Experimental study of the aerophone of Isturitz: Manufacture, use-wear analysis and acoustic tests

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Abstract

In order to evaluate the musical performance of the most complete Gravettian aerophone recovered at the site of Isturitz, two experimental replicas were reproduced from the ulna of a griffon vulture (*Gyps fulvus*), each with a different way of elaborating their holes (boring and scraping). The operational chain that involves their manufacture is a sequence of single and simple actions that does not require the use of specialized tools. Its acoustics are explained by performing sound in three different ways in both replicas.

Keywords: Isturitz, Aerophone, Operational chain, Use-wear analysis, Acoustics, Sound

1. Introduction

The presence of marks of anthropic origin, such as cuts, fractures or scrapes, observed on skeletal parts, which would have had scant or no meat attached, in species of birds considered to be of no particular interest for consumption (raptors and corvids), and the remains of feathers on some tools, suggest a possible use of avian resources for non-consumption purposes in European contexts of the Middle Palaeolithic (Mourer-Chauvire, 1975, 1989; Hardy et al., 2001; Fiore et al., 2004; Soressi et al., 2008; Dibble et al., 2009; Gaudzinski and Niven, 2009; Laroulandie, 2010; Hardy and Moncel, 2011; Peresani et al., 2011; Finlayson et al., 2012; Morin and Laroulandie, 2012; Romandini et al., 2014). This use has been related to symbolic behaviour, which does not seem to be either systematic or regular. The interpretation is suggestive, albeit speculative, since all the evidence handled is indirect and circumstantial. Hence, for the time being, such uses are not openly recognized until the arrival of modern humans and the development of complexes associated to the Upper Palaeolithic, from the Aurignacian onwards. The use of long bones, ulnas and radii, with regularly aligned holes, are considered the first musical instruments in the archaeological record (Fages and Mourer-Chauvi e, 1983; Conard et al., 2009).

The assemblage of remains with these characteristics is worth discussing. There is not always a concurring opinion on the true nature of some of the evidence: due to the lack of appearance of the bone carrying the perforations, the doubtful origin of the holes -anthropogenic or not-, or both. We believe that there are 14 sites that have provided evidence of this kind, yielding a total of 40 tubes in bone and ivory (Conard, 2007a, 2007b; Conard and Malina, 2008), the vast majority of which are highly fragmented (Table 1). Of that total, 23 were performed on bird radii or ulnas: swan (*Cygnus cygnus*), golden eagle (*Aquila chrysaetos*), bearded vulture (*Gypaetus barbatus*), and to a greater degree vultures (*Aegypius monachus* and *Gyps fulvus*); ten more may also belong to this group, although the fragments do not allow for a precise taxonomic classification. Of the total, 17, along with another possible five, are known to have originated from the French cave of Isturitz (Saint Martin d'Arberoue). Their number and the fact that their presence is recorded throughout all levels of the Upper Palaeolithic, makes the series of Isturitz unique. Recovered in excavations by E. Passemard between 1912 and 1922 and by R. and S. Saint-Perier between 1928 and 1950, the set was reviewed four decades later by D. Buisson (1990, 1994). However, the total estimate of the remains is not straightforward (Morley, 2013). D. Buisson excluded from his study five fragments with doubtful perforations or lacking them entirely, two of which appear in the well-documented article of Lawson and d'Errico (2002). Considering surface treatment or the work on some of the extremities, they could well be compared to the analysed remains. He also excluded an unspecified number of pipes with one perforation, arguing another use for the artefacts, because the hole was too close to a worked extremity. The total of perforated pipes described were 21, although in the figure that recapitulates the remains by levels, 22 are drawn. In our table, there are 22 entries for a total of 23 remains, including the 21 described by Buisson and the remains labelled as Ist SP52C and Ist SP52E (Scothern, 1992). In our opinion the fragment that Buisson included in that figure without description, the same one as in Saint-P eerier and Saint-Perier (1952, Table VII below left) is Ist SP52C, since they coincide in length, as deduced from the drawing of Buisson. However Morley (2013) assimilates it to Ist SP52. Hence, we believe that there are 23 fragments of perforated pipes, of which 2, the F3a 1914 and 75252 A3-Ist. 1939 83888 III are parts of a same, complete instrument.

Table 1. Aerophones with holes for musical fingering. * Does not include specimens made in similar tubes and identified already as whistles, ex.: Bolinkoba, Gourdan (2 examples), Goyet 132, Gudenush€ohle, Horodnica, Le Placard (several examples), Le Roc-de-Marcamps (4 examples), Pekarna (3 examples), etc., or other types of instruments such as kazoos (mirliton), ex.: Isturitz, Le Placard or Saint-Marcel, and buzz-bones, ex.: Les Roches, etc; at one time they were incorrectly assigned to this group. ** Does not include the piece from Laraux, which can be interpreted as a whistle or mouthpiece of a flute thatwas manufactured in plant material. There are other similar examples of later chronology, ex.: Inzihogten (Neolithic), Saviese (Chalcolithic) and Kalenberg (Iron Age).

The upper fragment was recovered by Passemard in 1914 from level F3 of Grande Salle or Salle d'Isturitz and remained unpublished until the revision of Buisson in 1990, while the lower one was recovered by R. and S. Saint-Perier in 1939 from level III. The validity of the stratigraphic divisions established in those excavations has raised some doubts, which have reduced the accuracy of the stratigraphic and cultural attribution of the remains. H. Delporte has already established a stratigraphic equivalence between sequences of both excavations and both halls (Salle Grande or Salle of Saint-Martin), correlating Passemard F3 and C levels to levels IV and III of R. and S. Saint-Perier (Delporte, 1974 and, 1980e1981). More recently other researchers have also offered critical readings for parts of this stratigraphic sequence (Esparza San Juan, 1990; for clarification. As a result, the perforated pipe in question, as most of those recovered, should be assigned to the Gravettian period. Only one belongs to an Aurignacian chronology and four are divided between the Solutrean and Magdalenian.

The morphology of the pipes and the presence of aligned and regularly spaced holes, both in Isturitz artefacts and others of similar nature from other archaeological sites, classify these objects as flutes, a musical instrument in the family of the aerophones. So it has been repeatedly stated in publications (Piette,1874; Passemard, 1923; Buisson, 1990; Münzel et al., 2002; Horusitzky, 2004; or Conard et al., 2009; among others), although variants have been proposed for the way they were played, according to the degree of simplicity of their mouth, organic or mineral matter added, or the position of the instrument (Absolon, 1936e1937; Buisson, 1990, 1994; Le Gonidec et al., 1996).

Aerophone F3a 1914 75252/A3-Ist. III 1939 83888, a piece considered virtually complete, constitutes from an organological point of view an ideal instrument to assess performance and potential uses. It is not surprising that various studies have been performed on this archaeological remain in the sound/musical field. These have centred mainly on its use as a flute, exploring different modalities of mouthpieces and bevels notch, fipple (recorder), or end-blowe and instrument position straight, oblique or transversal (Absolon, 1936e1937; Buisson, 1990, 1994; Buisson and Dartiguepeyrou, 1996; Le Gonidec et al., 1996; Lawson and d'Errico, 2002, pp. 122e124; Dauvois, 2005e2006; Wyatt, 2012; García Benito, 2014). A possible use as lip reed instrument in the manner of a horn or trumpet has also been suggested (Le Gonidec et al., 1996;

Lawson and d'Errico, 2002; Wyatt, 2012; García Benito, 2014); yet also as a reed instrument like a clarinete (Lawson and d'Errico, 2002; Wyatt, 2012; García Benito, 2014).

