566	Unknown	Inclined	0.3379779816613567
Bird	Horizontal	-1.6557785729811765	Bird	Vertical	-0.32875866116828184
Fish	Horizontal	-1.6557785729811765	Fox	Vertical	-0.32875866116828184
Fox	Horizontal	-1.6557785729811765	Hare	Vertical	-0.32875866116828184
Snake	Horizontal	-1.6557785729811765	Reindeer	Inverted	-0.21318999709587586
Unknown	Inverted	1.6402025041552188	Hind	Inverted	-0.20202138768833722
Flounder	Horizontal	-1.565943190468438	Unknown	Vertical	-0.17181306373243968
Ibex	Horizontal	1.5622284181174575	Bear	Inverted	-0.16439407246395932
Ibex	Inclined	-1.3836459560712828	Bison	Inverted	0.15775497987499268
Hind	Inclined	1.3636154232229902	Deer	Inverted	-0.14990261152025205
Deer	Horizontal	1.3594997945059244	Aurochs	Inverted	-0.1339272486707165
Salmon	Inclined	1.2727807517123533	Chamois	Inverted	-0.11585516903885441
Aurochs	Horizontal	1.2146157108275895	Flounder	Inverted	-0.11585516903885441
Chamois	Horizontal	1.050716040924294	Anthrop	Inverted	-0.09449018500208578
Reindeer	Vertical	-1.0501572607854717	Saiga	Inverted	-0.09449018500208578
Deer	Inclined	-1.0029064273645012	Salmon	Inverted	-0.09449018500208578
Hind	Vertical	-0.9951415638861046	SFF	Inverted	-0.09449018500208578
Aurochs	Inclined	-0.8960250734054696	Vulva	Inverted	-0.09449018500208578
Saiga	Horizontal	0.8569522958297986	Bird	Inverted	-0.06674053557206018
Vulva	Horizontal	0.8569522958297986	Fish	Inverted	-0.06674053557206018
Bear	Vertical	-0.8097923503910003	Fox	Inverted	-0.06674053557206018
Chamois	Inclined	-0.7751158735267941	Hare	Inverted	-0.06674053557206018
Flounder	Inclined	-0.7751158735267941	Snake	Inverted	-0.06674053557206018
Deer	Vertical	-0.7384085465693824	Bear	Inclined	0.004888266239368979

Table S14 – Standardised residuals from the χ^2 analysis of theme × inclination reveal non-random orientation patterns. Values ≥ |2| indicate over- or under-represented inclination categories for specific themes, highlighting differentiated graphic conventions in the depiction of zoomorphic and anthropomorphic figures.

S3.4. Co-occurrence and laterality analysis with "Salmon" and "Flounder" as "Fish"s

The fourth additional analysis consisted of repeating the statistical and network procedures after transforming "Salmon" and "Flounder"-s in "Fish" category, because of the discussion behind their controversial identification (Ruiz-Redondo, 2014).

The modified code is available in the following repository:

https://github.com/inakiintxaurbe/Rock-Art-Theme-Co-occurrence-Network/blob/main/Supplementary_codes/Script_with_salmon_and_flounder_as_Fish.R

The key modification is summarised in the following code snippet:

```
dat2 <- dat %>%
  transmute(
    GU    = as.character(GU),
    Theme = as.character(Theme)
  ) %>%
mutate(
    Theme = case_when(
      Theme %in% c("Saiga") ~ "Unknown",
      TRUE ~ Theme))
```

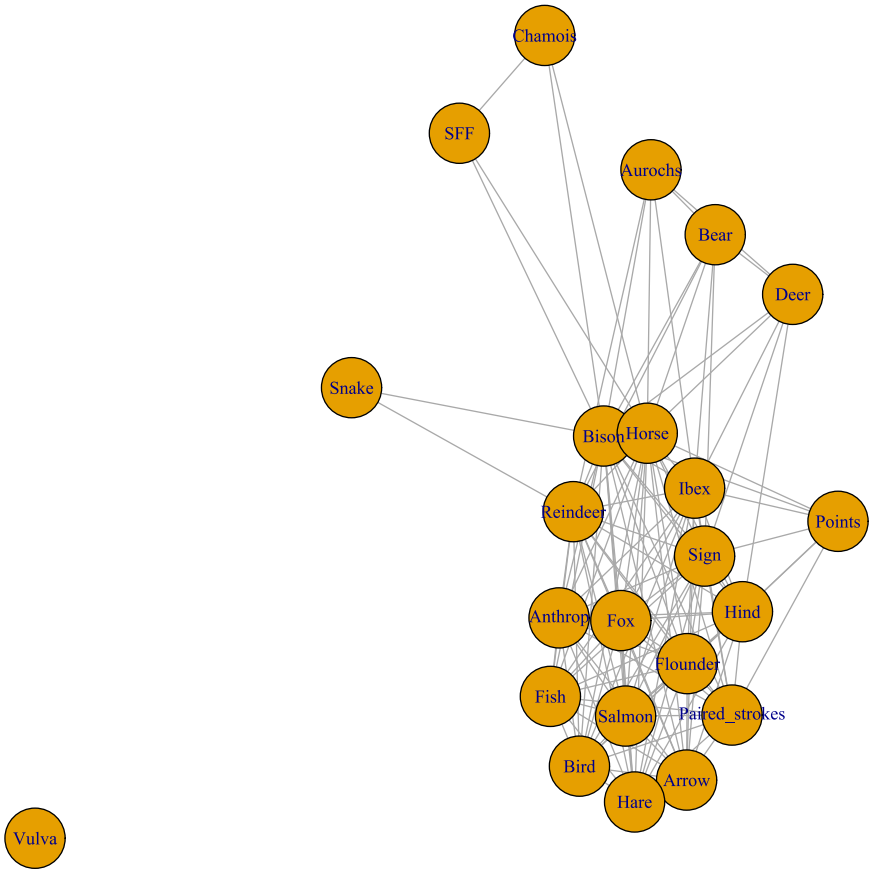
In this case, the `filter()` function removes all entries classified as "*Unknown*". A similar operation is applied in the dataset used for the analysis of figure orientation and inclination:

```
df_fig <- dat %>%
 transmute(
  GU    = as.character(GU),
  Panel  = sub("^([^\\.]+\\.[^\\.]+\\.[^\\.]+).*", "\\1", as.character(GU)),
  Theme  = as.character(Theme),
  Format = as.character(Format),
  Orient = as.character(Orient),
  Incl   = as.character(Incl)
 ) %>%
 filter(
  Format != "NF_F",
  Orient != "NF_O",
  Incl  != "NF_I",
  Theme != "Unknown",
  Theme  != "Saiga",
)
```

This second filtering step ensures that indeterminate figures are excluded not only from co-occurrence analyses but also from the study of laterality and inclination, so that only well-defined thematic categories are considered.

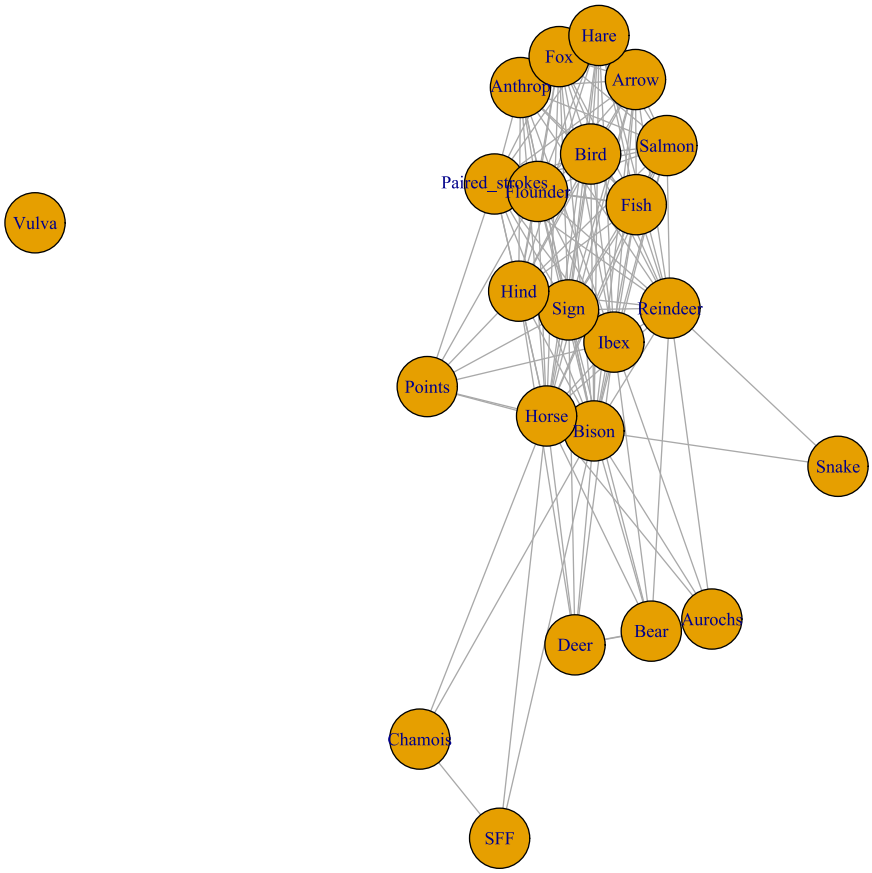
Since all scripts and outputs are fully accessible through the GitHub repository, we do not reproduce the Gephi network files here. Instead, we focus on assessing whether the exclusion of the "Unknown" and "Saiga" categories produce any significant structural changes. The figures presented in this section correspond to plots generated directly from the R environment using the following function:

```
plot(g)
# unfiltered co-occurrence network (jaccard-normalised)
```



or extract the corresponding frequency-weighted network, the following code was executed. The first line generates the network object, while the second produces its graphical representation:

