Ancient Noise Generators

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ZUSAMMENFASSUNG

In diesem Beitrag wird dargelegt, dass im vorspanischen Mexiko Klangwerkzeuge aus verschiedenen Materialien wie Knochen, Stein und Ton verwendet wurden, die verzerrte Klänge erzeugen. Einige Objekte der Fundgruppe müssen im Mund gespielt werden und sind deshalb als „Mundpfeifen" (buccal whistles) zu bezeichnen. Sie weisen zwei gegenüberliegende Perforationen und eine zentrale Kammer auf, in dem das Geräusch entsteht. In dem vorliegenden Artikel wird ein Überblick über vorspanische und heutige Geräuscherzeuger gegeben, organologische und akustische Eigenschaften einiger Exemplare werden dargestellt und ihre mögliche Verwendung diskutiert.

1. INTRODUCTION

Some previous results of the study of ancient noise generators were presented in the First Special Session on Ancient Acoustics section on Pre-Columbian Sounding Instruments[1]. A paper on the "Olmecan whistle" was presented in an international meeting on acoustics[2]. Some related consultation documents are posted in a web site as a first discussion of the *aerófono de piedra negra*[3].

In this paper the main results and new findings on other ancient lithic artifacts identified as buccal noise generators are presented. It will be centered in the stone objects of the buccal subfamily that were identified and analyzed by the author, but other similar noise-producing objects that were identified and published by other authors are commented. Those identifications, as well as similar contemporary aerophones, are important as evidence of the sound properties of this kind of artifact, because experts that have found some of them do not believe in their sonorous function as sound generators, or claim that their capacity to produce sounds is coincidental rather than determined.

The precise original uses of these ancient noise generators and their sounds are lost, but there are some similar contemporary artifacts that can generate similar noise signals that verify their main sonorous function. Also, experimental models, as well as acoustical and signal analysis can be used to verify the similarities of typical sound-producing mechanisms, as well as to demonstrate the sonorous effects derived from changes in shape and dimension. Acoustical parameters are useful to characterize the main function of the aerophones, to explore the possible spatial context in which to use their sounds, and to analyze the differences between them and to find probable uses.

The first investigator of some buccal noise generators made of clay was the deceased Mexican engineer Franco[4]. He published several drawings and comments on these aerophones dating from the Olmec period (Preclassic Mesoamerica, about 800 B.C.), and called them "buccal whistles" (Fig. 1d). Another researcher, Contreras Arias, called these artifacts "aerophones of double diaphragm"[5]. He suggested that an "aerophone of double diaphragm" is depicted with other musical instruments in the Florentine Codex (Fig. 1a)[6], indicating that buccal noise generators were used up to the 16th century and considered as musical instruments among the Aztecs. Contreras Arias also published a drawing of a cross-section of a buccal whistle of this type (Fig. 1e)[7]. Schöndube[8] and Contreras Arias[9] published photos of three *gamitaderas* (Fig. 1b) from Western Mexico, which are preserved in the Regional Museum of Guadalajara. Schöndube proposed that they belong to the migrating groups that came to Western Mexico in Prehistoric times and were used as *gamitaderas*[10] to call animals for hunting. In the

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1 Beristain *et. al.* 2002 (b), 2368.
2 Beristain *et. al.* 2002 (a), 2395.
3 Velazquez 2000 (c), 1.
4 Franco 1971, 20.
5 Contreras 1988, 61–72; Contreras 1988, 54.
6 Sahagún 1979, Libro 8, Párrafo 7, Folio 30.
7 Contreras 1988, 61.
8 Shondube 1986, 91–93.
9 Contreras 1988, 182
10 *Gamitear* or "calling" means to produce the sound of animals to attract them, usually for hunting.

same museum are some "mouth whistles" of clay preserved (Fig. 2), which were found in the shore of Chapala Lake, Jalisco. Dájer included in his book comments and the image of a so-called "microtonal ocarina" (Fig. 1c) made from bone found in Michoacán, which is preserved in the Museum of Araró, Michoacán[11]. It was classified as a "shuttle of a loom"[12].

Unfortunately, the detailed acoustical properties and the sounds of these aerophones were not provided or analyzed in the publications mentioned. Moreover, the designations of the noise generator as „aerophone of double diaphragm", "microtonal ocarina", „buccal whistle" and *gamitadera* are not adequate. The two perforations located face to face are not diaphragms, because their diameter is not variable. Ocarinas are globular aerophones. There are other types of "mouth or buccal whistles" and *gamitaderas* that function with a different system, as a membrane (Mirliton), a rubber band or a leaf generating a reedy sound, although some of them can produce sound closer to chaotic noise generators, for example, if vocalizations are added.

There are several complex family members of the aerophones in which the described system is the acoustic heart of the sounding mechanism. For example, tubular airducts are attached so that the position of the acoustical mechanism is placed outside the mouth, but due to their acoustical and organological complexity can not be described with detail in this paper (see Both, this volume). However, the tree of the family of noise generators is not well known. It is not included in the existing classification system of musical instruments and in any typological archaeological system of ancient artifacts.

Cross-sections revealing the organological structure of some complex members are shown in Fig. 3. Similar specimens were analyzed[13] by the author and Rawcliffe, who examined artifacts, which she designated „chamberduct flutes"[14]. She presented some of these instruments in the 2nd Symposium of the International Study Group on Music Archeology at Monastery Michaelstein, Germany[15]. In respect of the acoustical mechanism of the buccal noise generators, she commented[16]: "At the heart of this system is a small chamber in which two opposing holes direct the air in and out, as in the tea kettle's whistle or a Brazilian mouthwhistle"[17].

Franco comments[18] that these aerophones "produce a sound by a means that has not been described as yet for any instrument in the world"[19]. However, it is possible that similar instruments were used in other cultural areas. A prominent example[20] of a buccal noise generator is the so-called *sifflett en pierre*[21], which in the beginning of the 20th century was used for signaling in the Verdon Valley near Alos, France. Armengaud stated that in Turkey boys made similar whistles from a flattened bottle cap, bent at about 30 degrees, and perforated with a nail at a distance of a third of the bent edge.

2. ACOUSTICAL MECHANISM AND PLAYING TECHNIQUES

The acoustical mechanism of the noise generators is different from that of other well known aerophones, such as flutes and trumpets.

Armengaud, the only researcher who described the use of buccal noise generators in France, provided not only a drawing of the *sifflet en pierre* (Fig. 1f), but also its approximate size, material (a soft material, for example gypsum), the production technique (a deep slit is made with a knife and two perforations joining the slit, one perforation of greater diameter than the other one), and the playing technique. According to his description, this buccal noise generator is held (with the lips and the tongue) inside the mouth, with the side of the slit at the exterior or front side and the perforation of greater diameter at the downward or inferior side. Thus, the mouth cavity forms a chamber (internal airduct), through which the airflow is directed. It should be noted, that the mesoamerican buccal noise generators are very similar in shape and function. Armengaud also stated that it needs some practice to produce the sound. Additionally, he commented[22] that the sound is very loud, reaching a distance of 2–5 km.