2. Used materials

Our inquiry into the musical sound capacity and performance of this perforated pipe was preceded by the production of two replicas, as close to the original piece as possible. In some of the works cited above, replicas were also made for this aerophone, although with varying degrees of fidelity. One was created from a vulture ulna, but did not section its proximal epiphysis (Le Gonidec et al., 1996), for which the information on the manufacturing process is also provided (Buisson and Dartiguepeyrou, 1996); another used synthetic material (Lawson and d'Errico, 2002), and more recently, the unrealistic replica conducted by Wyatt (2012) appeared in a paper that nevertheless opened a wide range of organological possibilities.

The most important part in the manufacture of a perforated pipe is the tube. The ulnas of birds, and among them, some diurnal raptors, in the Accipitridae family, represent a significant volume of all known prehistoric perforated pipes. Its features cover all desired requirements: they are long and narrow bones, with a slightly flared shape, and an internal and very regularly cavity, so that the air flows unhindered. Furthermore, the limited thickness of the bone tissue allows for them to be easily worked. Bones are better preserved through time than other materials with similar characteristics, such as cylindrical, hollow stems of certain plants, or the calamus of some feathers, which may have reasonably served this purpose too, although their remains have not reached us.

The original aerophone seems to have been worked on a left ulna of a bearded vulture (*Gypaetus barbatus*) (Buisson, 1990). While its specific attribution becomes complicated, once bone epiphyses are not preserved, and although in Isturitz griffon or black vulture (*Gyps fulvus* or *Aegypius monachus*) bones were more commonly used, the only safe tipometric values that can be obtained from the bone fall within the ranges of the bearded vulture. Indeed, the width and thickness at the level of the nutrient foramen fall below the values of the vulture, which is a larger species (Fig. 1). Although the bearded vulture lives in parts of Aragon (Spain), it is an endangered species and access to its skeletal remains is not allowed. We were thus forced to use one right and left ulna from two adult griffon vultures. The difference in size between species leads to the only difference between the original aerophone and our replica: our tubes are 2e3 mm larger in diameter than the archaeological artefact. The length, size and arrangement of the holes are in strict conformity to the original (Fig. 2).

The bones, defleshed naturally and dry, were worked in these conditions, employing at different stages flakes, blades and some retouched pieces made in flint of very good quality, extracted from the area between the towns of Botorrita, Muel and Fuendetodos in the Middle Ebro Valley, south of the city of Zaragoza. There, it is possible to obtain nodules that although varying in size, morphology and colour, are all of extraordinary quality, of very fine grain and a smooth touch that respond very well to transformation. They are found stratified among Miocene white limestone units of San Caprasio and Montes de Castejón, which crown the structural platforms of La Muela and La Plana Muel-Jaulín, and also in secondary structures of the Huerva river terraces and glacis, which extends along its banks (Leorza, 2013; Mazo, 2013). The quality and abundance of the quarry is attested by its exploitation in the late eighteenth century, when two million pieces of gunflint were produced every year at the village of Botorrita; evidence for this activity is numerous.

Finally, our replicas differ in the way the holes were made, a feature we chose to compare, even if it did not result in any musical variation. The elaboration of holes in Isturitz pipes did not follow a fixed method, although perforation by rotation with a tool (used as a perforator or drill) was the least common. Another example is found in one of the most complete objects preserved (Buisson, 1990: fig. 5; Lawson and d'Errico, 2002: plate III). On the ventral surface of the bone, a convex surface (not flat as a dorsal), holes were made by rotation, or at least were completed in this way, without leaving traces of any previous work. Sometimes the bone was prepared by a recess or thinning of the wall by scraping, as performed by Buisson and Dartiguepeyrou (1996). The most common way of making the holes was by scraping and thinning of the walls (even when working on flat surfaces, such as the dorsal of vulture ulnas), as in the original artefact and our aerophone 2, or by means of successive and numerous incisions. In some cases, both techniques may be observed on the same tube, as in Pair-non-Pair (García Benito, 2014).

3. Aerophone reproduction: phases, tools and work traces

3.1. Phases

We used a total of 11 lithic pieces of flint: eight in the reproduction of aerophone 1 and three for aerophone 2. A total of 23 active areas were defined and documented photographically before work, of which 16 were finally used throughout the various stages of production (Tables 2 and 3). After being used, they were analysed to determine and register macroscopic and microscopic alterations, which are well known since the 1970s and 1980s (Tringham et al., 1974; Keeley, 1980; Plisson, 1985; Vaughan, 1985; Mazo, 1991). A binocular microscope Nikon SMZ 10 was used (in magnitudes between 6 and 40x), as well as a metallographic microscope Nikon Optiphot (between 100 and 400x). The images were taken with two digital cameras (5 Mpx), acquired from the Poli-eye series of Qualites.net: one for the microscope (PL-SM055-5) and the other for the binocular microscope (PL-SM055C-5) and DinoCapture 2.0 software. Changes observed on the surfaces of the bones were also controlled and recorded.

Fig. 1. Ulnas of adult black vultures (1 and 2), griffon vulture (3 and 4), bearded vulture (5) and golden eagle (6), placed, locating the nutrient foramen at the same height (white lines). The difference between the black vulture and the griffon vulture is clearly noticeable in the greater depth of the incisura radialis and *brachialis impressio* on the proximal epiphysis (top right); and of the *depressio radialis* in the distal (bottom right). In cases where the epiphyses are not preserved, the estimated distance between the distal end of the nutrient foramen and the tuberculum carpale (in the distal epiphysis), used to determine whether the bone belonged to a black vulture (*Aegypius monachus*) or to a griffon vulture (*Gyps fulvus*) may lead to misclassifications, as evidenced by ulna 3.

Fig. 2. Reproductions. Aerophone 1 (left) and 2 (right).

Table 2. Lithic artefacts used; colour; size; active areas; used areas; action; and duration of use (time). *Retouched while in use.

Table 3. Stages of the manufacture of replicas with the use of different tools and active areas. *Angle generated by the edges/Angle generates by the faces. From 0 (null) to 5 (maximum), degree of development of chipping, micropolish and effectiveness of the piece.

Ten phases were identified for the aerophone elaboration process; these phases are compared in Fig. 3; the same person carried out the manufacture in both cases. It should be noted that the tools were applied with intensity (even if only for a short time), as effectively as possible, taking full advantage of them in clearly realistic actions, regardless of how they could be affected.

3.1.1. Stage 1

The first stage of intervention on bone involves planning or scraping of the diaphysis, in order to clean the bone, reducing, if necessary, insertion tubercles of secondary feathers (papillae remigalis ventralis and caudalis). The result of this action is the modification of the bone surface, which changes in appearance especially at the microscopic level, from moderately rough and rather matte (Fig. 4(1)) to smooth and soft to the touch, shiny and micro faceted. The surface recorded traces of this action in the form of numerous, long bundles of parallel striae (Fig. 4(3)), on which occasional grooves were observed, much wider and deeper than what corresponds to an involuntary variation in the movement of the tool, usually caused by uncontrolled lateral displacements. For aerophone 1, a burin facet edge was used, applied on an active area of 81º, with unidirectional, transversal movements, with a low contact angle. In aerophone 2, two unretouched flakes were used, with active areas of 25 and 70%, and applying bidirectional transversal movements with contact angles of about 90%.