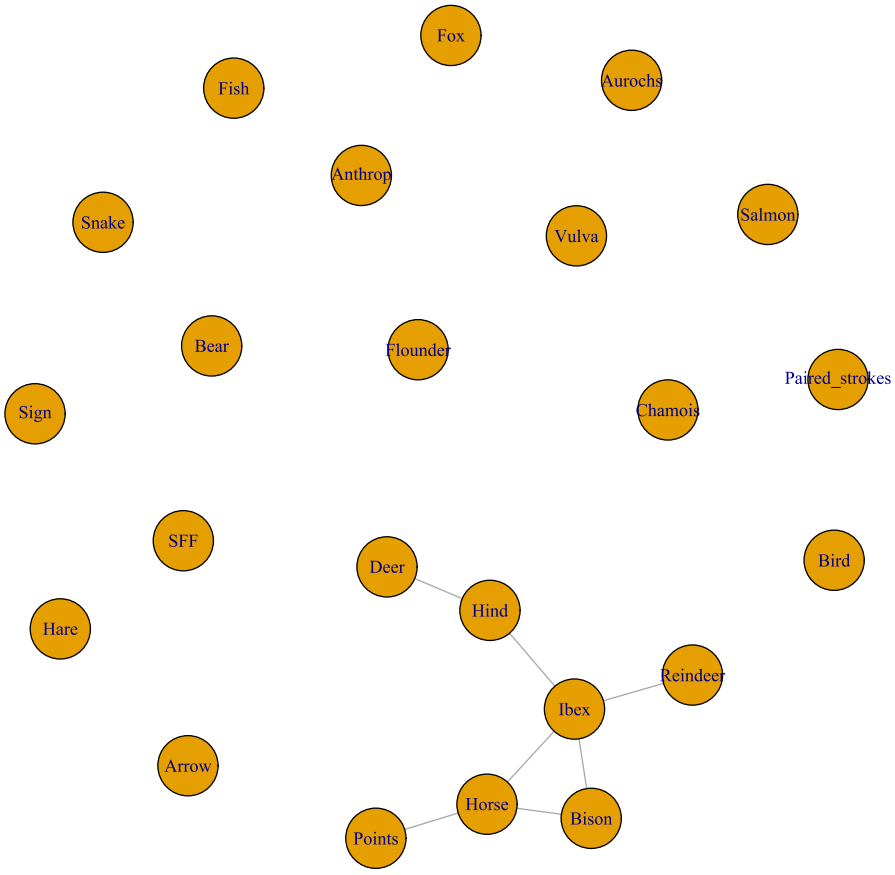
```
g2 <- graph_from_data_frame(edges_tt_weighted, directed = FALSE,
vertices = nodes)
plot(g2)
```



As observed, no substantial changes are detected in the overall network configuration following this modification. We next examine whether applying filtering thresholds—minimum co-occurrence frequency (min_weight = 3) and Jaccard similarity (min_jaccard = 0.12)—produces any notable structural differences.

To visualise the filtered network, the following code was used:

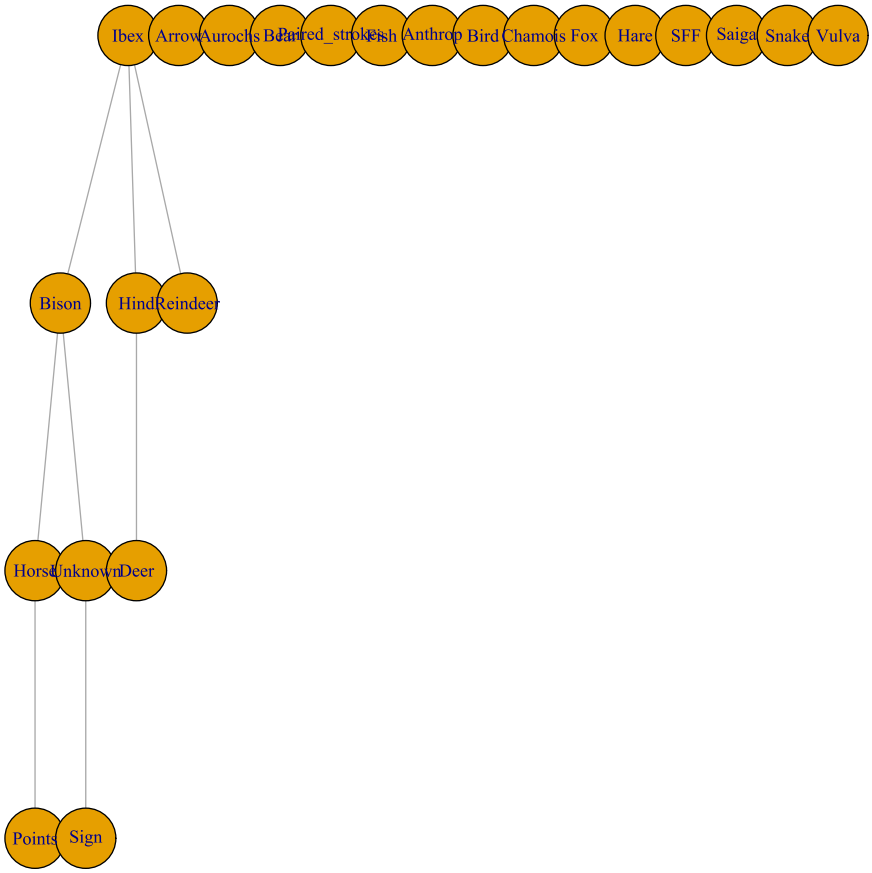
```
plot(g_filt)
```



In this network, no substantial changes are observed.

To visualise the Minimum Spanning Tree (MST), the following line of code was executed:

```
plot(mst_g)
```



In this MST, we again observe that ibex displaces bison from the leading position in the hierarchical structure, simply as a result of aggregating salmon and flounder into a single "fish" category. This further suggests that the observed hierarchical shifts are sensitive to taxonomic grouping rather than indicative of a fundamental structural change.

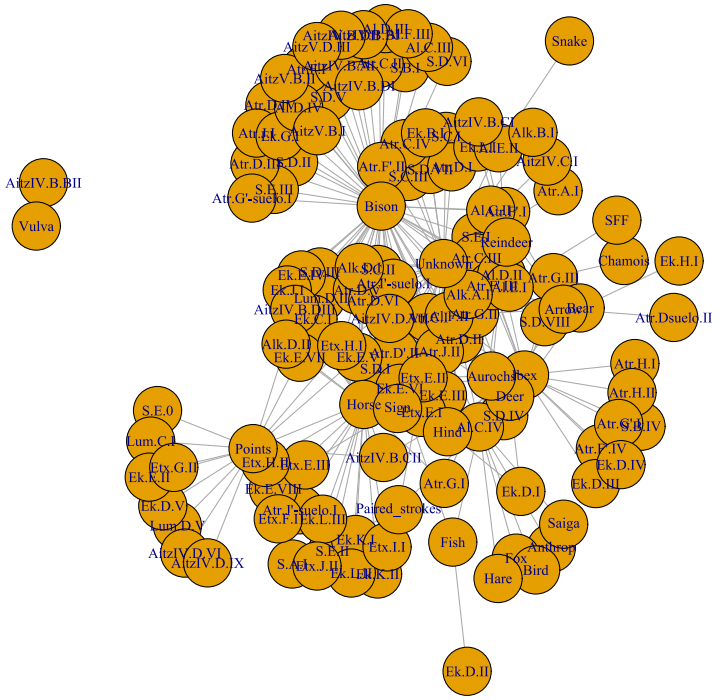
However, these variations do not alter the broader result: the co-occurrence system continues to be dominated by the same restricted group of large herbivores—bison, horse, and ibex—which remain the principal organisers of the corpus under all tested variants. The issue, therefore, is not instability of the overall structure, but controlled variability in the relative ordering of its major poles.

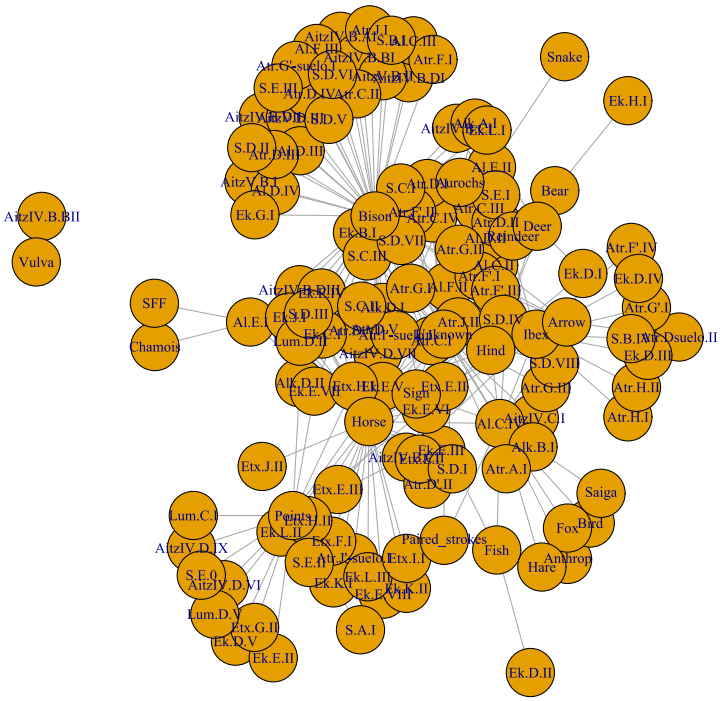
We then proceed to the bipartite analyses, starting with the binary bipartite network (presence/absence):

```
plot(g_bip_1)
```