As indicated before, several organological designs are present, but all specimens show two perforations face to face and a resonating chaos

11 Dajer 1995, Fig. 72.
12 Dajer 1995, 56.
13 Velazquez 2000 (b), 91–98.
14 Rawcliffe 1992, 12.
15 Rawcliffe 2002, 267, Figs. 14a, 15a, 15b.
16 Rawcliffe 1992, 11.
17 Tea kettle's whistles do not have the main chaos resonator chamber of the buccal noise generators, which cannot be classified as "flutes".
18 Franco 1971, 20.
19 Franco commented that the wave generator in these aerophones is a mass of air contained in an independent chamber that works as an air spring; its oscillations pass to the main chamber whose functional size can be changed to vary the frequency.
20 The information of this paper was found and sent to me by Uli Wahl, expert in aeolian instruments. (http://members.aol.com/woinem1/index/)
21 Armengaud 1984, 81.
22 Armengaud concluded that similar instruments made of clay and ivory existed also in pre-Columbian South America and in Greenland, respectively.

chamber between them. Fig. 4 shows the structure and main organological parameters of the simplest buccal noise generator with two perforations. Small variations of its dimensions may produce great changes in the characteristics of the noise.

Fig. 5 shows the main views and sections of the "multi-drilled ilmenite" (Fig. 6), a supposed prehispanic sound artefact discussed later in detail. The front view shows the channel where the sound is emitted. It shows the front diameter (9 mm) of the resonating chaos chamber and exit cavity. It is larger than their diameter in the back (5 mm). The section AA´ shows the detail of its main cavity and exit, as well as the internal circle of the lateral perforation, which is equal and face to face to that of the opposite side (4 mm in internal diameter). The surface of the front and the back of the specimen is flat but rounded in the corners, at the two lateral sides and extremes. The section BB´ shows the cut's detail of the lateral channels of the superior and inferior part, as well as the resonating chaos chamber with the corresponding open exit perforation placed to the left and its back perforation placed to the right. The three conical perforations (resonator cavity and two wind channels) are centered in a vertical plane, which are the required main elements to produce noise.

The sound mechanism functions as follows: 1. The incoming strong airflow (showed by the arrow) flows through the upper conical channel A of the stone; 2. At the exit channel A, the compressed input air flow is expanded, because the main chaos resonating chamber B has smaller pressure. Diffraction in all directions occurs, because the diameter of the channel A is small; 3. The expanded waves go backwards to the other side of chamber B and towards the internal circular edge of C, generating reflections to the back; 4. The strong main air flow, that comes from channel A, passes through channel C and backwards toward the mouth cavity 2, which functions as a Helmholtz resonator[23] or spring of air, generating other vibrating waves; 5. When those waves cross the perforation C more refractions within the main chamber B are generated; 6. In a few milliseconds, the combination of vibrating expansions, reflections, refraction and collisions, in both directions, with two circular edges in a reduced space, can generate a complex and turbulent dynamic of chaotic vibrating waves of pressure, producing the noise shown with volutes[24].

Acoustic models were intended to explain the general behavior of the noise generator design, using analogies of electric circuits[25], but the detailed functioning and the dynamics of the sound production of this type of aerophone is very complex and a matter for further research. From the mathematical point of view, the system belongs to the field of partial differential equations models of non-periodic, dynamic systems, since it operates in a wide range of vibrations, pressures and non-periodic waves of sounds, within a very small and narrow chamber and two special circular edges, like a chaotic and turbulent process. This class of mathematical model is in the unexplored border of several advanced fields of science, like the simulation and analysis of complex sounds, the dynamics of vortex and turbulent flows of fluids, and the scientific visualization of complex systems.

Buccal noise generators allows for sound modulation when specific playing techniques are applied, in which the acoustical system is changed with the tongue and lips. These sound modulations cannot be obtained within the more complex noise generators described by the authors previously mentioned. Fig. 7 illustrates how to play the aerophone. It should be played as shown in Fig. 5, with the section BB´ placed within the mouth, between the inner part of the lips and the tongue, which covers the back hole. The parts of the mouth-aerophone system are: input channel 1, formed between the palate and tongue, to generate the air flow (shown with the arrow); the buccal noise generator with the main resonating chaos chamber B[26] and two conical perforations or channels A and C, which are located face to face in a vertical axis (the inner circle of these perforations are two special circular edges, where the sound is generated), and; the irregular Helmholtz resonator of the mouth cavity 2.

3. CONTEMPORARY BUCCAL NOISE GENERATORS

In the following paragraphs two contemporary buccal noise aerophones of metal and plastic/metal will be discussed. The ancient noise generators of stone analyzed by the author will be commented on later in greater detail.

3.1. SHEPHERDS WHISTLES

In several countries "shepherds whistles" made of plastic (Fig. 8) and metal are used, which were

23 In mechanical models the Helmholtz resonator is represented as a spring and in electric models as a resistance.

24 Volutes are Mexican pictograms used to represent several classes of beings and weaving phenomena systems, such as the waves of sounds.

25 Menchaca/Velazquez 2000, 87–90.

26 Any aerophone has a main chamber in which some waves can resonate, as in this case B, but it is also a chaos chamber due to the special shape of the internal structure and the two holes face to face.

industrialized in the last century. Unfortunately, studies on these aerophones were not found in the literature. The main organological characteristics are that there is no angle between the two internal flat surfaces that form the resonator/chaos cavity and the distance between the two holes is very small (2 mm). Also, the diameter of the sonorous perforations is small (2 mm).

3.2. BOTTLE CAP WHISTLES

In Mexico, until the middle of last century a whistle of metal (Fig. 9) was made and used by adults and boys in several areas, including my home town Tequila in Jalisco, Mexico. For our research, its knowledge and use were very useful to identify and to play the ancient buccal noise generators, because its acoustical mechanism and the sounds produced are similar. It was made of a flattened and bended soda or beer bottle cap, with two perforations (2–3 mm diameter)[27]. The resonating chaos chamber is formed between the flattened internal surfaces of the metal at an angle of approximately 30 degrees, but it can produce several sounds at different angles. It was used to produce loud, noisy and whistling signals.

4. BUCCAL NOISE GENERATORS OF STONE

The lithic artifacts commented on this section were examined directly by the author and were identified as possible stone noise aerophones, because they can generate similar noise signals with a similar organological structure.

4.1. MULTI-DRILLED ILMENITES

One ancient lithic member of the buccal noise generator is an artifact with three perforations that was casually found by the author in the office of the deceased anthropologist F. Beverido, in Xalapa, Veracruz[28]. Unfortunately, there is no archaeological information on this black stone (Fig. 6). Probably the object was found in San Lorenzo, Veracruz, as Beverido worked in that Olmecan site with Coe, who recovered some “multi-perforated magnetites” near the Colossal Head No. 17, a huge antropomorphic basalt sculpture of 2 m in height representing a head. Coe comments that “the heights of Olmec civilization were reached as far back as the Early Formative, in the 1200–900 B.C. span”[29]. That black stone represents the first ancient aerophone identified and analyzed directly by the author[30]. According to microscopic observation, the black stone could be ilmenite, especially as many similar objects made from stones classified as ilmenite were found in San Lorenzo by Cyphers and Di Castro[31]. Ilmenite is a massive iron-black mineral composed of iron, titanium and oxygen that is a titanium ore ($FeTiO_3$), the hardness of which is about 5.5–6 Mohs[32]. Its color is black and its luster is metallic. The structure and description of the analyzed ilmenite was provided in section 2 and is shown in Figs. 5–6.