3.1.2. Stages 2-5

Stages 2 and 4 involved the removal of the epiphysis (in both cases starting first by the distal) by a transverse cut in the bone (Fig. 4(2)). Upon completion, a deep enough incision was cut along the entire perimeter, causing the bone to break by flexion. This left a rough edge (Fig. 4(5)) that was removed in stages 3 and 5. In the case of aerophone 1, it was removed with the burin facet edge and by rubbing with sandstone. For aerophone 2, only friction with sandstone was necessary; it offered better performance, because it was not as hard. The tools used for cutting were unretouched flakes, with contact angles of less than 41º for aerophone 1, and an angle of 65 for aerophone 2, applied with a bidirectional, longitudinal movement and a high contact angle. Traces remained on the bones from these actions, in the form of transversal grooves along the edges of the tube, above the scraped striae, produced by accidental slips of the cutting tool, when still not fitted deep enough into the line of work (Fig. 4(5)).

3.1.3. Stages 6-9

These phases comprise the successive perforation of four holes on the dorsal face of the pipe, starting with the closest to the distal edge of the bone (considered the mouth or proximal edge of the aerophone) and ending at the opposite end, the closest hole to the proximal edge of the diaphysis.

In the case of aerophone 1, the holes have been made by perforation of the bone wall, using a total of four pieces by applying a bidirectional, combined translational and rotational motion, with a high contact angle. Two of the pieces were borers that have proved absolutely ineffective (too fragile, because they are configured for an anteroposterior angle of the active area that is too low), suffering very severe wear immediately. The other two are burins used on their dihedral angle. The technique used to make the holes in aerophone 2 was different, reducing the bone wall by scraping. A single tool was used to create all holes. This unretouched tool, with an active area of 71º, was applied with bidirectional and transversal motions, from a high angle. Some traces of these stages remain in the bone in the form of incisions perpendicular to the pipe, located next to the holes (Fig. 4(4)). Traces of the same condition and the same situation are observed in prehistoric objects, such as the aerophone of Hohle Fels (Conard et al., 2009), a useful example for determining the location of the holes on the tube.

Fig. 3. Comparative development stages for the manufacture of aerophones 1 (left) and 2 (right). The duration and tools used for each phase are shown.

Fig. 4. Modification in the bone surface and manufacturing traces, using aerophone 1 as an example. 1. Natural bone surface. 2. Scraped surface and cut of the distal end of the bone, with the burr still present after fracture. 3. Scraped surface with multiple parallel striae (arrow indicates an accidental groove). 4. Marks made to indicate the position of one of the holes. The hole cuts mark A and B cuts the technology mark C. Marks accidentally generated by cutting the distal bone. Bottom left: Hole 1 of aerophone 1 made by perforation, resulting in a circular contour and a conical edge. Bottom right: Hole 1 of aerophone 2 made by scraping the bone, resulting in an irregular and elliptical contour.

3.1.4. Stage 10

The last stage consisted in the regularization of the inner edge of the perforations for aerophone 1 (Fig. 4 bottom left). Given the diameter of these perforations, it was necessary to perform a notch on a narrow blade to use as a tool. In aerophone 2, the holes were left as they were, raw (which explains its irregular and slightly elliptical contour), which we believed to be the best choice (Fig. 4 bottom right). Indeed, if the hole is open to a size close enough to the desired one, any attempt of regularization by subsequent perforation, will incur in the risk of losing control over the final result. The bonewall thins so much at the edges of the hole that any action (either by perforation or incision) may generate breakage and uncontrolled chipping of the bone, thus producing a very irregular hole, even greater in size than the desired one, as seen, for example, in hole 4. Finally, the finished pipes were rubbed with leather, to remove any debris that might remain, and their nutrient foramen was sealed with wax.

3.2. Use-wear

The effectiveness of the tools and the degree of development of work traces are summarized in Table 2, on a scale from 0 to 5; some of the changes resulting from the work process are reproduced in Figs. 5 and 6.

Regarding the presence of microchipping (quantified by the number of microchipping generated along the active area), some variation is observed among the tools used on aerophone 1: from absent (0), and therefore without altering the morphology of the edge; to very numerous (5), which results in a very severe modification of the cutting edges. These differences stem from and are associated to: the type of action performed (more violent for the longitudinal movements than for the transversal ones), the angle of the active area (generally larger for transversal movements), and to a lesser extent by length of time in use. In the case of aerophone 2, active areas of all the pieces registered microchipping in varying degrees, ranging from an average development (3), to numerous (4).

In relation to micropolishing, its characterization is based on the proposal of Plisson (1985), which evaluates features, such as frame, extension, distribution, morphology, etc. This trace is only recorded on one of the 8 pieces employed (used for almost half an hour) in the reproduction of aerophone 1. The lack of presence of this trace on the other tools is explained in most cases by the reduced time of use of the pieces (less than 5 min in the best of cases) and by the presence of chipping. For the tools used in the reproduction of aerophone 2, the degree of development of micropolishing ranges between the values of 1, undifferentiated, and 3, moderate. In archaeological terms, these values are too limited for any kind of functional interpretation. Values of 1 only produce data for the kinematics of the artefact (knowing beforehand that the artefact has been used), while values of 3 may only shed light on possible patterns of micropolishing, which may be used to determine the hardness of the material, but not what kind of material.

Regarding the degree of effectiveness, the tools employed in the elaboration of the aerophones have been adequate, except borers, which were clearly ineffective. Buisson and Dartiguepeyrou (1996) also recorded low efficiency levels for this type of artefact. They used only one piece of this type for the drilling of four holes, once the thickness of the bone wall had been reduced by scraping. The perforator had to be reconfigured 9 times, more than twice per hole. In our case, the tool became worn in such a short period of time, that it had to be discarded.

Finally, the manufacturing process of the aerophone itself required a minimum expenditure of time, which is consistent with what is recorded in other studies (Buisson and Dartiguepeyrou, 1996; Clodore-Tissot, 2009); the production of holes by scraping reduces the time required by perforation.

Fig. 5. Chipping suffered in pieces 5 and 2 and the micropolish registered in tool 3 (below). Some tools only operated for a few seconds, and most have suffered significant damage in the form of chipping. Brief

use and severe macroscopic damage basically reduced micropolish evidence to nothing. Only two pieces register micropolish in a moderate stage of development, although well distributed over the active area, adopting a self-reticular pattern of the work on hard materials. Chipping is present on all tools, although less intensely in the burins. The active areas are numbered clockwise from left to right.

Fig. 6. Macroscopic alterations of tools 9 and 10 and micropolish registered in the latter; both were used in the reproduction of aerophone 2. The edge angles of the different areas of the pieces are indicated inside the polar coordinates. Piece 10, with an angle of 65 degrees in active area 1, has effectively cut both ends of the bone. In the same active area, micropolish was recorded with a similar degree of development as tool 3, although more extensive.