To generate the count-weighted bipartite network (motif multiplicity), the following command was used:

```
plot(g_bip_2)
```


Snake
AitzIV.B.BII
Vulva
Bison
SFF
Reindeer
Chamois
Ek.H.I
Unknown
Atr.G.III
Arrow
Bear
Atr.Dsuelo.II
Atr.H.I
Atr.H.II
Aurochs
Ibex
Deer
Horse Sign
Hind
S.E.0
Lum.C.I
Points
Ek.K.II
Ek.D.V
Lum.D.V
AitzIV.D.VI
AitzIV.D.IX
Atr.G.I
Ek.D.I
Ek.D.IV
Ek.D.III
Paired_strokes
Fish
Saiga
Fox
Bird
Hare
Ek.D.II


Snake
Ek.H.I
AitzIV.B.BII
Vulva
Bison
Aurochs
Bear
Deer
Reindeer
Ek.D.I
Ek.D.IV
Atr.F'.IV
Atr.G'.I
SFF
Chamois
Arrow
Ibex
Hind
Atr.Dsuelo.II
Ek.D.III
Atr.H.II
Atr.H.I
Horse
Sign
Etx.J.II
Etx.E.II
Lum.C.I
Points
AitzIV.D.IX
Paired_strokes
Fish
Saiga
Fox
Bird
Hare
S.E.0
AitzIV.D.VI
Lum.D.V
Etx.G.II
Ek.E.II
S.A.I
Ek.D.II

Regarding the laterality analyses, the results are as follows:

Theme	Left	Right	n_total	prop_right	p_binom	direction	p_adj_BH	sig_Binom	sig_BH
Bison	119	82	201	0.4079601990049	0.010926428593989379	Left	0.076814940298043	*	
Horse	32	58	90	0.6444444444444	0.00804592813322509	Right	0.076814940298043	*	
Ibex	35	16	51	0.3137254901960	0.010973562899720565	Left	0.076814940298043	*	
Aurochs	4	0	4	0	0.125	Left	0.65625		
Unknown	29	26	55	0.4727272727272	0.7877061896700445	Left	1		
Reindeer	7	3	10	0.3	0.3437500000000001	Left	1		
Hind	4	5	9	0.5555555555555	1	Right	1		
Bear	2	4	6	0.6666666666666	0.6874999999999999	Right	1		
Deer	3	2	5	0.4	1	Left	1		
Chamois	2	1	3	0.3333333333333	1	Left	1		
Flounder	2	1	3	0.3333333333333	1	Left	1		
Anthrop	1	1	2	0.5	1	Equal	1		
SFF	0	2	2	1	0.5	Right	1		
Saiga	2	0	2	0	0.5	Left	1		
Salmon	1	1	2	0.5	1	Equal	1		
Vulva	2	0	2	0	0.5	Left	1		
Bird	0	1	1	1	1	Right	1		
Fish	1	0	1	0	1	Left	1		
Fox	1	0	1	0	1	Left	1		
Hare	1	0	1	0	1	Left	1		
Snake	0	1	1	1	1	Right	1		

Table S15 – Orientation (left/right) of thematic representations in the analysed corpus. For each theme, the table reports the number of left- and right-oriented figures, total observations (n_total), proportion of right-oriented figures (prop_right), and results of binomial tests (p_binom) assuming a null hypothesis of equal left/right distribution. Direction indicates the dominant orientation. Adjusted p-values (p_adj_BH) were computed using the Benjamini–Hochberg procedure to control for false positives arising from multiple testing. Significant tendencies prior to correction are indicated (*), highlighting orientation biases particularly among the main structuring themes (bison, horse, ibex), while results should be interpreted cautiously given the limited sample size of several categories.

Test	ChiSquare	df	p_value	CramersV
Theme x Orient	35.86524446641723	20	0.015951566477681638	0.2816875680388624

Table S16 – Results of the chi-square test assessing the relationship between theme and left/right orientation for the full corpus.

Theme	Incl	std_resid	Theme	Incl	std_resid
Horse	Horizontal	4.8132021452144205	Horse	Inverted	-0.7067160064779591
Anthrop	Vertical	4.316002639929543	Aurochs	Vertical	-0.6597151579552
SFF	Vertical	4.316002639929543	Anthrop	Inclined	-0.6321758700558046
Horse	Vertical	-3.481227804428251	Saiga	Inclined	-0.6321758700558046
Flounder	Vertical	3.337692325134339	SFF	Inclined	-0.6321758700558046
Bison	Horizontal	-3.247840501635873	Vulva	Inclined	-0.6321758700558046
Fish	Vertical	3.0484894035604317	Hare	Horizontal	0.6052846142922127
Snake	Vertical	3.0484894035604317	Chamois	Vertical	-0.5706935063701202
Reindeer	Inclined	2.8716646576070692	Bear	Horizontal	0.5626910968825534
Horse	Inclined	-2.828516296216757	Ibex	Inverted	-0.5054647335286906
Anthrop	Horizontal	-2.344224875369118	Ibex	Vertical	-0.4837734303826662
Salmon	Horizontal	-2.344224875369118	Saiga	Vertical	-0.465451265090441

SFF	Horizontal	-2.344224875369118	Vulva	Vertical	-0.465451265090441
Bird	Inclined	2.244507132764737	Hind	Horizontal	-0.4492113066215751
Fox	Inclined	2.244507132764737	Fish	Inclined	-0.4465199866242846
Bison	Inclined	2.2003850804635117	Hare	Inclined	-0.4465199866242846
Bison	Vertical	2.0543399431632907	Snake	Inclined	-0.4465199866242846
Salmon	Vertical	1.9252756874195514	Unknown	Horizontal	-0.41482197071448235
Reindeer	Horizontal	-1.6778019690921566	Unknown	Inclined	0.3379779816613567
Bird	Horizontal	-1.6557785729811765	Bird	Vertical	-0.32875866116828184
Fish	Horizontal	-1.6557785729811765	Fox	Vertical	-0.32875866116828184
Fox	Horizontal	-1.6557785729811765	Hare	Vertical	-0.32875866116828184
Snake	Horizontal	-1.6557785729811765	Reindeer	Inverted	-0.21318999709587586
Unknown	Inverted	1.6402025041552188	Hind	Inverted	-0.20202138768833722
Flounder	Horizontal	-1.565943190468438	Unknown	Vertical	-0.17181306373243968
Ibex	Horizontal	1.5622284181174575	Bear	Inverted	-0.16439407246395932
Ibex	Inclined	-1.3836459560712828	Bison	Inverted	0.15775497987499268
Hind	Inclined	1.3636154232229902	Deer	Inverted	-0.14990261152025205
Deer	Horizontal	1.3594997945059244	Aurochs	Inverted	-0.1339272486707165
Salmon	Inclined	1.2727807517123533	Chamois	Inverted	-0.11585516903885441
Aurochs	Horizontal	1.2146157108275895	Flounder	Inverted	-0.11585516903885441
Chamois	Horizontal	1.050716040924294	Anthrop	Inverted	-0.09449018500208578
Reindeer	Vertical	-1.0501572607854717	Saiga	Inverted	-0.09449018500208578
Deer	Inclined	-1.0029064273645012	Salmon	Inverted	-0.09449018500208578
Hind	Vertical	-0.9951415638861046	SFF	Inverted	-0.09449018500208578
Aurochs	Inclined	-0.8960250734054696	Vulva	Inverted	-0.09449018500208578
Saiga	Horizontal	0.8569522958297986	Bird	Inverted	-0.06674053557206018
Vulva	Horizontal	0.8569522958297986	Fish	Inverted	-0.06674053557206018
Bear	Vertical	-0.8097923503910003	Fox	Inverted	-0.06674053557206018
Chamois	Inclined	-0.7751158735267941	Hare	Inverted	-0.06674053557206018
Flounder	Inclined	-0.7751158735267941	Snake	Inverted	-0.06674053557206018
Deer	Vertical	-0.7384085465693824	Bear	Inclined	0.004888266239368979

Table S17 – Standardised residuals from the χ^2 analysis of theme × inclination reveal non-random orientation patterns. Values ≥ |2| indicate over- or under-represented inclination categories for specific themes, highlighting differentiated graphic conventions in the depiction of zoomorphic and anthropomorphic figures.

S3.5. Co-occurrence and laterality analysis without "Saiga" and "Unknown"s

The third additional analysis consisted of repeating the statistical and network procedures after transforming "Saiga"-s in "Unknown" category, because of the discussion behind their controversial identification (Ruiz-Redondo, 2014). After, we removed both of them —given their subjective nature— to see if they might introduce noise or bias into the results.