Cyphers and Di Castro state that about 10.000 “multi-drilled ilmenites” were excavated in San Lorenzo Hinterland, nearly 4 km south of the central region in the secondary Loma Zapote site, a side of the sedimentary river possibly dating from the Early Preclassic (the exact date was not provided); nearly 4.5 tons (more than 140,000 multi-drilled stones) were found in the site “ilmenites A4”, in three concentrations. Other ilmenites were found[33] in other Olmec site in Chiapas[34]. Cyphers and Di Castro[35] provide the following information and data on the ilemenites from San Lorenzo: The stones have four coarse regular faces and in their ends two irregular square faces. The specimens vary in their size from 1.5 cm by 1.8 cm to 5.4 cm by 2.5. The average is of 2–3 cm by 1.5 cm. Their weight ranges from 9 g to 110 g. Each ilmenite has three conical perforations that go from 0.5 cm to 1.5 cm in diameter and they were made in the same sequence. Always, the main perforation is the bigger one and the other two were made in its lateral adjacent sides. The sequence of the perforations is the same. Ilmenites without perforations were not found in San Lorenzo. The special raw material was not available in San Lorenzo and had to be transported from other areas. In Chiapas there are some ilmenite mines. They were widely used, because at least one was found in every domestic building in San Lorenzo.

27 Velázquez 2000 (a). The two perforations were made using a nail near the center and face to face with their centers in the same axis.
28 Velazquez 2001, 1.
29 Coe 1967, 63, Fig. 11.
30 Velazquez 2000 (c), 395–406; Beristain *et. al.* 2002 (a), 2395.
31 Cyphers/Di Castro 1996, 3–13. Some “small blocks” (multi-drilled ilmenites) are exhibited in the National Museum of Anthropology at Mexico City and in a web site with photos of the Museum of San Lorenzo. (http://www.delange.org/SanLorenzo/SanLorenzo.htm)
32 Mohs scale is a relative scale of the hardness of rocks and minerals, arbitrary reading from 1 (talc) to 10 (diamond). Hardness is the property of resisting abrasion or scratching.
33 In Plumajillo, Chiapas (Pac Phase of the Early Classic 1100-900 B.C.), about 2000 similar ilmenites without perforations, including 24 broken ones with perforations and a complete one with three perforations were found.
34 Agrinier 1987, 19-36.
35 Cyphers/Di Castro 1996, 5.

Among the previous hypothesis of other authors on the original function of the "multi-drilled ilmenites" the following ones are mentioned by Cyphers and Di Castro[36]: "pendants for personal adornment", "drill stones for making fire", "weights for fishing nets" or "counterbalances of *atlatl*"[37], and as "hammers". Since the authors argued against some of these hypothetical utilitarian functions provided by other authors, they will not be analyzed in detail in this paper. They propose that the "multi-drilled ilmenites were used as manual supports for drills or other applications that require rotation, like spinning processes and the making of ropes[38]. They mention that several perforations were made, because multi-perforated ilmenites were reused and some stones were broken during their use. Indeed, the last hypothetical uses might be applied, but were not confirmed by experimentation. Moreover, evidence to support the hypothesis was not found.

My hypothesis is that it is possible that most of the "multi-drilled ilmenites" of San Lorenzo have similar sound properties to the one examined by the author. The hypothesis is likely to be true for those stones that are not broken, which have the typical organological structure to produce noise and can be played within the mouth. The hypothesis was proved to be true with experimental models and acoustical and signal analysis, but for confirmation a direct study of the ilmenites of San Lorenzo will be necessary. Their large quantity[39] indicates that they were used widely and maybe in large sets. The concept of the Olmecs civilization may be enhanced if the sound properties of their "multi-drilled ilmenites" are confirmed.

4.2. OTHER LITHIC NOISE AEROPHONES

Similar lithic noise aerophones made of marble, serpentine and calcite were found in superficial surveys in the Olmec/Popoloca zone of San Juan Raya, near Zapotitlán Salinas, Puebla. In 2004, Porcayo, archaeologist of the National Institute of Anthropology and History (INAH), informed me about the discoveries and invited me to analyze the lithic objects. They have biconical perforations for the blow holes, but their main distinction is the slit cavity of the noise mechanism, instead of the conical main cavity of the ilmenites. Their general geometrical shape is approximate to a rectangular parallelepiped.

As the buccal noise generators are very similar in structure, it is possible to compare their main dimensions in Table 1. Some dimensions are very similar, especially the diameter of the conical perforations, which indicates that their makers used a very similar specialized organological-acoustical technology or knowledge. Unfortunately, the exact antiquity of those lithic aerophones is unknown.

4.2.1. BUCCAL NOISE GENERATOR OF MARBLE

In 2002, Pedro Miranda found this specimen (Fig. 10) on the surface at the Terrazas Paso del Coyote (site Z56) between the hills Campanario Ometepec and De la Hierba, near San Juan Raya, Puebla[40]. The estimated date for this site is Epiclassic/Early Postclassic (700–1100 A.D.), according to Castellón[41]. The object shows two sound mechanisms, but one of them is broken, possibly during the manufacture, because the depth of the main chamber was not completed to be able to produce noise. In this design the main chamber was not made with a conical perforation or drilling, but it is a slit. It is similar to the chamber of the "bottle cap whistle", but in this case it is different, because it is not open in its two sides. Marble is relatively soft (4–5 Mohs). The sound mechanism that is complete was made in the opposite side of the same piece of marble to reuse it. The main dimensions of the sound artifact are (in mm): length 22 (side of the complete mechanism) and 43 (broken side); width 22; height 10 (in the center) and 9 (in the extremes); the diameters of the biconical perforations of the complete mechanism are 7 and 3.5 in the external and internal surfaces of the wall; and the distance from the center of the conical perforation to the front side 5. The biconical perforations of the broken mechanism are not perpendicular to the external surface of the artifact wall, but inclined to the front side, and the external diameter is 9. The length of the complete main chamber in the front is 33; it is 8.5 deep and 5.5 wide. Another perforation was made for suspension.

36 Cyphers/Di Castro 1996, 4.

37 Like the bow, the *atlatl* accelerates a flexible shaft from the rear. For the bow the flexible shaft is called an arrow. For the *atlatl* the flexible shaft is called a dart.

38 Cyphers/Di Castro 1996, 6–7.

39 It seems that the more that 140,000 ilmenites of San Lorenzo are the largest quantity of similar ancient artifact made in stone that was found in an archaeological site and their ancient use was not identified.

40 Miranda did not know their sonorous properties and how to play the marble aerophone. He informed that a whistle in Popoloca language is called *Toto*. Popolocas of San Juan Raya commented that whistles were used to call snakes, but when they heard the noise generated by the marble aerophone they said that it was similar to that of an owl called *Lechuza de campanario* (*Tyto alba*).

41 Castellón (personal communication).

Element	Marble aerophone	Serpentine aerophone	Calcite aerophone
Aerophone length	43	31	43
Aerophone width	22	24	35
Aerophone thickness	9	8	9
Internal perforation diameter	3.5	2	3
External perforation diameter	7	6	6
Perforation distance to front side	5	6	7.5
Slit length	33	24	43
Slit depth	8.5	8	–
Maximum slit width (in its center)	5.5	4	6

Tab. 1 Main dimensions of the buccal noise generators with a slit (mm).