4. Acoustics analysis and archaeomusicological study

4.1. Previous research

As previously indicated, the experimental reproductions of the aerophone of Isturitz, in order to verify sound capabilities, have so far been scarce (Buisson and Dartiguepeyrou, 1996; Lawson and d'Errico, 2002; García Benito, 2014) and not always very successful (Wyatt, 2012). In addition, the interpretation and sounds produced by this kind of artefact have rarely been tested in a real and applied way. Studies have focused rather on the theoretical and generic explanation of their musical resources and possibilities. The first known study in this respect consisted of a virtual numerical simulation that calculated the pitch of the sounds in the case of being interpreted as a flute. They recorded two different acoustic regimes, with four and five sounds each, producing in the first G#3-A3-B3-D4-F#4; and in the second F4-A4-B4-D5. Approximately, the last frequency of the first register coincided with the initial one of the seconde an association that disappeared if the full length of the artefact was used. It has also been stated that, when used as an oblique flute, it produces a broad sound, which is however accompanied by a noise caused by air blowing into it, moreover, it only produces one register of sound while in our experiment we achieved three; as a straight flute, it emits an intense sound in up to three registers an interpretative modality, which we discarded as ineffective (Dauvois et al., 1998; Dauvois, 2005e2006). A subsequent investigation, after experimental manufacturing (Buisson and Dartiguepeyrou, 1996), compiled the views of three experts in different fields: an organologist, a flautist and an acoustic. Their comments were essentially theoretical, without delving further into the practical level. In spite of this, this work contains the first reference to its possible use as a lip reed instrument (Le Gonidec et al., 1996). Later, we find the detailed work of Lawson and d'Errico (2002), in the same line as the work presented here. Nevertheless, despite emitting assessments of great interest on the topic of sound, they do not fully manage to define its real and practical function. Three possibilities for the mouthpiece are offered in this work, the two mentioned so far, and a third, which functions by applying a reed. A more recent study explores these three possibilities in general, focusing particularly on different variants of reed with uneven results (Wyatt, 2012).

4.2. Acoustic-musical tests

Before performing the acoustic-musical tests, we had to address a number of issues regarding the manufacture of the aerophone in relation to its sound employment. They are the following:

- Conscious construction. When making an instrument, the artisan may have a preconceived idea of what is expected acoustically, or not. In the first case, the maker seeks an aesthetic-musical option a priori, while in the second, acoustic resources are explored a posteriori. Lack of knowledge on prehistoric acoustic preferences make it impossible to decide over one option.

- Thinning and countersink of the perforations. It is naturally produced by manufacture. Despite this, prehistoric people would probably have had less sensibility in the fingers (due to osteoarthritis, calluses, roughness, etc.), hence allowing for better control and facilitating the pneumatic function, although in modern instruments this factor is not so relevant.

- Perforation position. They are grouped in pairs, indicating that the instrument was almost certainly played employing both hands and using two fingers on each end (middle and index fingers, since they offer greater versatility and ease of use). Any other combination does not seem to be as reasonable, since fingers would be left unused with no place to support them; they are not symmetrical and complicate the grip.

- Hand position. Until the Baroque period, hand position was indistinct in Western music, building instruments in ambidextrous versions. This is not standardized in other musical cultures or in the traditional western world, so adopting one position or the other is optional for the musician, and falls within the orbit of his own comfort and cultural background.

Another aspect of this experiment was to decide on which end to locate the mouthpiece. Studies and experiments on archaeoorganological remains (Buisson, 1990, 1994; Dauvois, 1994a, 1994b, 1999, 2005e2006; Le Gonidec et al., 1996; Dauvois et al., 1998; Lawson and d'Errico, 2002; Wyatt, 2012; García Benito, 2014) indicate that it was located on the proximal end, since it was worked with greater care. Moreover, the distal end is broken so we do not know how it would have been finished. Previous research and experimentation by one of the authors, locating the mouthpiece on the distal side, returned uneven and inconclusive results; the obtained scales produced large intervallic leaps that made them incoherent, inconsistent, irregular and unworkable, with the exception of its use as an oblique flute (Vid. infra); this is due to the position of the holes on the tube in this format (García Benito, 2014)

This previous research work also experimented with a specimen, by maintaining its distal end uncut, i.e., the pipe was closed on one side. In the original piece, this part is fragmented and we do not know for sure how it would have looked. This experiment clarified whether it was useful to keep it that way or not. For the three variants of tested mouthpieces, the main disadvantage was that the last perforation, the fourth, was unusable as fingering hole, since it inevitably had to function as an air exit. Thus, the first position in all cases, with the pipe completely closed, does not work, and the second generally gives a rather inconsistent and poor sound. These factors would detract validity from the musical instrument, hence, we concluded that this was not its original morphology. To solve this problem, and as happens in the world of ethnographic music, the ideal situation would have been to make one or two additional holes at the end, like ears, so that it could function correctly (García Benito, 2014). However, it must be said that, so far, there is no evidence for any aerophone of this chronology to preserve the proximal epiphysis of the bone.

The two manufactured replicas (Fig. 2), despite intrinsic differences of the bones resulting from their build and elaboration (wall thickness, size, diameter, position and shape of the holes, etc.), acoustically work identically in all tested cases, with minor differences, that are actually only nuances. It has been confirmed that when two musicians play them together, they tune in without problem, because the instrument is versatile enough to obtain this result. The first mouthpiece option to be tested was that of an endblow instrument (oblique flute). To be interpreted as such, the instrument is placed in an oblique position over the mouth and the embouchure is adapted to direct the air on one side of the bone of the upper end, which acts as a bevel. The shape of the bone itself, in its proximal side, is irregular, narrow and not completely cylindrical, making it difficult to be played in this way it is somewhat easier if you play form the distal end, although the resulting scale (F#5-C6-D#6-G6-C7) and its intervallic relationship is more difficult to argue, even if this might not have been a problem in Prehistory; it can be thought of as a series of four notes, with one more bass that would act as a base or false bourdon. Also, we should not forget that this technique is not easy to perform and takes time and practice to learn how to do it. However, it is possible to learn and it is the option that offers more frequencies. In both replicas, it produces three different registers with slight differences (Fig. 7).

With replica 1 these sounds obtained are:

- 1st: G#5-A#5-C6-D#6-F#6-G6

- 2nd: F#6-G#6-C7-D7

- 3rd: C#7-D#7

With replica 2 the sounds obtained are:

- 1st: G5-A5-B5-D#6-F#6-G6

- 2nd: F#6-G#6-C7-D7

- 3rd: C#7-D#7

It was confirmed that the last frequency obtained in the first register is the same as the first achieved in the second register, a characteristic already mentioned when dealing with the numerical simulation. However, the tessitura does not match, with a difference of two octaves, although notationally it quite does Vid. supra (Dauvois et al., 1998: 53, fig. 2; Dauvois, 2005-2006: 230:232). The last two sounds of the first register were performed with clarity and comfort by means of a unique position, achieved by the amendment of the embouchure changing the throat positioning and air velocity. It was also proven that cross finger positions marked with an asterisk (*) in Fig. 7e have no great influence on the height of the sound, but somewhat on the timbre, although this effect is minimal. It was noted that the second register is not generally tuned in at a distance of an octave with the first one, as would be expected; the second ranges between half a tone and one tone lower in pitch. This is because harmonics are difficult to tune in bone flutes and are naturally low in sound.

Such small instruments, in size and diameter, do not seem to be common, although there are cases to be found in ethnographic music. The smallest we know are the supelka from Macedonia, which range between 24 and 35 cm long and the Greek flogheras, some of them made from the wing bones of birds of prey (Sadie, 1984, pp. 365e366, 475, 751e752, 770e788; Tranchefort, 1985, pp. 204e220), like the ones today exhibited at the Museum of Greek Folk Musical Instruments, from the area of Delphi, the island of Lesbos and the region of Epirus.

Fig. 7. Fingerings and sounds of both replicas.

In the archaeological record, an aerophone was discovered in 1938 in Samtavro (Mtskheta, Georgia). It was made from the shinbone of a swan, with three holes, 19.9 cm long and 1.1 and 1.8 cm long. It was found among the grave goods, belonging to an adolescent male between 14 and 15 years of age. The archaeologists called it: "the grave of a little shepherd". It is dated to the twelth and eleventh centuries BC. This archaeological remain has been identified with a typical instrument of the country, the salamuri (http://www.magticom.ge/magazine/2003-1/2003-1-10.html).

