« À coup d'éclats ! »
La fracturation des matières osseuses en Préhistoire :
discussion autour d'une modalité d'exploitation en apparence simple et pourtant mal connue
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Experimental data on the splitting and knapping of mammoth tusks and reindeer antlers

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Résumé : De nombreux sites préhistoriques ont livré divers artefacts décorés ou sculptés en ivoire et en bois de renne. Cette sculpture élaborée est, avec la chasse aux mammouths et aux rennes qui jouait également un rôle important, une des caractéristiques des cultures préhistoriques. Pour les groupes humains qui étaient installés dans les régions où l'ivoire pouvait être récupéré des cimetières naturels de mammouth, l'abondance de l'ivoire et des bois de cervidé a joué un rôle significatif pour le développement de l'art mobilier préhistorique sculpté et gravé. Les groupes ne disposaient pas d'outils métalliques, mais leur connaissance de l'ivoire et du bois de renne leur ont permis de produire des objets uniques d'un point de vue technique. L'analyse des artefacts en défenses et en bois de cervidé a montré que ces matériaux solides, durs et durables présentent une combinaison étonnante et paradoxale de caractéristiques.
Les défenses en ivoire et le bois de cervidé sont des matériaux qui témoignent pendant leur transformation à la fois une plasticité/ductilité et une fragilité. Nous avons pris en considération une seule technique de traitement qui a radicalement changé leurs propriétés. La congélation de l'ivoire et du bois de cervidé naturellement humide confère à ces matériaux une fragilité supplémentaire, ce qui les rend plus aptes à la taille par percussion telle qu'elle est pratiquée dans les industries lithiques. Nos expérimentations sur le fendage et la taille des défenses de mammouth et des bois de rennes sont présentées dans cet article. Deux facteurs principaux modifient de façon significative les propriétés de taille de ces matériaux, le premier étant la température et le second l'humidité. En fonction des différentes combinaisons des deux, les propriétés plastiques des bois de cervidé ainsi que de l'ivoire changent de manière significative. Nous distinguons trois points fondamentaux influant sur les qualités mécaniques : premièrement, l'ivoire ou le bois de cervidé naturellement humide, congelé à une température inférieure à -25°C deviennent des matériaux relativement durs et cassants ; deuxièmement, à température positive, l'ivoire ou le bois de cervidé naturellement humide sont des matériaux relativement mous et ductiles ; et troisièmement, l'ivoire ou le bois de cervidé « secs » sont des matériaux plutôt durs et visqueux (visco-élastiques).

Mots-clés : Paléolithique supérieur, Eurasie, analyse expérimentale, techniques de taille de défenses de mammouth, d'os et de bois de cervidé, stigmates.

Abstract: A great deal is known about prehistoric sites the excavations of which yielded numerous skilfully carved ivory and reindeer antler artefacts. High-level carving skills are primarily observed for prehistoric cultures in which mammoth and reindeer hunting played an important role as well as for prehistoric people living in regions in which ivory was available in natural burial places, the so-called "mammoth cemeteries". The abundance of ivory and antler raw materials therefore played an important role in prehistoric carving. These people had no metallic tools, but they had a great knowledge of the treatment of ivory and reindeer antler to create objects that are unique from a technical perspective. Analyses of artefacts made from tusks and antlers have shown that these strong, hard and durable materials have a mysterious and paradoxical combination of qualities.
Tusks (ivory) and antler raw materials during processing exhibit both plasticity/ductility and brittleness. We have considered only one technique which radically changed the properties of ivory and antler. Freezing of naturally moist ivory/antler provided these materials with extraordinary fragility, which made it possible to apply a knapping technique that was traditionally used for lithic industries. Experimental data related to the splitting and knapping of mammoth tusk and reindeer antlers are presented in this article. It could be stated that there are two main factors that significantly affect the knapping properties of ivory and antler raw materials, the first being temperature, the second moisture. Depending on the various combinations of temperature and moisture characteristics, antler as well as ivory significantly change their properties. We distinguish only the three most extreme cases for which fundamentally different mechanical qualities can be observed for these raw materials: 1. In a naturally moist ("fresh") and frozen state (below -25°C) ivory or antler is a relatively hard and brittle material. 2. Naturally moist ivory or antler at positive temperatures is a relatively soft and ductile material. 3. "Dry" ivory and/or antler is relatively hard and viscous (visco-elastic) material.