The modified code is available in the following repository:

https://github.com/inakiintxaurbe/Rock-Art-Theme-Co-occurrence-Network/blob/main/Supplementary_codes/Script_without_saiga_and_unknown.R

The key modification is summarised in the following code snippet:

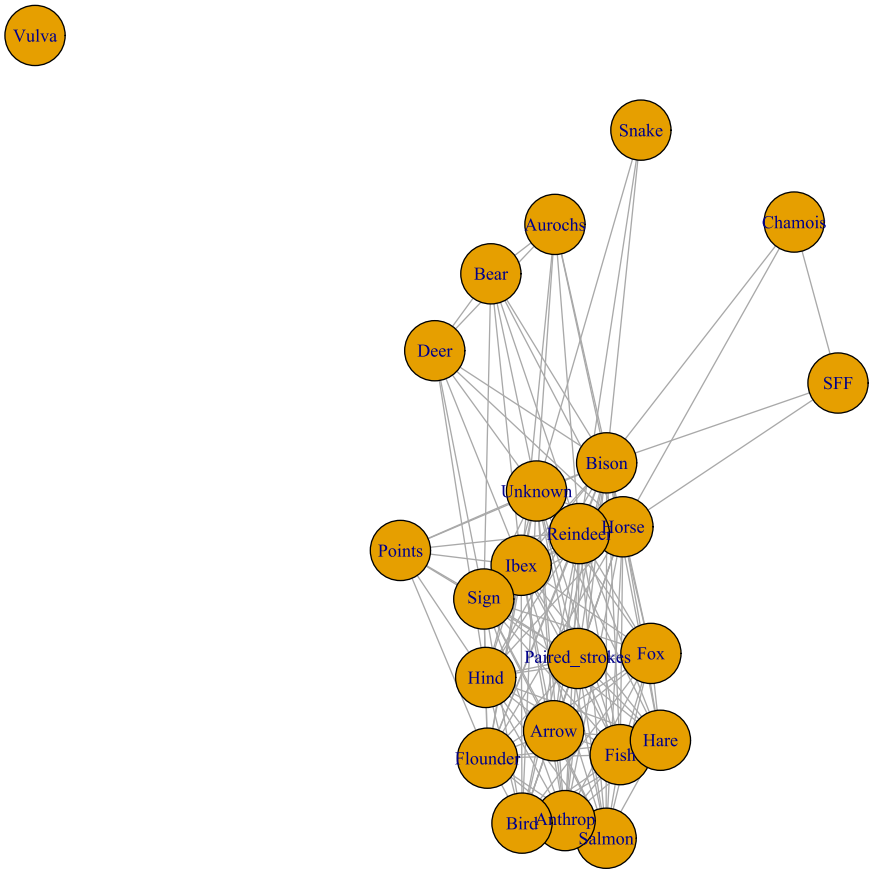
```
dat2 <- dat %>%
  transmute(
    GU    = as.character(GU),
    Theme = as.character(Theme)
  ) %>%
filter(Theme != "Unknown",
       Theme != "Saiga")
```

In this case, the `mutate()` function transforms all entries classified as "*Saiga*" in "*Unknown*".

This second filtering step ensures that indeterminate figures are excluded not only from co-occurrence analyses but also from the study of laterality and inclination, so that only well-defined thematic categories are considered.

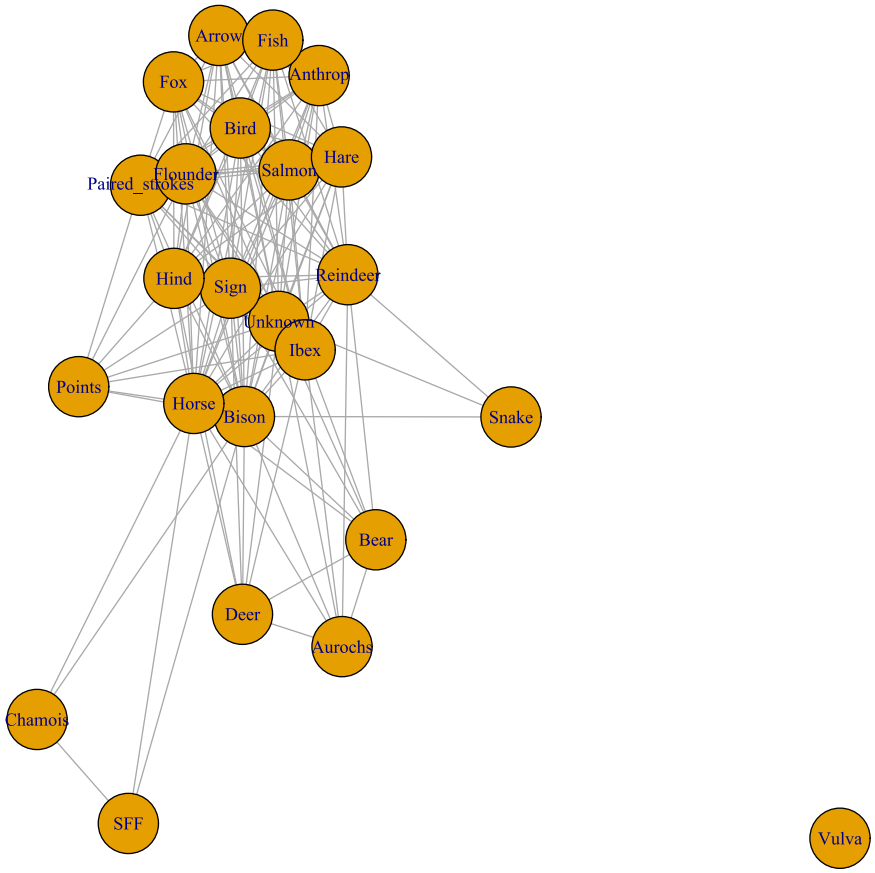
Since all scripts and outputs are fully accessible through the GitHub repository, we do not reproduce the Gephi network files here. Instead, we focus on assessing whether the exclusion of the "Unknown" category produces any significant structural changes. The figures presented in this section correspond to plots generated directly from the R environment using the following function:

```
plot(g)
# unfiltered co-occurrence network (jaccard-normalised)
```



or extract the corresponding frequency-weighted network, the following code was executed. The first line generates the network object, while the second produces its graphical representation:

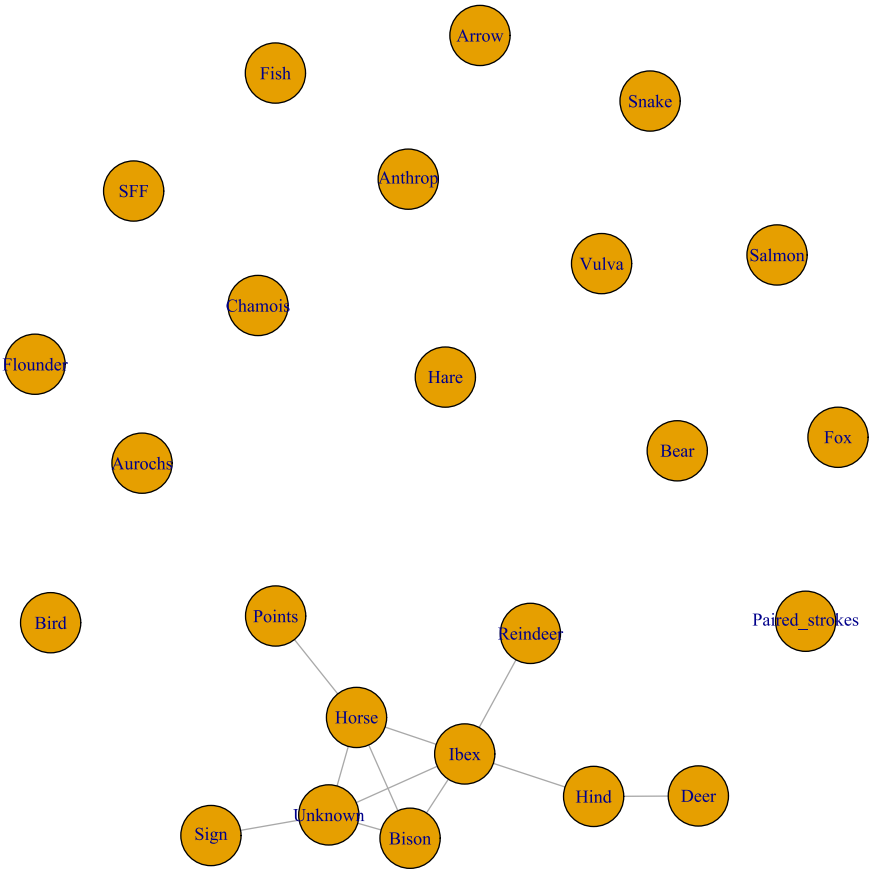
```
g2 <- graph_from_data_frame(edges_tt_weighted, directed = FALSE,
vertices = nodes)
plot(g2)
```



As observed, no substantial changes are detected in the overall network configuration following this modification. We next examine whether applying filtering thresholds—minimum co-occurrence frequency (min_weight = 3) and Jaccard similarity (min_jaccard = 0.12)—produces any notable structural differences.

To visualise the filtered network, the following code was used:

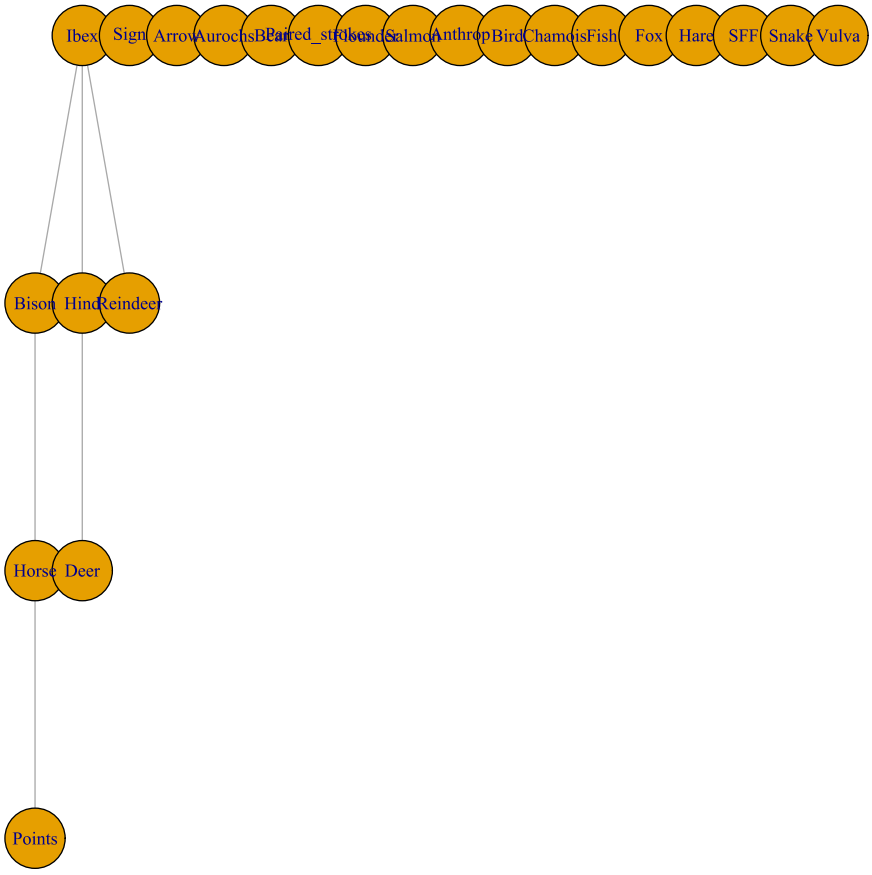
```
plot(g_filt)
```



In this network, no substantial changes are observed. The central structure remains organised around bison, ibex, and horse (with the expected exclusion of the “Unknown” category), together with a set of secondary elements, including points, signs, hind, deer, and reindeer.