Fig. 8. Used reeds and method of attachment in the aerophone.

The second mouthpiece option was tested as a reed instrument (clarinet). Three different reeds of varying sizes, all made from cane (*Arundo donax*), were used ein the Paleolithic other materials may have been used, such as similar grasses (*Phragmites australis*) or others, such as the calami of large feathers. These were placed at the proximal end of the replicas, held with wax (Fig. 8). To play them, the reed is inserted completely in the mouth; it is blown through the opening made on it, producing vibration on the reed practiced therein. Only one register is achieved with each one. However, this is neither relevant or a problem for its use. In ethnographic music in general, similar scales work perfectly in different musical cultures; they seek their variability in other sound-musical features (changes in tempo, volume, timbre, effects, etc.), which is certainly the case with these artefacts. Both replicas work equally with open and closed fingerings; there are only small differences in timbre. They have a full sound, with potency, body and broad volume (Fig. 7).

Replica 1 produces the following scales:

- With the small reed: D-4-D4-D#4-F#4-G#4.

- With the medium reed: F#4-G4-A4-A#4-C5/C#5.

- With the large reed: D4-D4-D#4-F#4-G4.

Replica 2 produces the following scales:

- With the small reed: D4-D#4-E4-G4-A4.

- With the medium reed: F#4-G4-G#4-A#4-C5.

- With the large reed: It could not be introduced into the tube, because it was too narrow, so this option was not tested.

The small and large reeds, hold no logical relationship in size with the rest of the instrument (pipe), so they have offered more problems than solutions. The fifth does not tune in well with these two reeds, which is essential, since the perfect fifth is physically present in the harmonic series (3rd harmonic), and in the majority of musical cultures of the world (unlike the third which is tuned in differently in each place, according to other aspects of cultural and social order). If this intervallic relationship works well, it does not matter how the other sounds are organized, because they will always find a natural reference or support in these two notes. In addition, almost all current, traditional music fifths are perfect. We also attested that a different scale was reached in each test (compare with: García Benito, 2014), so they are not regular and constant reeds, as would be desirable. Also, these scales repeated sounds, and barely performed.

All these problems disappeared with the medium sized reed. It fitted the pipe and always produced the same scale, with slight differences (caused by variations in its position, which was not always exact). Hence, it is constant, and the fifth is tuned in well. Finally, when used on both replicas, the results were very similar. As for the elaboration of the reeds, they would have been built based on trial and error, much like in the ethnographic world. Once one complied with the artisan's tastes or sound-musical intentions, it was copied as many times as necessary. After it ceased to work, its life could be extended, by fitting a bridle with a tendon, fibber or gut. It is worth mentioning that, although acoustically indistinct, the opening direction of the reed is also unknown.

In this type of instruments the sound is not articulated, such as in end-blow instruments (which perform attacks or sttacato), because it is complex. Thus, air is spent all at once; circular breathing may also be used, if the technique is known. Therefore, the instrument allows for articulation of the “bagpipe type”, with closed fingering (Fig. 7); when there is a change of sound, the gravest one is briefly heard, acting as a false Bourdon, and giving the feeling of a staccato.

The third mouthpiece option was tested as a lip reed instrument (horn). In order to produce sound, the air is introduced through its proximal end. Here, the player's lips are placed in semi-closed position. So, when air passes through them, they are put into vibration generating it. It is a very complicated and forced mouthpiece, due to the narrowness of the pipe, but possible to play with technique and practice (Fig. 7). The production of various sounds eharmonice with each fingering, in the manner of current brass instruments, is rendered impossible, if the musician is not prepared for it. So, replica 1 produced the scale A4-B4-C#5-E5-G5 and replica2 the scale A4-B4-C#5-E5-F5/F#5.

5. Conclusions

The manufacturing process of this type of aerophone is very simple, and it can obviously be made only with unretouched supports. Piece number 9, for example, which could be easily classified as debris, has been remarkably effective in the process of bone scraping of aerophone 2. Its two active areas, well different from each other, have been equally effective, simply by varying the contact angle. The time of manufacture surely could be reduced if the bone is worked while wet.

In our case, the manufacturing time decreased from 1 h, which could surely be reduced if the bone was wetted. Moreover, holes made by scraping of the wall, instead of perforation reduces manufacturing time by 19%. The artefacts were not used conservatively, in terms of microscopic traces. The tools were applied to the actions with intensity (even if it was for a short time), in the most effective way possible, taking full advantage of them in clearly realistic actions, regardless of how they could be affected. Tools were notably deteriorated, showing severe macroscopic transformation in a large number of active areas. By contrast, and precisely for this reason, micropolishing evidence was very scant.

Regarding the way the holes were made, the reduction of wall hickness by scraping is faster than perforation and repeated incision, although control over the size of the hole is reduced, and to a certain extent also over its position, especially if on the dorsal surface. This is because in some ulnas (from bearded and griffon vultures), the dorsal surface is flat, and more resistant to work along the rim, where the flight feathers are inserted. The thinning of the bone is faster on the opposite side, causing the holes to shift slightly to the side in relation to the bone axis.

It also loses control over shape. By perforation, the hole results in a regular, circular perimeter, while the morphology of the hole obtained by recess is dependent of the variable thickness of the bone wall, and its borders are less resistant.

It has been suggested that the thinned morphology resulting from perforation by repeated incisions would have served to improve pneumatic efficiency, thereby facilitating plugging of holes with the fingertips, fingers which would have been hardened and calloused by work, and less flexible than ours (Lawson and d'Errico, 2002). It is a possibility to contemplate, although it must also be said that the morphology of borers or dihedral angles of burins produce perforations with inverted cone walls, which can be accentuated if the wall is later regularized, as we did for aerophone 1 (phase 10). Although information is difficult to gather, it seems that there is a predominance of perforations by incision or recess over rotation in these palaeolithic instruments, after which the frequency is reversed in later time periods. We are tempted to think therefore that this way of making the holes, in a good many of these Isturitz pipes or earlier ones from Hohle Fells or Geissenklosterle (Munzel et al., 2002; Conard et al., 2004, 2009), may be the result of reproducing processes, which may have already been applied on these other, alternative materials, (plants or feathers), and for which perforation is clearly the less effective method.

Acoustically, it has been proved that this perforated pipe may be played in three possible ways from its proximal end.

Looking back on the results from the mouthpiece test, any of the tested options is feasible, since none showed great difficulty in producing musical sound, except for the specific nuances of each example. Besides, each of these alternatives holds its own peculiarities and characteristics that make them unique in relation to the pitch/sound offering, the amount, quality and structure of their scales, and individual timbre.

The option that offers more sound possibilities, in terms of the quantity of sounds obtained, is as an end-blow instrument. Nevertheless, the timbre produced as a reed instrument is very suggestive, without forgetting its particular use as a lip reed instrument. However, the difficulty of interpretation, and the need for complex and specific training in the first and third options, or the need to fabricate reeds in the second, illustrates how each one presents advantages and disadvantages.

No big problems or inconveniences were found in the different scales produced by each test, except for those fitted with small and large reeds. So, there is no specific reason to rule out any of the options, considering the musical and sound diversity occurring in humanity.

Thus, choosing only one of them is very difficult, because the aesthetic and sound-musical taste of the Palaeolithic is unknown to us. As a working hypothesis, we propose that a good way to understand and investigate this archaeo-organological remain is to view it as a "multi-instrument", which would encompass all the options that we have seen so far in a single element of study.