Keywords: Upper Palaeolithic, Eurasia, experimental use-wear analysis, technologies of mammoth tusks, knapping of bone and antler, traces of tusk and antler knapping.

Currently, a large number of prehistoric sites are known in Eastern Europe and Siberia, the excavation of which has yielded numerous, varied, and skilfully crafted objects made from mammoth tusks and reindeer antlers. A high level of ivory, antler and bone carving skills can be stated first of all in the material culture of those prehistoric people who had the opportunity to extract tusks from the natural burials of dead mammoths, the so-called 'mammoth cemeteries' such as Bereliokh (Vereshchagin, 1977), or those whose subsistence was based on the hunting of mammoths or reindeer.

The abundance of ivory and antler raw materials played an important role in the development of bone processing skills during prehistoric periods. People of this era had a sound knowledge of the methods used for processing mammoth tusks and reindeer antlers, which made it possible to create unique products from a technical perspective such as the two-metre-long spears known from the adolescent burial in the Upper Palaeolithic settlement at Sungirsky dated to 28000–27000 BP (Bader, 1978) or the Palaeolithic Venus figurines stemming from the upper layer *p* of the Kostienki 1 site, as well as from the Avdeevo, Gagarino, Khotylevo II and Mal'ta sites dated to 23000–21000 BP (Praslov and Rogachev, 1982; Gvozdover, 1995; Zamiatnin, 1934; Khlopachev, 2006; Gerasimov, 1941). Over the past millennium many ancient techniques related to bone processing have fallen into oblivion and been lost, but there is still great deal of interest in their study. Indeed, studies into ancient methods of mammoth tusk and reindeer antler processing have a long history in Russian archaeology (Gerasimov, 1941; Semenov, 1957; Filippov, 1978, etc.).

Analyses of artefacts made from tusks and antlers has shown that these strong, hard, and durable materials have a mysterious and paradoxical combination of qualities. Both of these materials were well cut, sawed, abraded, and polished, and at the same time they were suitable for use with the traditional lithic knapping technique (Khlopachev, 2000-2001). Thus, ivory and antler raw material during processing shows both plasticity/ductility and brittleness.

Plasticity is the quality of a material to irreversibly change its dimensions and shape (significant deformation) under the action of mechanical loads. Brittleness is the quality of a material to break down with a slight deformation.

The point is that both types of material can be knapped in the same way as flint or other brittle materials. This is clearly indicated by the numerous archaeological finds of a variety of tusks and antler flakes and blades as well as cores and nuclei from which they were removed. These flakes, as well as the removal scars on cores, exhibit all the signs of an 'artificial' knapping platform, including cone of fracture, bulb of force, compression waves, a complex system of spatial organisation of various flake scars, etc. Artefacts of this kind are not uncommon; they are found almost everywhere in Europe, in Asia, and in America (Khlopachev, 2006; Khlopachev and Girya, 2010; Khlopachev et al., 2013; here: fig. 1 to fig. 3). During our studies it was found that there are two main factors that significantly affect the knapping properties of ivory and antler raw materials, the first being temperature, the second moisture. Depending on the various combinations of temperature and humidity characteristics, antler as well as ivory significantly change their properties.

We consider that it is important to emphasise that in the large range of possible intermediate states of antler and ivory, we distinguish only the three most extreme states, which indicate fundamentally different mechanical qualities related to these types of raw materials:

– naturally moist ('fresh') and frozen (below −25°C) ivory or antler is a relatively hard and brittle material;

– naturally moist ivory or antler at positive temperatures is a relatively soft and ductile material;

– 'dry' ivory and/or antler is a relatively hard and viscous material.