To visualise the Minimum Spanning Tree (MST), the following line of code was executed:

```
plot(mst_g)
```



The MST, however, does show some changes. Ibex replaces bison at the top of the hierarchical structure, while reindeer and hind move up in relative position. In this configuration, bison acts as an intermediary node linking to horse representations.

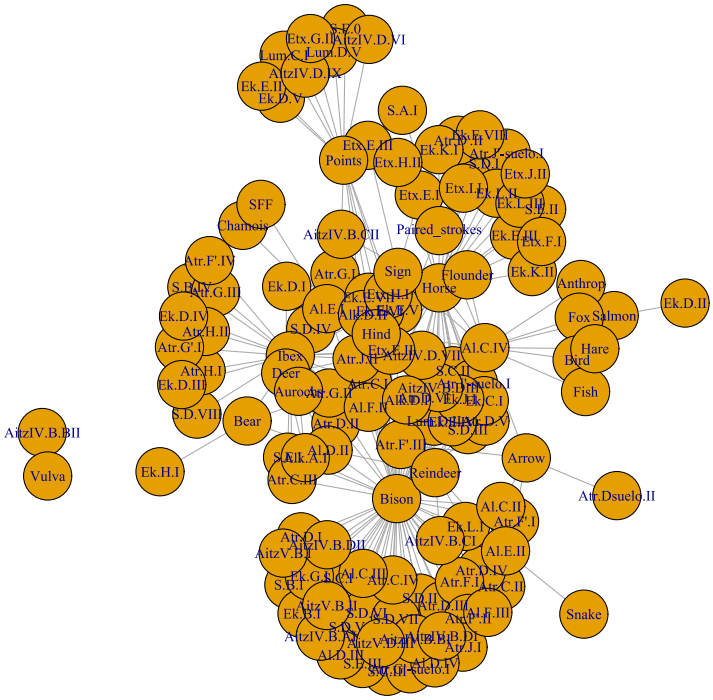
This result is likely influenced by the specific weight of the Atxurra assemblage, which is characterised by an unusually high number of ibex representations (Garate et al., 2020), including sectors almost exclusively devoted to this taxon (Intxaurbe et al., 2020). Comparable configurations—at least in large Late Glacial assemblages—are otherwise only documented in the western Cantabrian region (Asturias), particularly in the caves of El Covarón and El Bosque de Táranu (Ruiz-Redondo & Garate, 2014).

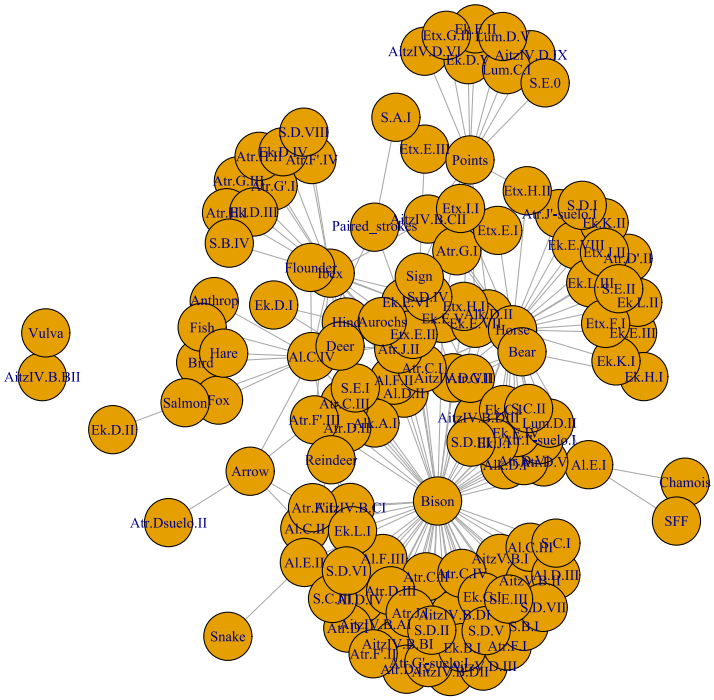
We then proceed to the bipartite analyses, starting with the binary bipartite network (presence/absence):

```
plot(g_bip_1)
```

To generate the count-weighted bipartite network (motif multiplicity), the following command was used:

```
plot(g_bip_2)
```


S.A.I
Points
Etx.E.III
Etx.H.III
Etx.J.II
Etx.I.I
Etx.E.I
Paired_strokes
Etx.F.I
Ek.K.II
Sign
Flounder
Horse
Anthrop
Fox.Salmon
Ek.D.II
Hare
Bird
Fish
Hind
Ibex
Deer
Aurochs
Bear
Reindeer
Arrow
Atr.Dsuelo.II
Bison
Snake
AitzIV.B.BII
Vulva
Ek.H.I
SFF
Chamois


S.A.I
Points
Etx.E.II
Etx.H.II
Etx.I.I
Paired_strokes
Etx.E.I
Atr.G.I
Sign
Flounder
Horse
Anthrop
Ek.D.I
Fish
Hare
Bird
Deer
Aurochs
Bear
Ek.K.I
Ek.H.I
Vulva
AitzIV.B.BII
Salmon
Fox
Ek.D.II
Arrow
Reindeer
Atr.Dsuelo.II
Bison
Chamois
SFF
Snake

Regarding the laterality analyses, the results are as follows:

Theme	Left	Right	n_total	prop_right	p_binom	direction	p_adj_BH	sig_Binom	sig_BH
Bison	119	82	201	0.4079601990049	0.010926428593989	Left	0.06949923169823025	*	
Horse	32	58	90	0.6444444444444	0.008045928133225	Right	0.06949923169823025	*	
Ibex	35	16	51	0.3137254901960	0.010973562899720	Left	0.06949923169823025	*	
Aurochs	4	0	4	0	0.125	Left	0.59375		
Reindeer	7	3	10	0.3	0.343750000000000	Left	1		
Hind	4	5	9	0.5555555555555	1	Right	1		
Bear	2	4	6	0.6666666666666	0.687499999999999	Right	1		
Deer	3	2	5	0.4	1	Left	1		
Chamois	2	1	3	0.3333333333333	1	Left	1		
Flounder	2	1	3	0.3333333333333	1	Left	1		
Anthrop	1	1	2	0.5	1	Equal	1		
SFF	0	2	2	1	0.5	Right	1		
Salmon	1	1	2	0.5	1	Equal	1		
Vulva	2	0	2	0	0.5	Left	1		
Bird	0	1	1	1	1	Right	1		
Fish	1	0	1	0	1	Left	1		
Fox	1	0	1	0	1	Left	1		
Hare	1	0	1	0	1	Left	1		
Snake	0	1	1	1	1	Right	1		

Table S18 – Orientation (left/right) of thematic representations in the analysed corpus. For each theme, the table reports the number of left- and right-oriented figures, total observations (n_total), proportion of right-oriented figures (prop_right), and results of binomial tests (p_binom) assuming a null hypothesis of equal left/right distribution. Direction indicates the dominant orientation. Adjusted p-values (p_adj_BH) were computed using the Benjamini–Hochberg procedure to control for false positives arising from multiple testing. Significant tendencies prior to correction are indicated (*), highlighting orientation biases particularly among the main structuring themes (bison, horse, ibex), while results should be interpreted cautiously given the limited sample size of several categories.

Test	ChiSquare	df	p_value	CramersV
Theme x Orient	34.1269840701595	18	0.012148324145670573	0.2939343940843267

Table S19 – Results of the chi-square test assessing the relationship between theme and left/right orientation for the full corpus.