Finally, this work dismantles the idea that all archaeoorganological remains consisting of a perforated pipe are flutes. As just evidenced, they can be flutes or any of the other types of aerophones, tested, or still to be tested, as long as the mouthpiece does not prove otherwise. This kind may be referred to as 'Aerophones with holes for musical fingering' or simply, 'aerophones', without any further indication, until theirs adscription to one group or the other may be scientifically proven through experimentation.

Moreover, this line of experimental study, which combines use-wear and archaeomusicological analyses, may be adequately applied for research on other, similar European Paleolithic examples that still lack study.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.quaint.2015.11.033.

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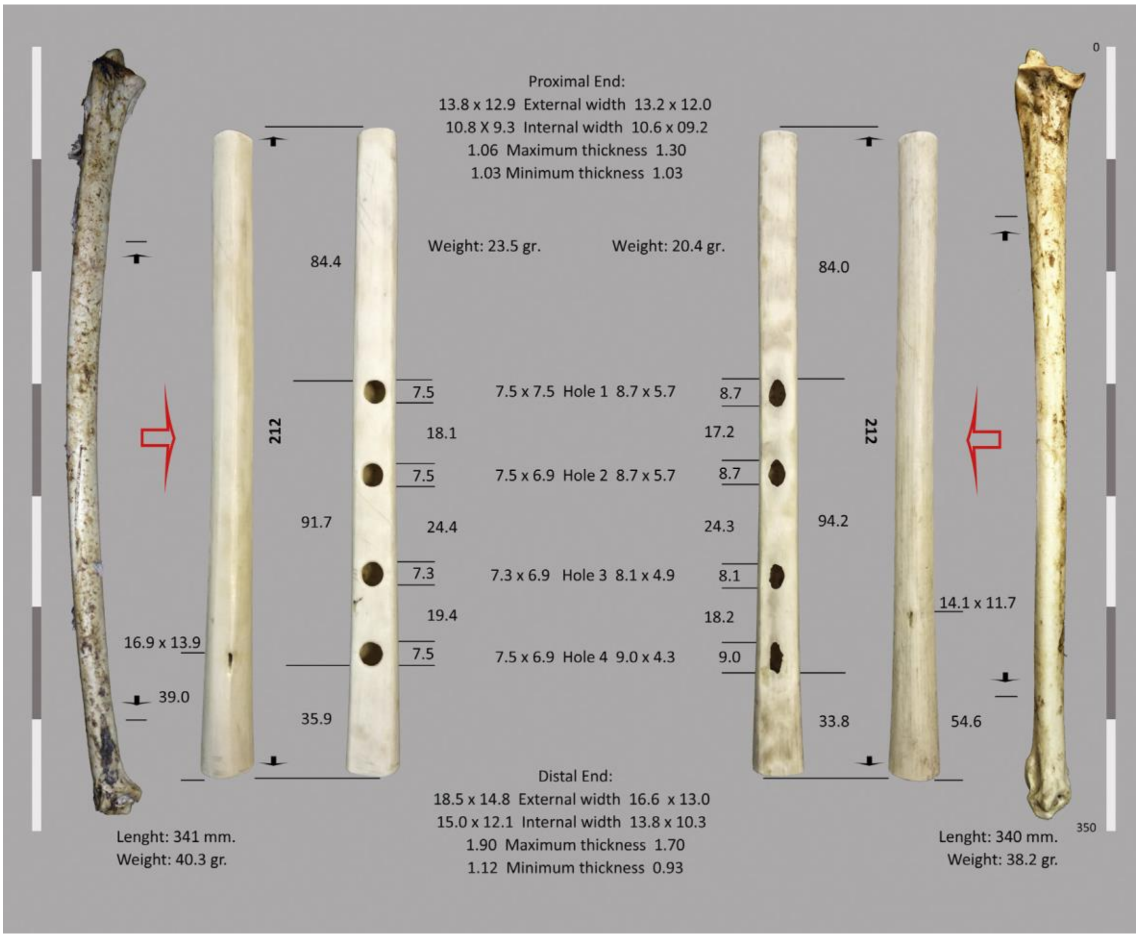
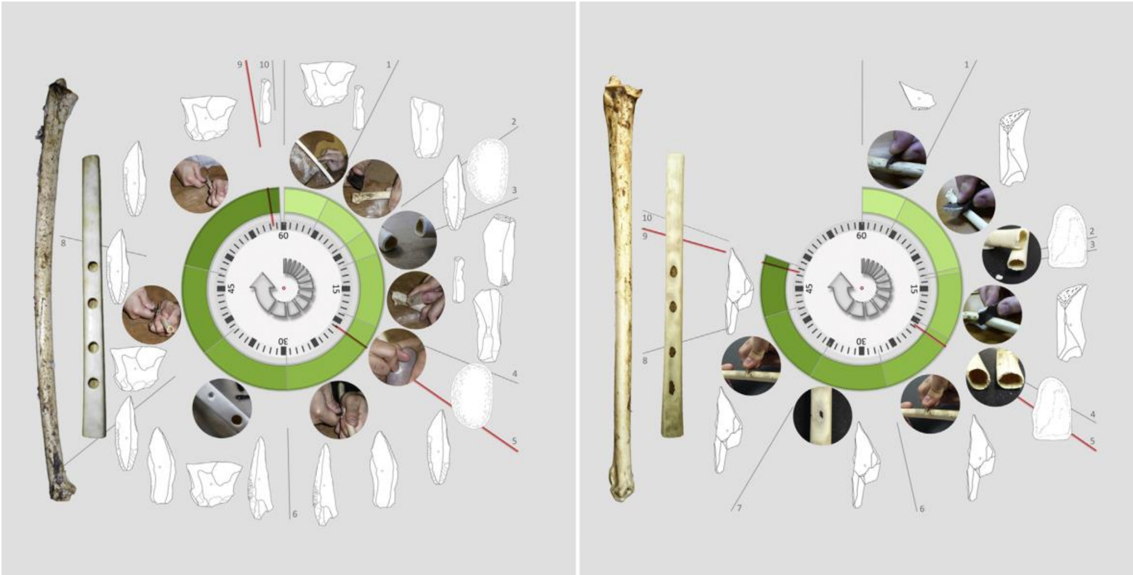
1
2
3
4
5
6
CMP
2
3
4
5


Proximal End:
13.8 x 12.9 External width 13.2 x 12.0
10.8 X 9.3 Internal width 10.6 x 09.2
1.06 Maximum thickness 1.30
1.03 Minimum thickness 1.03
Weight: 23.5 gr.
Weight: 20.4 gr.
84.4
84.0
7.5 x 7.5 Hole 1 8.7 x 5.7
7.5 x 6.9 Hole 2 8.7 x 5.7
7.3 x 6.9 Hole 3 8.1 x 4.9
7.5 x 6.9 Hole 4 9.0 x 4.3
7.5
18.1
7.5
24.4
7.3
19.4
7.5
8.7
17.2
8.7
24.3
8.1
18.2
9.0
212
212
91.7
94.2
35.9
33.8
16.9 x 13.9
39.0
14.1 x 11.7
54.6
Distal End:
18.5 x 14.8 External width 16.6 x 13.0
15.0 x 12.1 Internal width 13.8 x 10.3
1.90 Maximum thickness 1.70
1.12 Minimum thickness 0.93
Lenght: 341 mm.
Weight: 40.3 gr.
Lenght: 340 mm.
Weight: 38.2 gr.
0
350