A clear difference between fossil mammoth tusks and 'fresh' tusks, in our opinion, is that well-preserved ivory, being in permafrost, has a higher degree of moisture than the tusk during the life of the animal. Tusk raw material belongs to a special group of biological composites, which swell through the absorption of moisture; in fact 8–10% of a 'fresh' tusk consists of water (Korago, 1992).

After the death of an animal, mammoth tusks lose natural nutrient medium; their integrity in this case depends entirely on the temperature and humidity of the environment. In order to preserve the tusks' homogeneity, it is necessary that the temperature does not exceed +25°C, and that humidity is between 45 and 55% (Schmid, 1989, p. 58). Depending on the taphonomy (burial and deposition conditions) the rapid entry of a tusk into a humid environment without previous long exposure in the air prevented the appearance of drying cracks on its body and subsequent cryogenic cracking, and thus ensured better preservation of bone material during its stay in frozen ground. Which means that such tusks can be conditionally regarded as 'fully soaked'. The existence of such differences between the fossil and the ancient lifetime of the mammoth ivory is not in doubt, but they quickly level off immediately after the extraction of the tusks from the ground, during their drying.

MAMMOTH TUSK AND ANTLER KNAPPING, SPLITTING IN A DRY STATE

By 'dry' tusk raw materials we mean the state of ivory when, due to the release of its natural moisture, it becomes significantly denser, loses its translucency and changes its external pinkish-brownish color to matt white. The initial experiments were carried out on the splitting of a 'dry' mammoth tusk by one of the authors in 1983, on the occasion of the Kostenkovsky Palaeolithic Expedition. Subsequently, they were repeatedly reproduced by the authors in laboratory and field conditions, using raw materials of various degrees of desiccation, sizes and shapes. The results of these experiments do not add anything new to the observations made previously by A. K. Filippov in the 1970s (Filippov, 1983, p. 14).

Fig. 1 – Elongated ivory flakes stemming from Upper Palaeolithic sites. 1: Khotylevo II; 2: Yeliseyevichi 1.
Fig. 1 *– Éclats allongés d'ivoire provenant de sites du Paléolithique supérieur. 1 : Khotylevo II ; 2: Yeliseyevichi 1.*

It is possible to produce an average size flake from a tusk body core by repeatedly striking at one point at a platform angle close to 80° using a massive stone hammer.

A necessary condition for this is also the presence of a strong massive platform and, if possible, the preservation of the same direction of different impacts. Small, short and irregularly shaped flakes up to 2 cm wide can be removed from such a nucleus by one or two strokes. The term 'flaking' or 'cutting' to determine the process of obtaining such chips is inappropriate. Since the 'dry' mammoth tusk can be broken with great difficulty, the use of the term 'striking' is more appropriate here.

The degree of viscosity of dry tusks is very high. When a large flake is removed, the greater effort must be made to separate it from the core. However, this does not mean that a very strong blow will ensure a free removal of the flake. Very rigid limits on the possible strength to be applied to the ivory core striking platform are imposed by the ability of the cleavage zone to withstand this impact without destruction. Thus, the successful removal of spalls from cores of dry mammoth ivory is possible by multiple powerful (insofar as the strength of the spalls platforms allows) impacts. Such restrictions significantly narrow the morphological variability of the spalls that can be produced by the knapping of 'dry' tuft raw material. It is impossible to knap large flakes with small, dotted or linear platforms, as well as thin elongated spalls with regular outline (blade and bladelets) from a dry tusk nucleus.

We did not experiment with the flaking of 'dry' frozen ivory. Such an experiment was conducted at our request by our colleague O. V. Kuznetsov, a use-wear specialist, in the suburbs of Chita (Russia, East Siberia), in conditions of forty-degree-Celsius frost. No noticeable changes in the properties of the 'dry' tusk in the cold and dry conditions of the Transbaikalian winter were noted during the experiment. With great difficulty using a heavy and massive hammerstone only a few small flakes were removed from the mammoth ivory core with a comfortable striking platform (fig. 4). This confirmed our assumption that low temperatures do not change the knapping properties of dry mammoth tusks.