4.2.2. BUCCAL NOISE GENERATOR OF SERPENTINE

A similar buccal noise generator of serpentine was found in 2000 by Silviano Reyes in the surface of the Llano de Tierra Colorada, near San Juan Raya, Puebla (Fig. 11). The hardness of serpentine is similar to that of marble (4–5 Mohs). This artifact could not be analyzed acoustically, because its sound was not recorded and the required equipment was not available. The main dimensions of the aerophone are (in mm): length 31 (front side); width 26; height 8; external and internal diameters of the biconical perforations 6 and 2; distance from the center of the conical perforation to the front side 6. The length of the chamber in the front is 24; it is 8 deep and 4 wide. It has a little perforation on one side for suspension. Unfortunately, there is no estimated date for the site.

4.2.3. BUCCAL NOISE GENERATOR OF CALCITE

Another very similar noise aerophone probably made of calcite (Fig. 12) was found by Blas Castellón in the same area of San Juan Raya, in the site Agua de Burro II (Z91). The estimation of the dates for Z91 site are the Classic (400–800 A.D.) and Post Classic periods (1200–1521 A.D.), according to Castellón[42]. In 2004, it was possible to take photos and measurements of the artifact as it is now. Unfortunately, it was not cleaned and therefore it was not possible to sound it. The main dimensions (in mm) of the stone are: length 43 (front side); width 35; height 9; diameters of the biconical perforations 6 (external) and 3 (internal); distance from the center of the conical perforation to the front side 7.5. The length of the chamber in the front is 43 and it is 6 wide. Its depth could not be measured, as it is filled with soil.

5. EXPERIMENTAL MODELS

Experimental models are useful, because some experiments are not recommended with ancient objects, especially when they can be damaged or are not available for direct analysis, or they are still not cleaned. They can be very useful to test the hypothesis that the ancient objects indeed represent sound artefacts, to analyze their acoustical and organological properties and to explore possible ways of construction.

The experimental replicas were made of different materials to analyze the design with conical perforations and a slit as resonating/chaos cavities and their effects in the generated sounds. The main result of the experiments with the models is that all the objects made with the typical acoustical mechanisms can produce similar signals to those of the ancient and modern noise aerophones. In other words, there is no doubt of the sound capacity of these acoustic designs with conical or slit main cavities and two perforations face to face. The indirect sound validation was possible not only with ancient aerophones, but also with hundreds of experimental models with similar sounding mechanisms that were made in several materials including stone.

The perforation of the biconical holes and the carving of the slit cavity in marble must be done very carefully, because any mistake during the drilling can break the piece in its weakest parts, as happened with the experimental models of the multi-drilled ilmenite. Marble is even more fragile. The lapidary work in the slit design (Fig. 13) can be done in one or two hours, using modern tools and materials, but drilling of the common conical holes in soft stone such marble is not difficult. One conical cavity may be perforated in a few minutes, even with manual tools. The special work

42 Castellon (personal communication).

is the carving of the resonating chamber. To make the slit cavity a rotating cutter with a disk shape of the common UFO (unidentified flying object) “flying saucer” is needed (Fig. 14). However, it is not easy to perforate the two conical holes with their center’s line in the same axis, to make the two internal holes face to face, as is required to produce a loud noise. The material does not affect the sounds, but their structure, dimensions, internal surface and way of operation may change the frequency components of the noise signals. When the dimensions of the sounding mechanism are small the sound seems “whistling”[43], but when the dimensions are increased loud noisy sounds can be produced. The main upper limit is the size of the stones and the ability to operate them inside the mouth as their dimensions can affect the way they are played. For, example, due to the width of the stone aerophones with slit, they must be played over the tongue as is shown in Fig. 15, because the tongue cannot be at their back side.

Some models were used to test the way of operation and to discover the type of noise they can produce. They can generate several complex noise signals, if sounds from the vocal folds are added and different configurations of the vocal tract and tongue are used to change the volume and shape of the internal mouth cavities, as may happen with several other ancient aerophones. They seem simple, but they can produce complex sounds when they are coupled to the acoustic possibilities of the vocal system, as will be shown later. It is possible to create other resonator formed with the hands around the lips at the exit of the mouth to change the pitch of the signals. Also, the angle of the artifact can produce variation in the sounds and the tongue can stop the sound periodically and rapidly to generate a series of signals of different duration, like those required for a signal code.

Several lapidary experiments and analyses were necessary to test the last hypothetic non sonic utilitarian functions of the ilemenites proposed by Cyphers/Di Castro. Usually, other ancient utilitarian objects of stone do not show unnecessary perforations and in any lapidary objects unnecessary drillings are not made. For the non sonic utilitarian functions only one perforation is required and the structure of three holes and its special alignment in a plane is not necessary. It is not easy to perforate the two conical channels with their center in the same axis, and it is more difficult to perforate the two biconical channels face to face in a hard and small stone with manual drilling. It is not likely that the ancient makers made many difficult and unnecessary perforations, if the non sonic uses do not require them. Due to its hardness, the lapidary work of the ilmenite is more difficult[44] than other softer stones like marble and serpentine. It may be supposed that the multi-drilled stone was not used as a support for a rotating stick, because the internal surface of the analyzed ancient ilmenite is not polished and its size is not conveniently held by hand for a prolonged period of operation[45].

6. ACOUSTICAL AND SIGNAL ANALISIS

It is impossible to know how these noise aerophones and their signals were used exactly, as there is a lack of archaeological and iconographic information. However, even in that common situation in the ancient organology, acoustical analysis can provide the main acoustic parameters and characteristics to recognize, at least, the possible spatial context of their sound function. The sounds generated by the noise aerophones are the main evidence of their acoustical properties, and the signals can be analyzed. However, in analyzing such noises, the techniques of musical analysis are not useful: it is better to use tools that are used to study complex signals. The recordings were made with a laptop WindBook, M Series, and a microphone from Audio tecnica ATR97. To obtain the dB levels a digital RadioShack sound level meter was used. The program Adobe Audition was used to clean and edit the wav sounds. Fig. 16 shows the spectrograms[46] of buccal noise generators made from plastic, metal, marble and ilmenite [CD I, sound sample 3]. The top of the graphs show the intensity of the recorded short and flat sounds. The spectral signals show their frequency components. The main quantitative and comparative parameters and characteristics of the signals (frequency components and acoustic power[47]) can be

43 As it happens with the shepherds whistle design.

44 The perforation in a stone of similar hardness to the ilmenite (obsidian) took nearly eight hours, using modern lapidary tools and materials. Much more time is required to perforate three times and manually a stone of similar hardness. It is improbable that unnecessary perforations were made on a very large quantity of the ilmenites of San Lorenzo.

45 For that purpose the support must be of a suitable size (near 5×5×1 cm). The size of the ilmenite is 3×2×1 cm.

46 Spectrograms are used to analyze complex signal with variable frequency components during the time. The spectrograms included in this paper were obtained using the program Gram of R. Horne. In this case the frequency scale is linear, in a band of 0–22040 Hz. The spectrum amplitude in the scale of the graph has a minimum of 0 dB (white) and maximum of 90 dB (black).