9
10
1
2
3
60
45
15
30
8
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5
6
1
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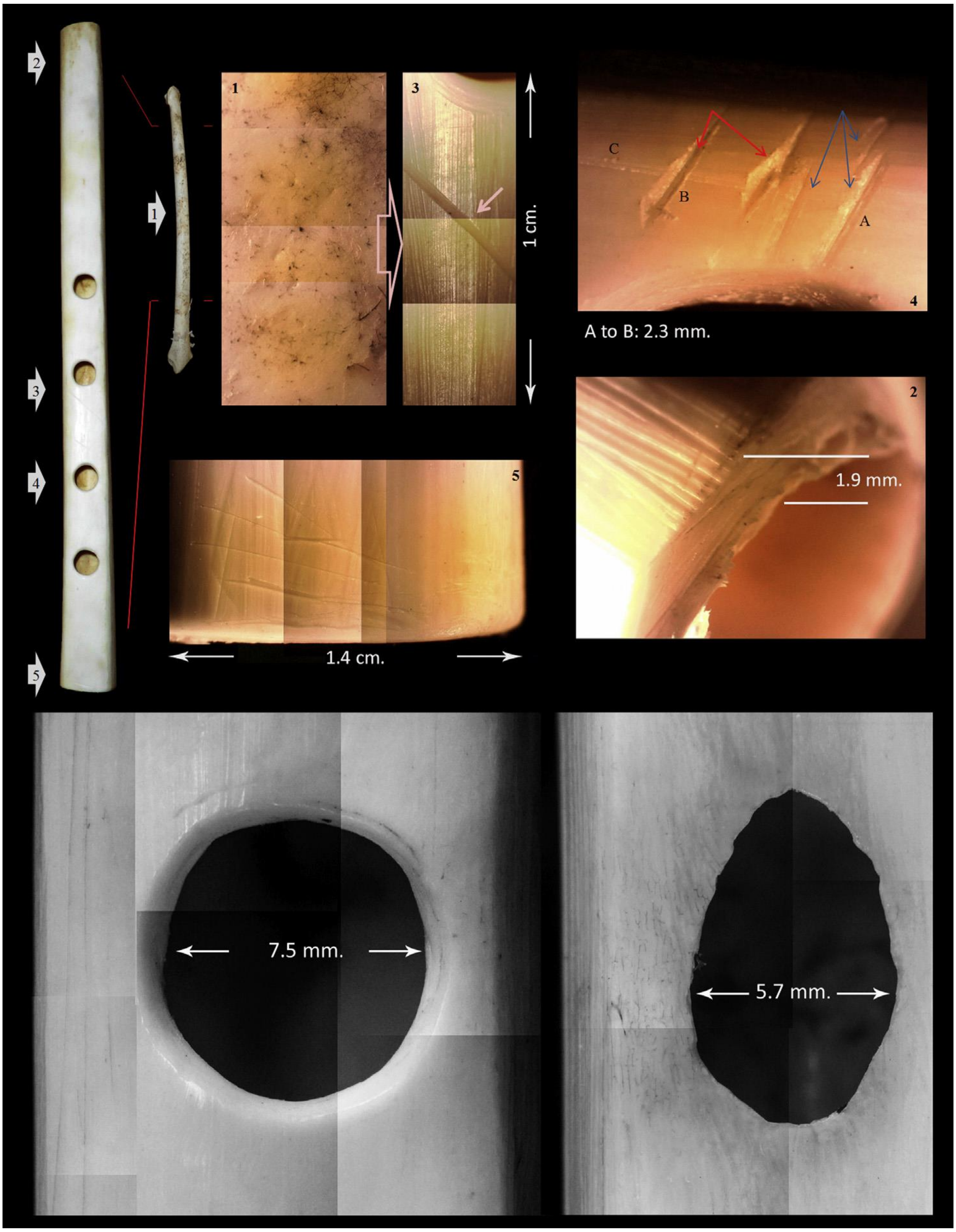
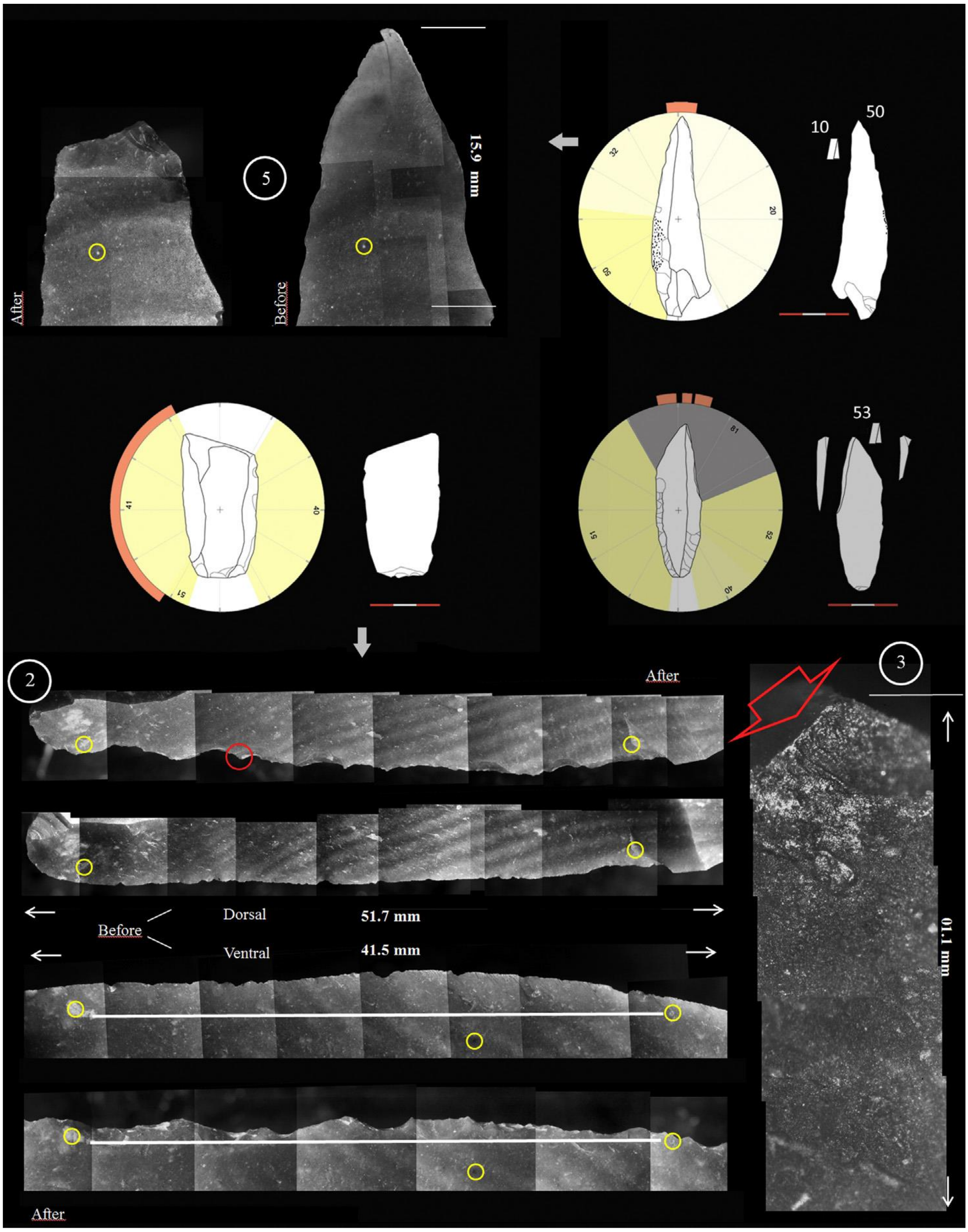
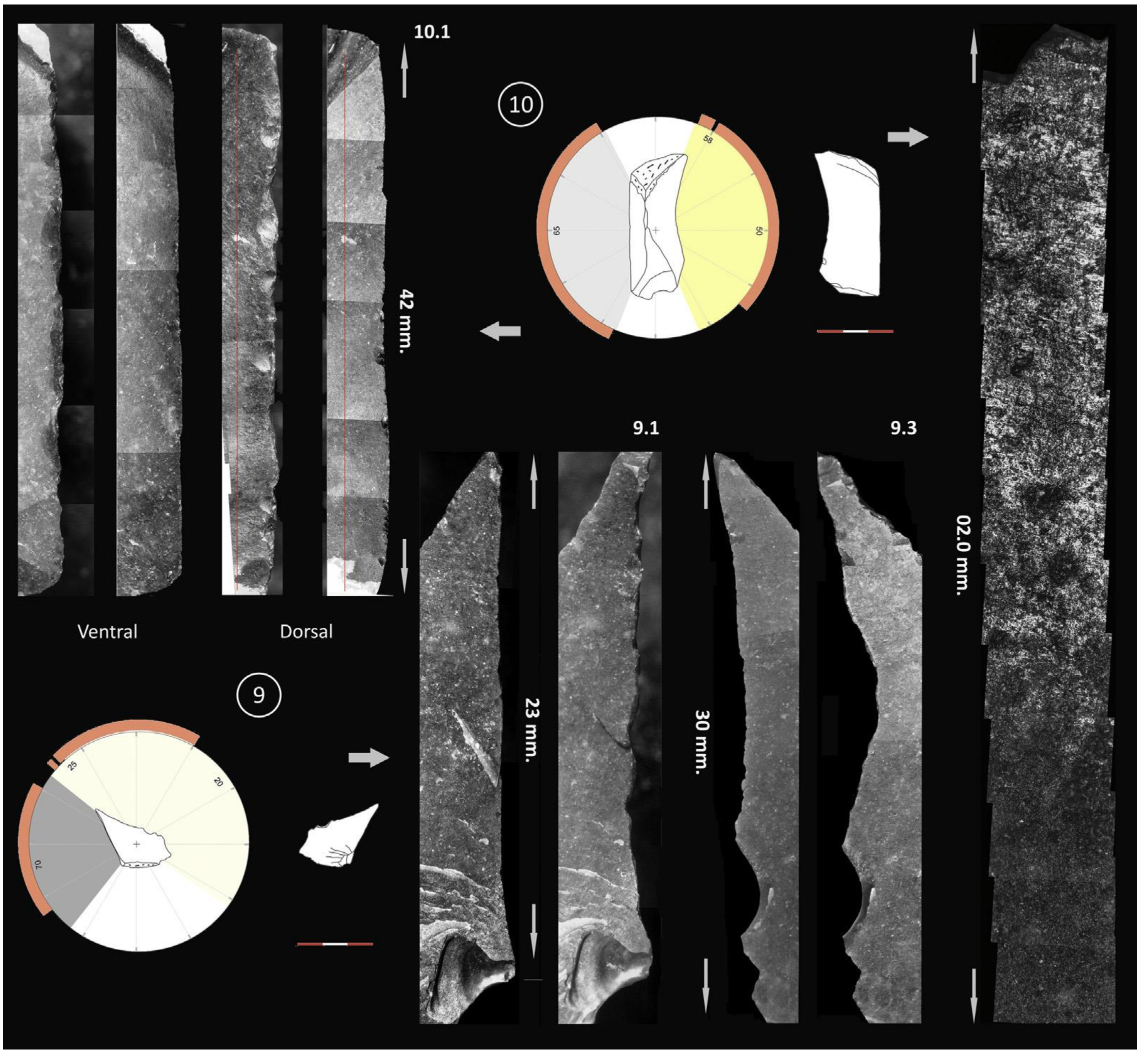