The chips obtained from the 'dry' tusk are shown in the figure (fig. 5). The signs that distinguish them from chips that were obtained under other raw-material conditions are few and uninformative. For such spalls the following characteristics can be identified:

Fig. 2 –Transverse ivory flake. Yana, Upper Palaeolithic site (material collected from a washed out occupation layer located on the river bank).
Fig. 2 *– Éclat d'ivoire transversal. Yana, site du Paléolithique supérieur (pièces récupérées d'un niveau d'occupation lessivé sur les berges de la rivière).*

– the presence of a massive platform, often with a non-conical (bending) fracture initiation;

– a more pronounced relief texture grid of Schreger lines, especially on transverse fracture surfaces.

It was not possible to establish further specific features. Morphologically similar flakes can be removed from wet frozen ivory cores. The only difference: the grid of Schreger lines on the 'frozen' chips has a much weaker relief. Therefore, when analysing artefacts such as short ivory flakes, it is difficult to determine whether these are the result of 'dry' or naturally wet tusk knapping.

Much more definitely determined are flakes that could not be produced from 'dry' ivory nuclei. This definition can be made by comparing the proportion of striking platforms and the flakes themselves. Consequently, when analyzing archaeological material, the definition of the method of splitting and, most importantly, the qualitative state of the tuft raw material at the time of its splitting in prehistory should be conducted in a 'by-contradiction' way. That is, large chips with small areas, long, narrow and thin chips (plates) cannot physically be obtained from a dry tusk ivory.

We do not see any special need to analyse in detail the features of dry antler splitting. It is well known that antler tools of different forms are used by present-day experimenters for flintknapping. Because this material is sufficiently hard and has exceptional viscosity, it is possible to knap any size of flakes from any brittle stone even at the most blunt (unprofitable) platform angles. So, there is no need to prove specifically that in the normal state antler is not a knappable material; it is not brittle.

KNAPPING OF NATURALLY MOIST MAMMOTH TUSK AND ANTLER AT POSITIVE TEMPERATURES

The possibility of knapping naturally wet mammoth tusks is traditionally associated with the application