47 The maximum radiated acoustic power W was estimated using two equations (in MS Excel format): one to calculate the intensity of the sound I = + (10 ^-12)* 10 ^ (dB/10) in Watts/m^2 and other to obtain W = 4* PI()*I in Watts, where dB is the sound pressure level measured with a sonometer in the same conditions, in this case at 1 m and 0 degrees, and PI() = 3.1415…

provided measuring with a sonometer in similar conditions. The distance over which the sounds can be detected can also be measured.

6.1 ACOUSTICS OF CONTEMPORARY BUCCAL NOISE GENERATORS

6.1.1 THE SHEPHERDS WHISTLE

Its signal includes a strong fundamental and a harmonic with noise of low intensity. It sounds like whistling. The fundamental (F0) varies from 2420 Hz to 2550 Hz with one very strong harmonic and others of low intensity. The whistling has a pitch between C_7 and more than E_7 of the musical tempered scale with A_4=440 Hz. Its maximum radiated acoustic power is about 0.4 Watt or 105 dB of sound pressure, but lower than the sounds of the “bottle cap whistle”. However, its higher frequency components are produced in the range of maximum sensitivity of human hearing and of some animals. It can be heard in any shepherds competition field, at a distance of more than 200 m.

6.1.2 THE BOTTLE CAP WHISTLE

It produces a signal with noise of high intensity in a very wide band (0 to more than 20 kHz). The estimated maximum radiated acoustic power is about 1 Watt or 109 dB of sound pressure. Its perceived power is louder, because the strongest noise frequency components (2–6 kHz) are located in the range of the maximum sensitivity of humans and some animals. It can be heard up to more than 500 m in the open field. The small thickness of the metal wall and the sharpness of two circular holes are the main cause of the high acoustic power of the generated sounds.

6.2 ACOUSTICS OF ARCHAEOLOGICAL BUCCAL NOISE GENERATORS

6.2.1 THE BUCCAL NOISE GENERATOR OF ILMENITE

The frequency components of a sound generated by the multi-perforated ilmenite have two strong peaks or crests with noise of medium intensity. The mean of the lowest crest varies from 2280 Hz to 2600 Hz. The other crest is also wide in frequency (5500–8600 Hz). Its estimated maximum radiated acoustic power is 0.1 Watt or a sound pressure level 99 dB. Those acoustic properties indicate that the aerophone of ilmenite can be heard in any closed space, if it is played alone.

6.2.2 THE BUCCAL NOISE GENERATOR OF MARBLE

The frequency components of the marble aerophone are generated in a wide band noise signal with similar low intensity, but it has a crest of medium intensity (between 1700 Hz and 6000 Hz). The acoustic power and sound pressure level of the noise of this marble piece is about 0.063 Watts or 97 dB. The perceived acoustic power of the marble noise generators was tested in San Juan Raya and they could be heard at a distance of up to and more than 150 m.

6.3 SYNOPSIS OF THE ACOUSTICAL ANALYSIS

In general, with the exception of the “shepherds whistle”, the examined aerophones produce noise with a wide band of frequencies with a very low value of the acoustic quality factor of the sound Q[48], but the spectral components may be altered.

The sounds of the aerophones of metal and marble can be heard at a considerable distance, and more in the case of animals that have a higher hearing sensitivity. The strong signals in the range of maximum hearing sensitivity explain the perception at long distance of its sounds. The aerophones of marble and ilmenite have less power, which means that they can be heard by humans at shorter distances, but some animals are more sensitive to the higher frequency sounds. It is possible to have an idea of the radiated acoustic power levels, in relation to the power of some well known musical instruments, because there are comparable estimations of their Watts levels. The power of the French horn and the clarinet is about 0.05 Watts, the flute is 0.06 Watts and the piccolo is 0.8 Watts. These wind musical instruments are well heard in orchestras or bands, and more so when they are played alone or in a group at the same time. The noise aerophones that has less acoustic power, the marble aerophone, is similar to the flute but it can be heard at a greater distance, because they have more frequency components in the audible range of humans. The power of the multi-drilled ilmenite is higher than the flute, but lower than the piccolo. The power of the bottle cap whistle is higher that all these wind musical instruments. The intensity and frequency components of the

48 $Q = w_0/(w_2-w_1)$, where w_2 and w_1 are the angular frequencies over the resonance frequency w_0, in which the mean relative power had lost one half of its value and $w_0 = 2*PI()*F_0$. Also, Q = Pc/P, where Q is the gain of a resonator that act as an amplifier. Pc is the amplitude of the acoustic pressure inside the cavity and P is the external acoustic pressure.

Analyzed aerophones	Sound pressure dB	Power output Watts
Bottle cap whistle	109	1
Shepherds whistle	105	0.4
Noise generator of ilmenite	99	0.1
Noise generator of marble	97	0.063

Tab. 2 Sound pressure and power output of analyzed aerophones.

signals can be altered by the manner of excitation, as is shown in the spectrogram (Fig. 17) of some short complex ilmenite sounds [CD I, sound sample 4]. Fig. 18 shows the spectral signal when vocalized waving vibrations are added [CD I, sound sample 5). The equipment used can affect the spectral signals. The power output and sound pressure of the examined buccal aerophones are shown in Table 2 and their relative intensity in decibels is shown in Fig. 19.

This kind of noise aerophones can be excited in the range of the pneumatic capacity of blowing pressure: 0–60 cm of H_2O (or 0–6 kPa). The pressure can be measured by a water-filled U tube connected to a fine plastic tube inserted in the corner of the lips.

When the buccal aerophones are played and heard in a small field or in enclosed spaces, their sounds are more impressive than if they are played at long distances in an open field. If they are played in a big set or group at the same time, special sound effects can be produced, as complex beats or “phantom sounds” that may be infrasonic (with F0 less than 20 Hz). Beats are considered as “phantom sounds” because they can not be measured with metrology equipment or detected physically. They do not produce sound pressure waves in the air. Their effects and sensations are generated psychoacoustically by the brain. The infrasonic beats can excite neurons in the cortex of the brain, which may produce beneficial physical and mental effects or generate altered states of conscience[49].

The acoustical properties of the analyzed sounds indicate uses for signaling and communication, to call and to imitate the sounds of some animals and to produce special effects in humans.

7. WORKS FOR THE FUTURE AND CONCLUSIONS

One work for the future is to study the animal sounds, in this case to know which of them can produce similar noise signals. Some specific hypothetical applications of ancient users might be analyzed and tested in an indirect way, as is the case of their possible hunting use. For example, it is possible to analyze the similarities between the signals of the experimental models and ancient noise aerophones and the animal callers that are used by the actual hunters, if it is not possible to see the direct effect of them on the animals that still are alive. It might be possible, if institutional programs are established, to study the sounds of the past as the biological sounds that still can be heard and recorded. It is probable that the hunting use of ancient noise aerophones can be validated, because a hunter that heard the noises of my experimental models commented that they are similar to those of several animals[50]. As mentioned above, many animals can hear these sounds very well, because the generated frequencies are in the band of their maximum hearing sensitivity, as is the case of dogs, deer, etc. It is known that in Mexico the *gamitaderas* or deer callers have been used in several zones[51]. It was reported that in the Maya zone, the call used by a local guide is a common predator call (generated with a deer caller) and the broker deer (*Mazama gouazoubira*) responds aggressively[52]. Knowledge of and the ability to produce hunting calls was vital practice, for ancient people, and more for those that lived before the invention of agriculture, when they were nomadic.