Theme	Incl	std_resid	Theme	Incl	std_resid
Horse	Horizontal	4.867063165548497	Chamois	Inclined	-0.7716419858716385
Anthrop	Vertical	4.28361041606802	Flounder	Inclined	-0.7716419858716385
SFF	Vertical	4.28361041606802	Deer	Vertical	-0.7448323844321462
Horse	Vertical	-3.573363420841799	Aurochs	Vertical	-0.6653458759399545
Bison	Horizontal	-3.5471628015634864	Anthrop	Inclined	-0.6292409511229611
Flounder	Vertical	3.3101879139881842	SFF	Inclined	-0.6292409511229611
Fish	Vertical	3.0251236605344656	Vulva	Inclined	-0.6292409511229611
Snake	Vertical	3.0251236605344656	Hare	Horizontal	0.60248479008396
Reindeer	Inclined	2.8978133781517235	Chamois	Vertical	-0.5754710043634734
Horse	Inclined	-2.850315727068122	Bear	Horizontal	0.5540160362259542
Bison	Inclined	2.422395924791803	Horse	Inverted	-0.543903397871528
Anthrop	Horizontal	-2.356251368965666	Ibex	Vertical	-0.5208350994786989
Salmon	Horizontal	-2.356251368965666	Vulva	Vertical	-0.46927192760295733
SFF	Horizontal	-2.356251368965666	Hind	Horizontal	-0.4637684858531506

Bird	Inclined	2.2560604310365604	Fish	Inclined	-0.4443755394465952
Fox	Inclined	2.2560604310365604	Hare	Inclined	-0.4443755394465952
Bison	Vertical	2.0764778866925786	Snake	Inclined	-0.4443755394465952
Salmon	Vertical	1.9071692442325319	Ibex	Inverted	-0.3855283358525654
Reindeer	Horizontal	-1.6979162598698627	Bird	Vertical	-0.33140399651922514
Bird	Horizontal	-1.6640056107080805	Fox	Vertical	-0.33140399651922514
Fish	Horizontal	-1.6640056107080805	Hare	Vertical	-0.33140399651922514
Fox	Horizontal	-1.6640056107080805	Reindeer	Inverted	-0.16136898679057854
Snake	Horizontal	-1.6640056107080805	Hind	Inverted	-0.15288963339267955
Flounder	Horizontal	-1.5775925550402414	Bear	Inverted	-0.1243515667376897
Ibex	Horizontal	1.5477937730006321	Deer	Inverted	-0.11337130233508705
Hind	Inclined	1.3814056974791349	Aurochs	Inverted	-0.10127262191492918
Ibex	Inclined	-1.3728572722375216	Chamois	Inverted	-0.08759272365756143
Deer	Horizontal	1.3540880239695736	Flounder	Inverted	-0.08759272365756143
Salmon	Inclined	1.2826834772891131	Anthrop	Inverted	-0.07142811012736064
Aurochs	Horizontal	1.2095833925034083	Salmon	Inverted	-0.07142811012736064
Reindeer	Vertical	-1.0601699436192142	SFF	Inverted	-0.07142811012736064
Chamois	Horizontal	1.0461929575530018	Vulva	Inverted	-0.07142811012736064
Hind	Vertical	-1.0044618686503575	Bird	Inverted	-0.05044316475723805
Deer	Inclined	-0.9987365756167877	Fish	Inverted	-0.05044316475723805
Bison	Inverted	0.983678712733272	Fox	Inverted	-0.05044316475723805
Aurochs	Inclined	-0.892154094835223	Hare	Inverted	-0.05044316475723805
Vulva	Horizontal	0.8531254956599824	Snake	Inverted	-0.05044316475723805
Bear	Vertical	-0.8169710681046086	Bear	Inclined	0.014044441648040295

Table S20 – Standardised residuals from the χ^2 analysis of theme × inclination reveal non-random orientation patterns. Values ≥ |2| indicate over- or under-represented inclination categories for specific themes, highlighting differentiated graphic conventions in the depiction of zoomorphic and anthropomorphic figures.

S4. REFERENCES IN THE SUPPLEMENTARY INFORMATION

Altuna, J. (1997). Ekain y Altxerri. Dos santuarios paleolíticos en el País Vasco. Haranburu, San Sebastián.

Altuna, J. (1984). The prehistory of Ekain cave. Current Anthropology, 25(4), 529-530.

Altuna, J. (2019). Indusketa Arkeologikoak eta Haien Emaitza. In Agirre-Mauleon, J. (dir.),. Ekain, Aranzadi Bilduma, 4, Aranzadi Zientzia Elkartea, Donostia-San Sebastián, pp. 32-51.

Altuna, J., Apellaniz, J. M. (1976). Las figuras rupestres paleolíticas de la cueva de Altxerri (Guipúzcoa). Munibe, XXVIII. Sociedad de Ciencias Aranzadi, San Sebastián.

Altuna, J., & Apellaniz, J. M. (1978). Las figuras rupestres paleolíticas de la cueva de Ekain (Deva, Guipúzcoa). Munibe, XXX. Sociedad de Ciencias Aranzadi, San Sebastian.

Altuna, J., & Mariezkurrena, K. (2008). Nuevos hallazgos en la Cueva de Ekain (Gipuzkoa, País Vasco). Zephyrus, LXI, 17-32.

Altuna, J., Armendariz, A., Etxeberria, F., Mariezkurrena, K., Peñalver, X., & Zumalabe, F. (1995). Carta Arqueológica de Gipuzkoa. II. Cuevas. Munibe (Antropologia-Arkeologia), Suplemento 10, Sociedad de Ciencias Aranzadi, Donostia-San Sebastián.

Aranbarri, J., Arriolabengoa, M., Rios-Garaizar, J., Aranburu-Mendizabal, A., Uzquiano, P., Arranz-Otaegui, A., González-Sampériz, P., & Garate, D. (2023). Human Peopling and Vegetation Response to Upper Pleistocene-Middle Holocene Climate Variability in Northern Iberia: The Sedimentary Record of Atxurra Cave. Available at SSRN: https://ssrn.com/abstract=4585264 or http://dx.doi.org/10.2139/ssrn.4585264

Aranzadi, T., & Barandiarán, J. M. (1934). Contribución al estudio del arte moviliar magdalaniense del país vasco. Anuario de Eusko Folklore, 14, 213-234.

Aranzadi, T., & Barandiarán, J. M. (1935). Exploraciones de la caverna de Santimamiñe (Basondo, Cortezubi). 3ª memoria: yacimientos aziliense y paleolíticos. Exploraciones en la cueva de Lumentxa (Lequeitio), Imprenta de la Excma. Diputación de Bilbao, Bilbao.

Aranzadi, T., Barandiarán, J. M., & Eguren, E. (1925). Exploraciones de la caverna de Santimamiñe (Basondo-Cortézubi). I. Figuras rupestres, Artes Gráficas Grijelmo, Bilbao.

Aranzadi, T., Barandiarán, J. M., & Eguren, E. (1931). Exploración de la caverna de Santimamiñe (Basondo, Cortezubi) 2ª Memoria: Los niveles con cerámica y el conchero, Imprenta de la Diputación, Bilbao.

Aranzadi Zientzia Elkartea (2016). Caracterización del macizo y sistema kárstico de Alkerdi y de su entorno de protección. Tomo IV GEOLOGÍA. Urdazubi-Urdax, Nafarroa-Navarra. (*Umpublished rapport*).

Arribas Pastor, J. L., & Berganza Gochi, E, (2018). Excavaciones en la cueva de Lumentxa (Lekeitio, Bizkaia) Campañas de 1984 a 1993. Kobie (Serie Paleoantropología), 36, 1-26.

Arriolabengoa, M., Intxaurbe, I., Medina-Alcaide, M. Á., Rivero, O., Rios-Garaizar, J., Líbano, I., Bilbao, P., Aranburu, A., Cheng, H., Edwards, R. L., & Garate, D. (2020). From cave geomorphology to Palaeolithic

human behaviour: Speleogenesis, palaeoenvironmental changes and archaeological insight in the Atxurra-Armiña cave (northern Iberian Peninsula). Journal of Quaternary Science, 35(6), 841–853.

Arriolabengoa, M., Intxaurbe, I., González, J., & Garate, D. (2024). Cueva de Ekain. Caracterización Geológica. Arkeoikuska, 23, 352.

Barandiarán, J.M. (1961a). Excavaciones Arqueológicas en Vizcaya: Silibranka, Atxurra y Goikolau, Revista de la Excelentísima Diputación de Vizcaya 17. In Barandiarán, J.M. (Ed.), Obras Completas de José Miguel de Barandiarán XV, La Gran Enciclopedia Vasca, Bilbao, pp. 199–219.

Barandiarán, J.M. (1961b). Excavaciones en Aitzbitarte IV (trabajos de 1960). Munibe, 13, 183-285.

Barandiarán, J.M. (1963a). Excavaciones en Aitzbitarte IV (trabajos de 1961). Munibe, 15, 23-42.

Barandiarán, J.M. (1963b). Excavaciones en Aitzbitarte IV. (trabaos de 1962). Munibe, 15, 69-86.

Barandiarán, J. M. (1964a). La cueva de Altxerri y sus figuras rupestres. Munibe, XVI, 3/4, 91-141.

Barandiarán, J.M. (1964b). Excavaciones en la caverna de Aitzbitarte IV (Campaña de 1963). Munibe, 16, 12-23.

Barandiarán, J.M. (1965). Excavaciones en Aitzbitarte IV (Campaña de 1964). Munibe, 17, 21-37.

Barandiarán Maestu, I. (1967). El Paleomesolítico del Pirineo Occidental. Bases para una sistematización tipológica del instrumental óseo paleolítico. Monografías arqueológicas III. Universidad de Zaragoza, Zaragoza.

Barandiarán Maestu, I. (1974). Arte paleolítico en Navarra. Las cuevas de Urdax. Príncipe de Viana, 134/135, 9-47.

Barandiarán Maestu, I., Cava, A., & Elorrieta, I. (2010). Alternancia/complementariedad en la ocupación de las cuevas de Alkerdi y Berroberría. Cuadernos de Arqueología Universidad de Navarra, 18, 9-40.

Bayarri, V., Castillo, E., Ripoll, S., & Sebastián, M. A. (2021). Control of Laser Scanner Trilateration Networks for Accurate Georeferencing of Caves: Application to El Castillo Cave (Spain). Sustainability, 13(24), 13526.