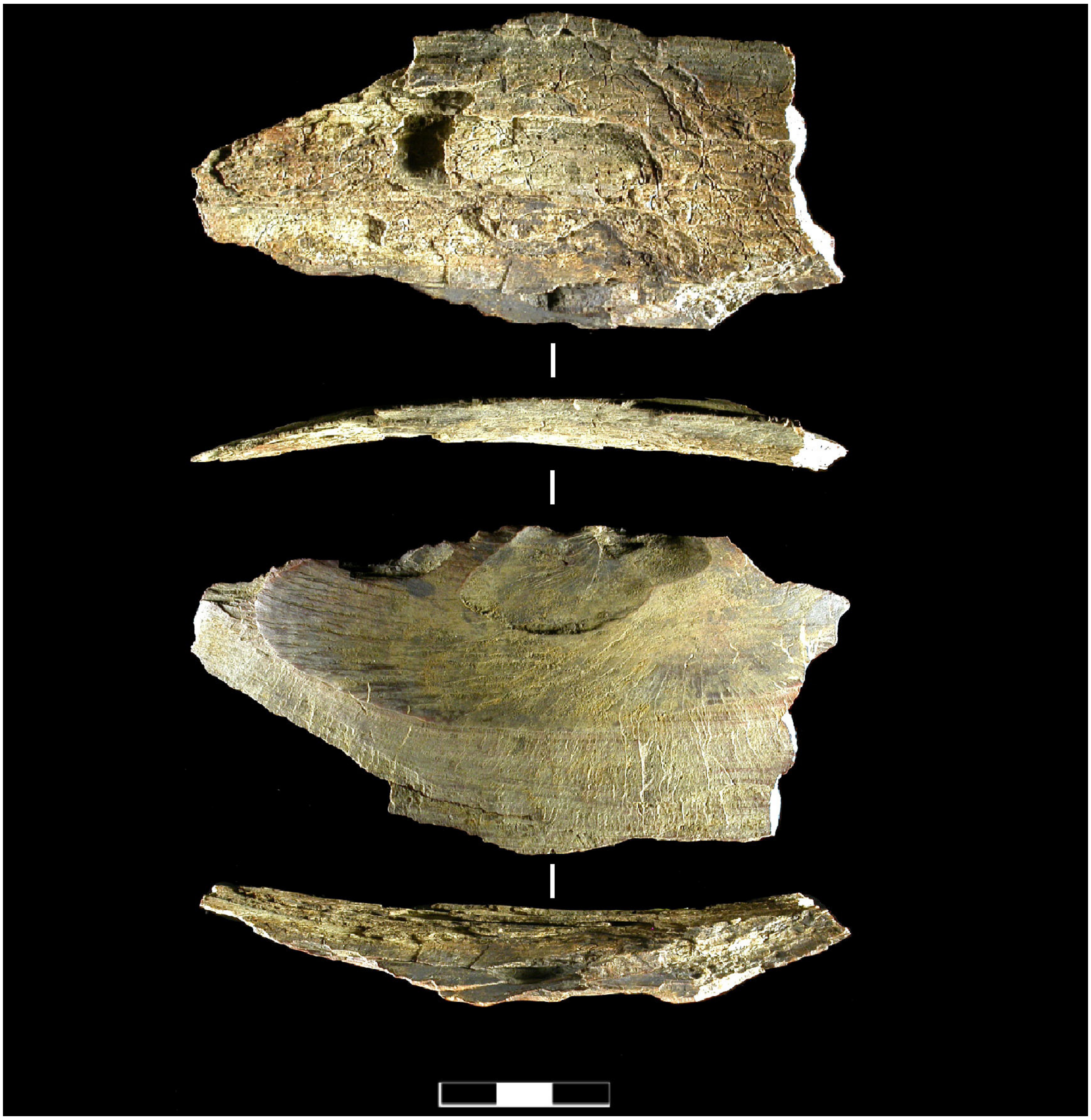

Fig. 3 – Transverse ivory flake. Yana, Upper Palaeolithic site (material collected from a washed out occupation layer located on the river bank).
Fig. 3 – *Éclat d'ivoire transversal : Yana, site du Paléolithique supérieur (pièces récupérées d'un niveau d'occupation lessivé sur les berges de la rivière).*

of a 'very strong blow'. This idea has passed from one scientific work to another since M. M. Gerasimov (Gerasimov, 1941). We carried out several experiments on the splitting of mammoth tusks in a naturally moist state, after the rapid entry of a tusk into a humid environment without previous long exposure to air. A big fragment of a complete tusk extracted from the permafrost which was left outdoors for more than ten years in the Arctic tundra on Zhokhov island was chosen as a blank.

It should be noted that the modern climate on the island in the summer is very moist (70-100% humidity), the daytime temperature rarely exceeds +6ºC, and such high temperatures happen no more than a few hours per year. The state of this tusk was defined as 'naturally wet', since after extraction from the ground it was clearly dry and concentric cracks of desiccation appeared on it, but at the same time the tusk mass retained its semi-translucency.

One end of the tusk fragment was accurately sawn off at a very favourable angle for the longitudinal knapping. This end was used as a core platform. Blows were struck using an iron 10 kg sledgehammer. The mass of the tusk segment (over 30 kg) provided sufficient stability of the nucleus at the time of impact and guaranteed a reliable application of the maximum force moment to

Fig. 4 – 'Dry' ivory knapped in a frozen state. Direct percussion using a heavy hammerstone. Experiment carried out by O. V. Kuznetsov in the Transbaikal region.
Fig. 4 *– Ivoire « sec » taillé à l'état congelé. Percussion directe avec un percuteur lourd en pierre. Expérimentation réalisée par O. V. Kuznetsov dans la région de Transbaikal.*

the nucleus platform. Another similar experiment with a weakly frozen mammoth tusk and a very heavy hammerstone was performed in a low-temperature freezer KHN-4 with a CARRIER monoblock (with a volume of 4 m^3) of the MAE RAS (Peter the Great Museum of Anthropology and Ethnography, the Kunstkamera) and gave the same results. Thanks to these experiments it could be demonstrated that after several dozen strokes the striking platform of the ivory nucleus was crushed and distorted (fig. 6), but there was no separation of even such chips as in the splitting of the 'dry' tusk (fig. 5).