The exact effects of noise generators are a matter of future research. The existence of these types of aerophones indicates that in the past complex noise signals were generated and used intentionally. It is probable, that the ancient people, who had a greater contact with nature, used the noise effects in ceremonial life. It is known that the wind was very important in the ancient cultures. For example, one of the most important gods was *Ehecatl*, the Aztec wind god. Even now, the noise is produced by natural phenomena like the wind and by many animals and it is included in several phonemes like the “SH” and noise signals are used in sonic therapies.

The study of any ancient sound artifact must be multidisciplinary, but it is not always possible. The main limitations to study this particular fami-

49 Monroe Institute 2005 1.
50 Hugo Herrera (personal communication).
51 Jesus Mora (personal communication).
52 Boddington 1999, 78.

ly of instruments and other ancient aerophones is that it was not possible to find institutions, laboratories, equipment and personnel suitable and available to support the required formal analysis. There is a lack of interest and support to study the ancient organology and it was not possible to have direct access to the aerophones of this family preserved in museums and collections to be able to develop independent, technical and systematic research on them. The information and their descriptive data available to the public are very limited and superficial. Even the few data included in the official registration of archaeological goods is not provided to the public.

The existing classification systems in organology and its actual terminology can not be complete until the main types of existing ancient sound artifacts or a good sample of them, are examined and published, as those analyzed in this paper.

The main work for the future is to study all the aerophones that have been recovered. For this kind of program a specialized institution is necessary. It will no be easy, because they are stored in many museums and collections of Mexico and other countries. One can only imagine the thousands of ancient sonorous artifacts that have been recovered by authorized and unauthorized archaeological explorations or by professional and unprofessional diggings. It seems that those that have access to the recovered ancient sound artifacts do not have the technical knowledge and equipment to study them formally and systematically.

With very few exceptions, the studies published on ancient aerophones do not provide the information and data to understand their organological structure and exact dimensions, the main acoustical parameters and the signal analysis of the sounds that they can produce, even such basic ones as those provided in this paper. Since the beginning of the last century, scientific methods, techniques and tools have been applied to study western musical instruments, but very few of them have been used to study ancient aerophones. However, standard physical or acoustical protocols to analyze musical instruments were not found in the literature, because cultural and other preferences affect the technical criteria and results of their evaluation. It seems that in those scientific fields the main objective is limited to try to understand the musical instrument's systems[53]. If it is not possible to know how the ancient musical instruments and sound artifacts were made and played exactly, at least, it is possible to use scientific and technical methods and tools to try to understand their sound systems and signals. To know the sounds of the past, the recovered artifacts that are preserved in good conditions or their models can be better that any available writing.

The analysis of the known ancient noise generators may help to study and identify other recovered aerophones of this family. It may enhance the actual concept of ancient cultures and the knowledge of their music, organology and acoustics. The study and modeling of the ancient designs can help not only to understand their characteristics and how they can be made and played, but to recreate a millenary, beautiful, rich and extraordinary sonic art and technology.

53 Fletcher/Rossing 1991, v (Preface).

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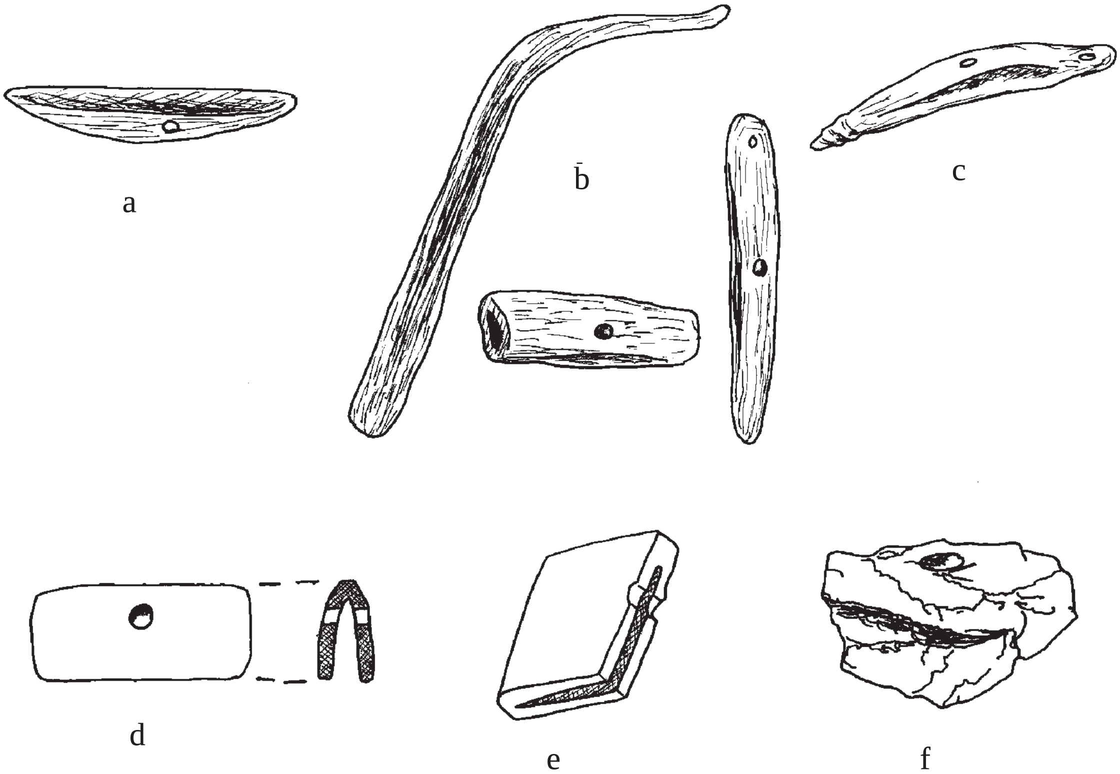

Fig. 1 Drawings of some ancient buccal noise generators.

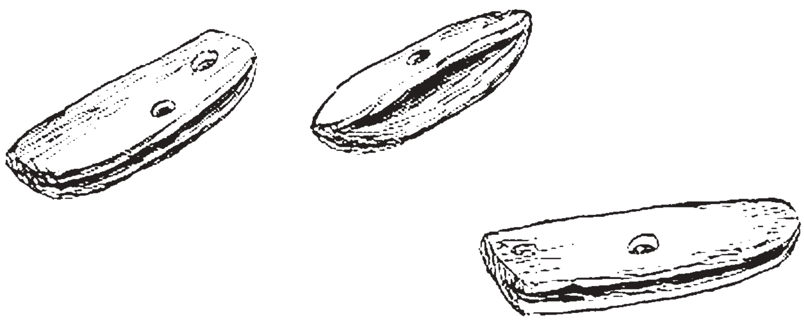

Fig. 2 Clay buccal noise generators of Jalisco.

Fig. 3 Dissected clay models of some Mesoamerican complex noise generators.

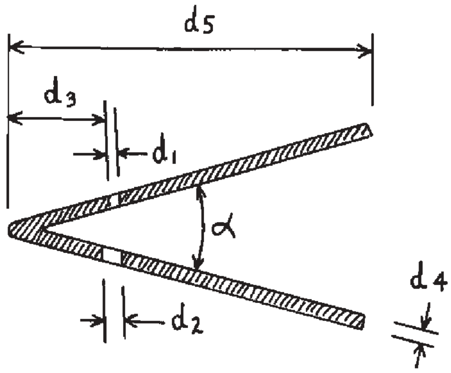

Fig. 4 Structure and parameters of the basic buccal noise generator.