Brunet, J., & Vidal, P. (1978). CAMOU-CIHIGUE - 64, Pyrénées-Atlantiques (Aquitaine). Etcheberriko-Kharbia. Protection des figurations préhistoriques. RAPPORT n° 457A. ministère de la Culture et de la Communication. Laboratoire de Recherche des Monuments Historiques, CHAMPS-SUR-MARNE.

Chalmin, E., Menu, M., & Altuna, J. (2002). Les matières picturales de la grotte d'Ekain (Pays Basque). Munibe, 54, 35-51.

Ebrard, D. (2013). Les grottes sepulcrales de Soule. In Ebrard, D. (coord.), 50 ans d'archéologie en Soule. Hommage à Pierre Boucher (1909-1997). Ikerzaleak, 7, Ikerzaleak, Mauleon, pp. 147-155.

Fano, M., Rivero, O., & Garate., D. (2012). Cueva de Ekain. Revisión arte paleolítico, I: Campaña. Arkeoikuska, 11, 339-341.

Fortea, F.J. (2007). 39 edades 14C AMS para el arte paleolítico rupestre en Asturias. In Excavaciones Arqueológicas en Asturias: 1999-2002, Principado de Asturias, Oviedo, pp. 91-102.

Fritz, C., Tosello, G., & Conkey, M. W. (2016). Reflections on the identities and roles of the artists in European Palaeolithic societies. Journal of Archaeological Method and Theory, 23(4), 1307–1332.

Galán, C. (1992). El río subterráneo de Ekain, su fauna hipogea, y la génesis de sus cuevas (macizo de Izarraitz, Gipuzkoa, País Vasco).
https://www.aranzadi.eus/fileadmin/webs/Publicaciones/pdfs/EKAIN.pdf (Accessed September 30, 2023).

Galán, C. (2011). Descripción del sistema de la cueva de Altxerri, plano digital georeferenciado y notas sobre su fauna hipógea (Orio, Gipuzkoa).
https://www.aranzadi.eus/fileadmin/webs/Publicaciones/pdfs/ALTXERRI.Total.pdf (Accessed September 30, 2023).

Garate, D. (2017). Los primeros artistas de Bizkaia. Las cuevas decoradas durante el Paleolítico. Kobie (serie Anejos), 15. Diputación Foral de Bizkaia, Bilbao.

Garate, D., & Rivero, O. (2015a). La 'Galería de los Bisontes': Un nuevo sector decorado en la Cueva de Alkerdi (Urdazubi/Urdax, Navarra). Zephyrus, 75, 17-39.

Garate, D., & Rivero, O. (2015b). Estudio del arte parietal paleolítico de la cueva de Alkerdi (Urdax, Navarra). (*Umpublished rapport*).

Garate, D., & Bourrillon, R. (2012). La grotte ornée d'Etxeberri (Camou-Cihige, Pyrénées-Atlantiques): un art audacieux. In Clottes J. (dir.), L'art pléistocène dans le monde / Pleistocene art of the world / Arte pleistoceno en el mundo, Actes du Congrès IFRAO, Tarascon-sur-Ariège, septembre 2010, Symposium « Art pléistocène en Europe ». N° spécial de Préhistoire, Art et Sociétés, Bulletin de la Société Préhistorique Ariège-Pyrénées, LXV-LXVI, 2010-2011, Société Préhistorique Ariège-Pyrénées, Tarascon-Sur-Ariège, pp. 193-207.

Garate, D., & Bourrillon, R. (2017). La grotte d'Etxeberri. In Garate, D., & Bourrillon, R. (coords.), Les grottes ornées du massif d´Arbailles (Soule, Pyrénées-Atlantiques) Etxeberri, Sinhikole et Sasiziloaga. Préhistoire du Sud-Ouest, 25-2017-2, Association Préhistoire du Sud-Ouest, Direction Régionale des Affaires Culturelles Occitanie et Nouvelle Aquitaine et du Conseil General du Lot, Cabrerets, pp. 149-189.

Garate D., & Rivero, O. (2026). Una nueva lectura para los grabados descubiertos por Norbert Casteret en la cueva de Alkerdi 1 (Urdazubi, Navarra). In Garate-Maidagan, D. & González Urquijo (coord.), Reflejos de una sociedad. Estudios sobre el Paleolítico superior en homenaje al profesor César González Sainz. Ediciones Tantín, Santander, pp. 379-389.

Garate, D., Rios-Garaizar, J., & Ruiz-Redondo., A. (2013a). El arte parietal paleolítico de la cueva de Lumentxa (Lekeitio, Vizcaya). Kobie (serie paleoantropología), 32, 5-28.

Garate, D., Ríos-Garaizar, J., Ruiz-Redondo, A., & Tapia, J. (2013b). Evidencias de arte parietal paleolítico en la cueva de Aitzbitarte IV (Errenteria, Gipuzkoa), Munibe (Antropologia-Arkeologia), 64, 33-42.

Garate, D., Rivero, O., Ruiz-Redondo, A., & Rios-Garaizar, J. (2015a). At the crossroad: A new approach to the Upper Palaeolithic art in the Western Pyrenees. Quaternary international, 364, 283-293.

Garate, D., González Sainz, C., López Quintana, J.C., Guenaga Lizasu, A., García Gamero, A., Aranzabal Gaztelu, G., & Medina-Alcaide, M.Á. (2015b). Arte parietal paleolítico en Morgotako Koba (Kortezubi, Bizkaia). In López Quintana, J. C. (coord.) La cueva de Morgota (Kortezubi, Bizkaia): evaluación arqueológica y estudio del conjunto parietal paleolítico, Kobie (Serie BAI), 5, Diputación Foral de Bizkaia, Bilbao, pp. 57-74.

Garate, D., Rios-Garaizar, J., Rivero, O., & Felix Ugarte Elkartea (2016). Trois nouvelles grottes ornées à Aitzbitarte (Pays Basque). International Newsletter of Rock Art, 75, 1-5.

Garate, D., Rivero, O., Ríos-Garaizar, J., Arriolabengoa, M., Medina-Alcaide, M. Á., Ruiz-López, J. F., Intxaurbe, I., Salazar, S., & Libano, I. (2020a). The cave of Atxurra: A new major Magdalenian rock art sanctuary in Northern Spain. Journal of Archaeological Science: Reports, 29, 102120.

Garate, D., Rivero, O., Rios-Garaizar, J., Intxaurbe, I., & Salazar, S. (2020b). Modelled clay animals in Aitzbitarte IV Cave: A unique Palaeolithic rock art site in the Cantabrian Region. Journal of Archaeological Science: Reports, 31, 102270.

Garate, D., Rivero, O., Rios-Garaizar, J., Intxaurbe, I., & Salazar, S. (2020c). Arte parietal paleolítico en la cueva de Aitzbitarte V (Errenteria, Gipuzkoa): un nuevo conjunto diacrónico en la Región Cantábrica oriental. Trabajos de Prehistoria, 77(2), 320-336.

Garate, D., Rivero, O., Rios-Garaizar, J., Arriolabengoa, M., Intxaurbe, I., & Salazar, S. (2020d). Redefining shared symbolic networks during the Gravettian in Western Europe: New data from the rock art findings in Aitzbitarte caves (Northern Spain). PLoS ONE, 15(10), e0240481.

Garate, D., Rivero, O., Rios-Garaizar, J., Medina-Alcaide, M. Á., Arriolabengoa, M., Intxaurbe, I., Ruiz-López, J. F., Marín-Arroyo, A. B., Rofes, J., García Bustos, P., Torres, T., & Salazar, S. (2023). Unravelling the skills and motivations of Magdalenian artists in the depths of Atxurra Cave (Northern Spain). Scientific Reports, 13(1), 17340.

Garate, D., Arriolabengoa, M., Intxaurbe, I., Salazar, S., Torres, A., Cheng, H., & Pérez-Mejías, C. (2025). Cave art resilience: An interdisciplinary proposal for monitoring the state of conservation in Santimamiñe, Lumentxa, and Altxerri heritage sites (northern Iberian peninsula). Archaeometry, 67(5), 1061-1080.

González Sainz, C. (2005). Sobre la actividad gráfica magdaleniense en la región cantábrica. Datación y modificaciones iconográficas. In Corchón, M. S., & Bicho, N. (eds.), O Paleolítico, Actas do IV Congresso de Arqueología Peninsular Promontoria Monográfica 2, Universidade do Algarbe, Faro, pp. 157-181.

González Sainz, C. (2016/17). En el límite de lo figurativo. Posibles representaciones femeninas del Magdaleniense reciente en la Cámara de Santimamiñe y en la Galería C de La Pasiega, Kobie (Serie Paleoantropología), 35, 99-114.

González Sainz, C., & Ruiz Idarraga, R. (2010). Una nueva visita a Santimamiñe: precisiones en el conocimiento del conjunto parietal paleolítico. Kobie (Serie Anejos), 1. Diputación Foral de Bizkaia, Bilbao.

González Sainz, C., Cacho Roca, R., & Altuna, J. (1999). Una nueva representación de bisonte en la cueva de Ekain (País Vasco). Munibe (Antropologia-Arkeologia), 51, 153-159.

González-Sainz, C., Ruiz-Redondo, A., Garate-Maidagan, D., & Iriarte-Avilés, E. (2013). Not only Chauvet: Dating Aurignacian rock art in Altxerri B Cave (northern Spain). Journal of Human Evolution, 65(4), 457-464.

Holt, B. M. (2003). Mobility in Upper Palaeolithic and Mesolithic Europe: Evidence 656 from the lower limb. American Journal of Physical Anthropology: the Official Publication of the American Association of Physical Anthropologists, 122(3), 200-215.