This experiment, the result of which was clear to us from the beginning, is very important precisely for its failure. It proves that wet mammoth ivory raw materials, dried as much as possible under arctic tundra conditions in the summer, are not suitable for knapping, even when super-powerful strikes are applied. The same can be said with respect to antler. Humidification only softens the antler, strengthening its plasticity and reducing its ability to split to zero.

KNAPPING OF NATURALLY MOIST MAMMOTH TUSK AND ANTLER AT LOW TEMPERATURES

Experiments on knapping of mammoth tusk in a frozen state were conducted by the authors in 2004. The initial experiment was carried out using an ordinary household refrigerator in which the mammoth tusk was placed in the freezer compartment. This piece of mammoth ivory did not release its natural moisture and had a well-prepared convenient platform for flakes to be removed at one end. The tusk was cooled at a temperature of −18°C for six hours (longer use of extreme cooling mode was impossi-

Fig. 5 – Knapping spalls of 'dry' frozen ivory stemming from direct percussion using a heavy hammerstone.
Fig. 5 *– Chutes d'ivoire « sec » congelé issues de percussion directe avec un percuteur lourd en pierre.*

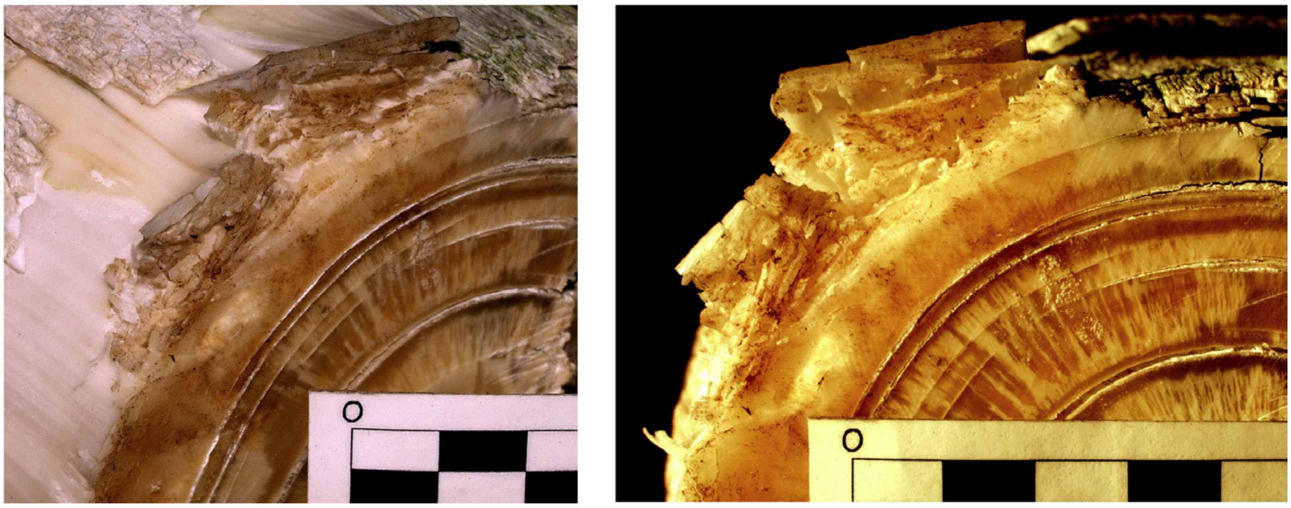

Fig. 6 – Striking platform of a 'naturally moist' ivory core after several dozens of strokes using a heavy metal hammer. Experiment carried out on Zhokhov island in 2001.
***Fig. 6** – Plan de percussion sur bloc d'ivoire naturellement humide après plusieurs coups percussion directe avec un percuteur en métal lourd. Expérimentation réalisée sur l'île de Zhokhov en 2001.*

ble in this refrigerator!). After cooling the ivory core was subjected to knapping with a hammerstone. Almost immediately after the removal of the first flakes, it became clear that the knapping process was easier than in the case of dry tusks at room temperature, but still not easy enough. The flakes obtained in these experiments are shown in the figure (fig. 7). As this experience has evidenced, ivory knapping must be carried out quickly, because in just a few minutes the surface layer of the nucleus had time to warm up and, as a result, lost its fragility.