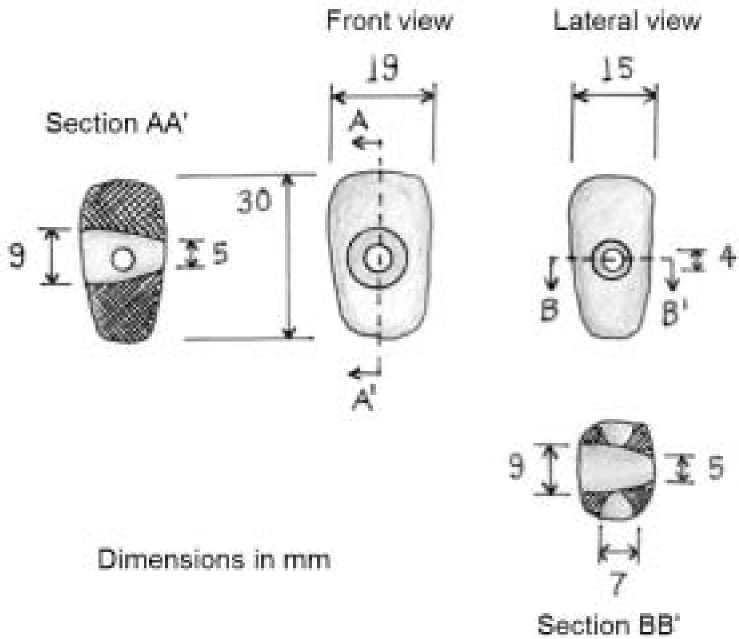

Fig. 5 Main views of the buccal noise generator of ilmenite.

Fig. 6 Buccal noise generator of ilmenite.

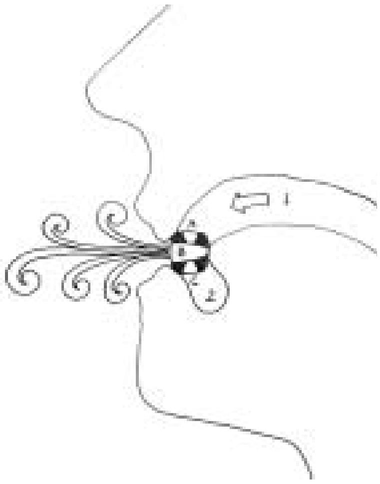

Fig. 7 How to play the multi-drilled ilmenite aerophone within the mouth.

Fig. 8 Shepherds whistle sent by Hillary Kerrod, New Zealand.

Fig. 9 Bottle cup whistle.

Fig. 10 Buccal noise generator of marble.

Fig. 11 Buccal noise generator of serpentine.

Fig. 12 Buccal noise generator of marble.

Fig. 13 Experimental lithic models with slit cavity.

Fig. 14 A modern abrasive tool used to make the slit cavity in soft stones.

Fig. 15 How to play the buccal noise generator of stone with a slit within the mouth.

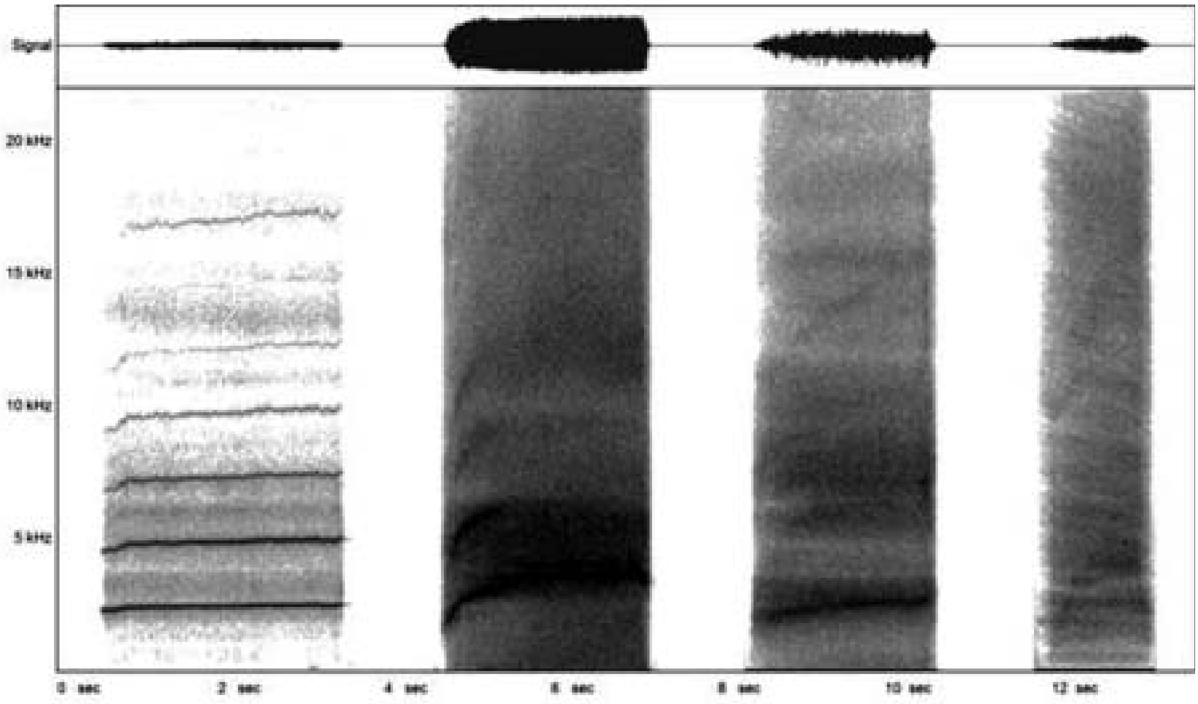

Fig. 16 Spectrograms of the aerophones of plastic, metal, ilmenite and marble.