Hoyos, M. (1993). Procesos de alteracion de soporte y pintura en diferentes cuevas con arte rupestre del norte de España: Santimamiñe, Arenaza, Altamira, y Llonín. In Fortea, J. (coord.), La Protección y conservación del arte rupestre paleolítico: Mesa Redonda Hispano-Francesa: Colombres, Asturias 2 al 6 de junio de 1991, Gobierno del Principado de Asturias, Oviedo, pp. 51-74

Intxaurbe, I. (2024). The exploration and appropriation of the underground environment in the Palaeolithic: an approach from geology and rock art. PhD Thesis, Universidad del País Vasco / Euskal Herriko Unibertsitatea, Leioa.

Intxaurbe, I., Rivero, O., Medina-Alcaide, M. Á., Arriolabengoa, M., Ríos-Garaizar, J., Salazar, S., Ruiz-López, J.F., Ortega-Martínez, P., & Garate, D. (2020). Hidden images in Atxurra Cave (Northern Spain): A new proposal for visibility analyses of Palaeolithic rock art in subterranean environments. Quaternary International, 566, 163-170.

Intxaurbe, I., Arriolabengoa, M., Medina-Alcaide, M. Á., Rivero, O., Rios-Garaizar, J., Salazar, S., Líbano, I., & Garate, D. (2021). Quantifying accessibility to Palaeolithic rock art: methodological proposal for the study of human transit in Atxurra Cave (Northern Spain). Journal of Archaeological Science, 125, 105271.

Intxaurbe, I., Garate, D., Arriolabengoa, M., & Medina-Alcaide, M. Á. (2022). Application of Line of Sight and Potential Audience Analysis to Unravel the Spatial Organization of Palaeolithic Cave Art. Journal of Archaeological Method and Theory, 29(4), 1158-1189.

Intxaurbe, I., Arriolabengoa, M., Garate, D., Cheng, H., & Pérez-Mejías, C. (2023a). Virtual reconstruction of the Palaeolithic landscape in Santimamine cave (Bizkaia, Spain). Journal of Archaeological Science: Reports, 52, 104219.

Intxaurbe, I., Garate, D., Arriolabengoa, M., Rivero, O., & Medina-Alcaide, M. Á. (2023b). Ilunpeetako sekretuak argiztatzen. Santimamiñe, Altxerri eta Etxeberriko kobazulo apainduen ikerketa arkeologiko espaziala eta zabalkuntza 3D erreplika birtualen bidez. Barandiaran Bilduma. 23, Fundación José Miguel de Barandiarán, Vitoria-Gasteiz.

Laval, E., Garate, D., & Bourrillon, R. (2017). L'étude de la matière colorante. In Garate, D., & Bourrillon, R. (coords.), Les grottes ornées du massif d´Arbailles (Soule, Pyrénées-Atlantiques) Etxeberri, Sinhikole et Sasiziloaga. Préhistoire du Sud-Ouest, 25-2017-2, Association Préhistoire du Sud-Ouest, Direction Régionale des Affaires Culturelles Occitanie et Nouvelle Aquitaine et du Conseil General du Lot, Cabrerets, pp. 189-198.

López Quintana, J. C. (Dir.) (2011). Cueva de Santimamiñe: revisión y actualización (2004-2006). Kobie (Serie BAI), 1. Diputación Foral de Bizkaia, Bilbao.

Maeztu, J., & Aranzabal, G. (2011). La caverna de Santimamiñe y su entorno geográfico. In López Quintana, J. C. (dir.) Cueva de Santimamiñe: revisión y actualización (2004-2006), Kobie (Serie BAI), 1, Diputación Foral de Bizkaia, Bilbao, pp. 411-420.

Manteca, J., Muñoz, R., Mutiloa, I., Sansinenea, K., & Santafosta, M. (1997). Estudio espeleológico de Aitzbitarte. Munibe (Ciencias Naturales - Natur zientziak), 49, 3-47.

Medina-Alcaide, M. Á. (2020). Lighting the Darkness of the Caves with Palaeolithic Art: an Integral and Interdisciplinary Vision of the Internal Archaeological Context and the Wood Charcoals. PhD Thesis. Euskal Herriko Unibertsitatea, Vitoria-Gasteiz.

Moure, A., & González Sainz, C. (2000). Cronología del arte paleolítico cantábrico: últimas aportaciones y estado actual de la cuestión. In Actas do 3º Congresso de Arqueologia Peninsular (Vila Real, 1999). Paleolítico da Península Ibérica, Vol. II. ADECAP, Porto, pp. 461-473.

Neufert, E. (1951). Bauentwurfslehre. Grundlagen, Normen und Vorschriften über Anlage, Bau, Gestaltung, Raumbedarf und Raumbeziehungen: Maße für Gebaüude, Raüume, Einrichtungen und Geräte mit dem Menschen als Maß und Ziel, Tempelhof, Berlin.

Ochoa, B., & García-Diez, M. (2018). The use of cave art through graphic space, visibility and cave transit: a new methodology. Journal of Anthropological Archaeology, 49, 129-145.

Ochoa, B., Vigiola-Toña, I., García-Diez, M., & Garrido-Pimentel, D. (2018). Más que pinturas de caballos en la Cueva de Ekain (Deba, Gipuzkoa): los grabados digitales paleolíticos en Europa Occidental. Trabajos de Prehistoria, 75(1), 146-154.

Ochoa, B., Vigiola-Toña, I., & García-Diez, M. (2019). Coming back to Ekain (Deba, Gipuzkoa): a new Upper Palaeolithic graphic ensemble in the Erdibide Passage. Munibe (Antropologia-Arkeologia), 70, 65-71.

Ochoa, B.; García-Díez, M.; & Ruiz-González, D. (2021). Cueva de Ekain. Arkeoikuska, 20, 292-294.

Pastoors, A., & Weniger, G.C. (2011). Cave art in context: methods for the analysis of the spatial organization of cave sites. Journal of Archaeological Research, 19(4), 377-400.

Rios-Garaizar, J. (2011). El nivel IXb de Ekain (Deba, Gipuzkoa, Región Cantábrica): Una ocupación efímera del Auriñaciense Antiguo. Munibe (Antropologia-Arkeologia), 62, 87-100.

Rios-Garaizar, J., Garate, D., & Bourrillon, R. (2017). Le contexte archéologique. In Garate, D., & Bourrillon, R. (coords.), Les grottes ornées du massif d´Arbailles (Soule, Pyrénées-Atlantiques) Etxeberri, Sinhikole et Sasiziloaga. Préhistoire du Sud-Ouest, 25-2017-2, Association Préhistoire du Sud-Ouest, Direction Régionale des Affaires Culturelles Occitanie et Nouvelle Aquitaine et du Conseil General du Lot, Cabrerets, pp. 199-206.

Rios-Garaizar, J., San Emeterio, A., Larrea, M., Marín-Arroyo, A. B., Agudo, L., Cubas, M., & Garate, D. (2019). La secuencia prehistórica de la cueva de Atxurra (Berriatua, Bizkaia): evaluación de las excavaciones de JM Barandiarán Ayerbe (1934-1935). Munibe (Antropologia-Arkeologia), 70, 21-34.

Rios-Garaizar, J., San Emeterio, A., Arriolabengoa, M., Aranbarri, J., Rofes, J., Marín-Arroyo, A. B., Rivero, O., Intxaurbe, I., Arranz-Otaegui, A., Salazar, S., Medina-Alcaide, M. Á. & Garate, D. (2020). Sporadic occupation in Armiña cave during the Upper Magdalenian: what for?. Journal of Archaeological Science: Reports, 30, 102271.

Rivero, O. (2010). La movilidad de los grupos humanos del Magdaleniense en la región cantábrica y los Pirineos: una visión a través del arte. PhD Thesis. Universidad de Salamanca.

Rivero, O., Garate, D., Salazar, S., & Intxaurbe, I. (2019). The Cantabrian Lower Magdalenian striated hinds on scapulae: Towards a new definition of a graphic morphotype. Quaternary International, 506, 69-79.

Ruiz Idarraga, R. (1987). Avance al estudio del nivel VIII de la cueva de Santimamiñe. Kobie (Serie Paleoantropología), 16, 133-142.

Ruiz Redondo, A. (2014). Entre el Cantábrico y los Pirineos: el conjunto de Altxerri en el contexto de la actividad gráfica magdaleniense. PhD Thesis. Universidad de Cantabria. Nadir, Santander.

Ruiz-Redondo, A., & Garate, D. (2014). Variabilidad temática en el arte gurativo magdaleniense de la Cornisa Cantábrica: el caso de la sierra de Cuera (Asturias). In Corchón, M.S., & Menéndez, M. (eds.), Cien años de arte rupestre paleolítico: centenario del descubrimiento de la cueva de la Peña de Candamo (1914-2014). Acta Salmanticensia. Estudios históricos y geográficos; 160, Universidad de Salamanca, Salamanca, pp. 143-154.

Straus, L.G. (1983). El Solutrense vasco-cantabrico: una nueva perspectiva. Centro de Investigación y Museo de Altamira, Madrid.

Utrilla, P. (1981). El Magdaleniense Inferior y Medio en la Costa Cantábrica. Monográficos del Centro de Investigaciones y Museo de Altamira, 4, Ministerio de Cultura, Santander.

Utrilla, P. (1986). La varilla pseudoexcisa de Aitzbitarte IV y sus paralelos franceses. In Estudios en Homenaje a Antonio Beltrán, Facultad de la Filosofía y Letras, Zaragoza, pp. 205-225.

Vanara, N. (2000). Le karst des Arbailles (Pyrénées-Atlantiques, France). Karstologia, 36(1), 23-42.