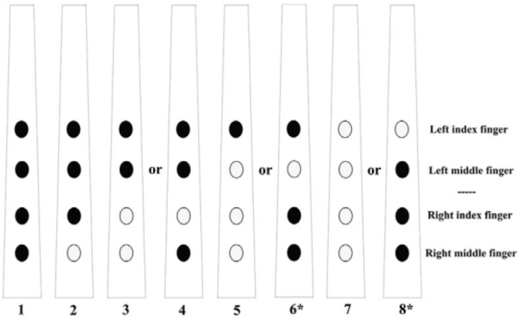
1
3
1 cm.
C
B
A
4
A to B: 2.3 mm.
2
1.9 mm.
5
1.4 cm.
2
1
3
4
5
7.5 mm.
5.7 mm.



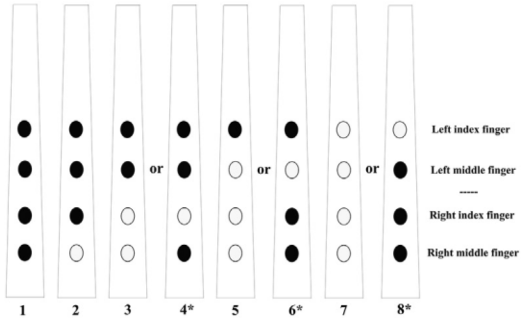
15.9 mm
5
After
Before
10
50
53
2
After
3
Before
Dorsal
51.7 mm
Ventral
41.5 mm
01.1 mm
After


10.1
10
42 mm.
Ventral
Dorsal
9.1
9.3
02.0 mm.
9
23 mm.
30 mm.

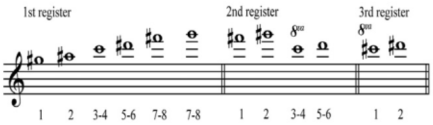
End-blow instrument



Lip reed instrument

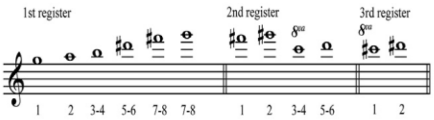


Aerophone 1



Aerophone 1

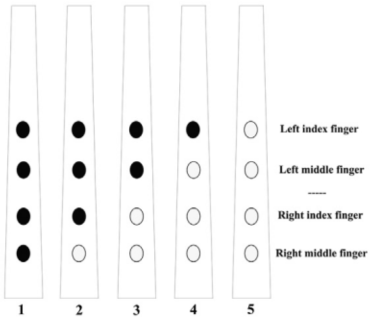
Aerophone 2



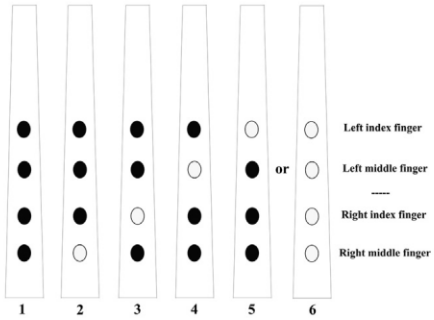
Aerophone 2

Reed instrument

Open positions



Close positions



Aerophone 1

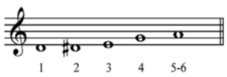
Small reed

Medium reed

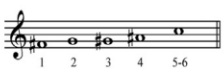
Large reed

Aerophone 2

Small reed



Medium reed




CMP
5 cm.