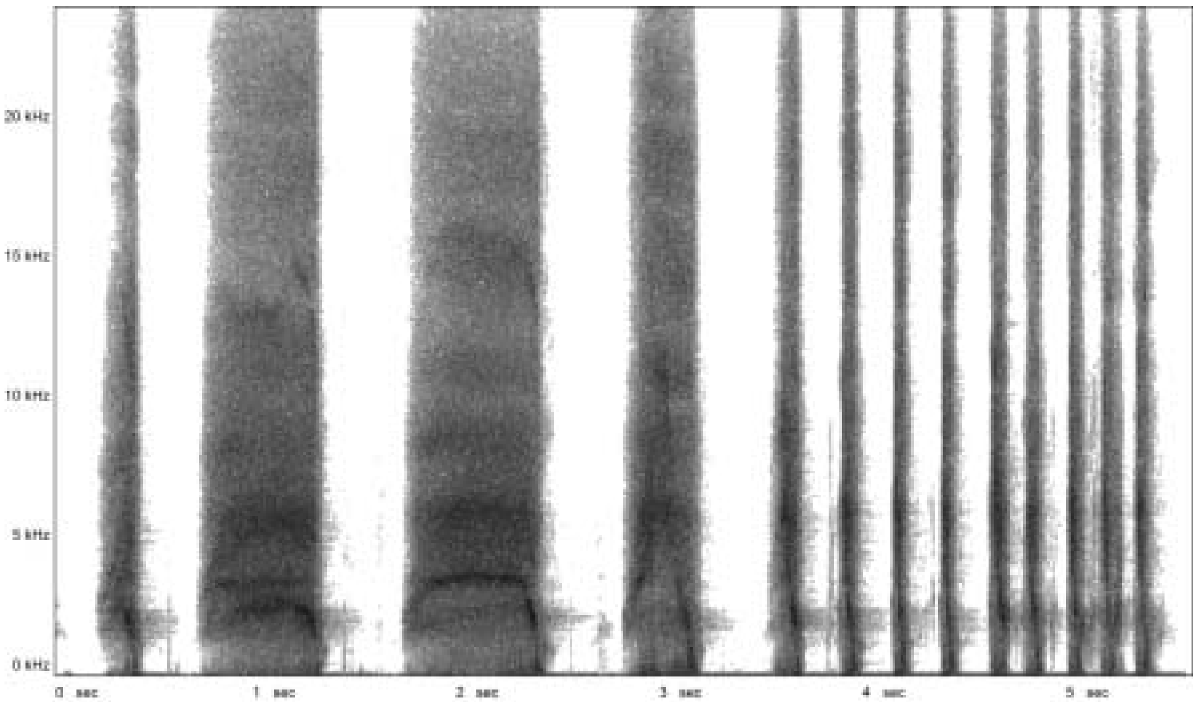

Fig. 17 Spectrograms of the buccal noise generator of ilmenite.

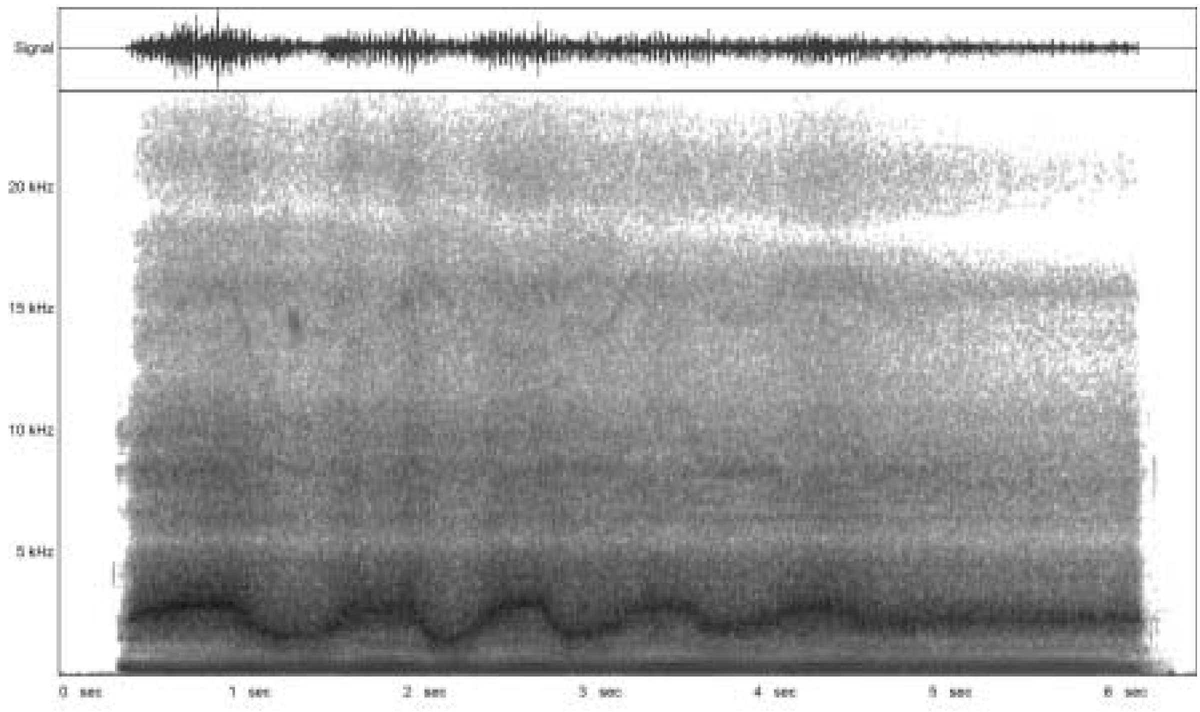

Fig. 18 Spectrogram of the buccal noise generator of ilmenite excited with vocalized waving vibrations.

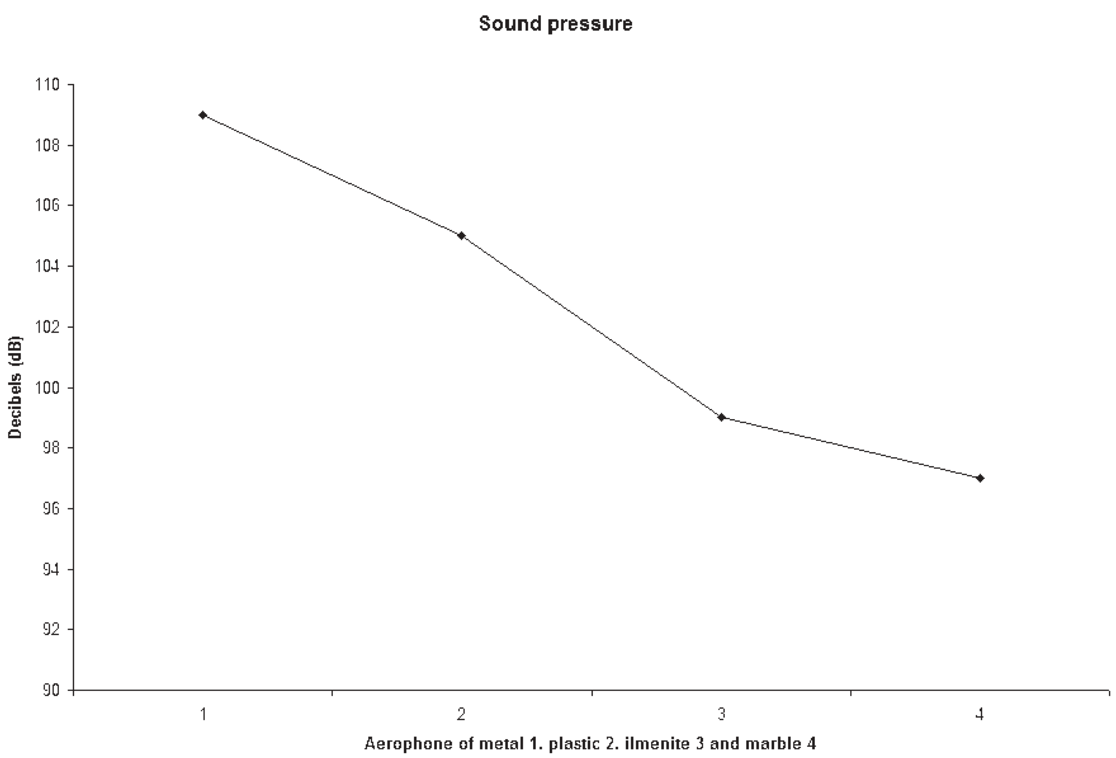

Fig. 19 Sound pressure levels (output decibels).