Fig. 7 – Ivory spalls stemming from direct percussion using a hammerstone after freezing in a home refrigerator at −18°C, experiments carried out in 2004.
***Fig. 7** – Chutes d'ivoire produites par percussion directe avec percuteur en pierre après congélation à − 18° dans un réfrigérateur domestique. Expérimentation réalisée en 2004.*

Fig. 8 – Knapping of ivory by direct percussion using big and medium size hammerstones, experiment carried out in 2004 at Murinsky Park, St. Petersburg at –5ºC.
Fig. 8 *– Taille de l'ivoire par percussion directe avec des percuteurs de moyenne et grande taille, expérimentation réalisée en 2004 dans le Parc Mourinsky à Saint-Pétersbourg par − 25°C.*

An attempt to use the KHN-4 low-temperature freezer with the CARRIER monoblock (of a volume of 4 m^3) of the Laboratory of conservation and restoration of the MAE RAS in our experiment was unsuccessful. It did not provide the low temperature needed. Our attempts to produce any flakes using a heavy hammerstone from the surface of the mammoth tusk cooled in this freezer over six days did not yield the positive results. After the impact the platform at the end of the tusk fragment was crumpled and the crack did not occur. The situation could not

Fig. 9 – Stone hammer and a few flakes produced on the occasion of experiments carried out in 2004 at Murinsky Park, St. Petersburg.
Fig. 9 *– Percuteur en pierre et quelques éclats produits lors de l'expérimentation réalisée en 2004 dans le Parc Mourinsky à Saint-Pétersbourg, 2004.*

Fig. 10 – Stone hammer used for the knapping of ivory, experiment carried out in 2004 at Murinsky Park, St. Petersburg at −25°C.
Fig. 10 *– Percuteur en pierre utilisé pour la taille de l'ivoire, expérimentation réalisée en 2004 dans le Parc Mourinsky à Saint Pétersbourg par − 25°C.*

Fig. 11 – Successful removal of a transverse ivory flake, experiment carried out in 2004 at Murinsky Park, St-Petersburg, at −25°C.
Fig. 11 *– Détachement réussi d'un éclat transversal d'ivoire, expérimentation réalisée en 2004 dans le parc Mourinsky à Saint Pétersbourg par − 25°C.*

be changed either by replacing the hammerstone with an even heavier one, or by core platform rejuvenation.

Further experiments were conducted in winter of 2004 in the open air in the Murinsky park of St. Petersburg at a temperature of −25°C (fig. 8). As in the previous experiment, a fragment of 'fresh' (never dried out) tusk 0.5 m long and 0.15 m in diameter was taken to conduct the research. This piece had two well-prepared platforms and deep V-shaped groove cut along the tusk. It was kept in frost for three and a half hours. This time knapping of the frozen mammoth tusk was more successful. With the help of a medium-sized hammerstone it was possible to obtain several elongated and transverse flakes (fig. 9 to fig. 11). Most of the flakes were removed from the platform on the lateral surface of the tusk—from the side of the deep longitudinal groove. The largest separated flake had a width exceeding 15 cm (fig. 12 and fig. 13).

Fig. 12 – Large transverse ivory flake produced on the occasion of experiments carried out in 2004 at Murinsky Park, St. Petersburg at −25°C.

Fig. 12 *– Large éclat transversal produit lors de expérimentation réalisée en 2004 dans le Parc Mourinsky à Saint Pétersbourg par − 25°C.*

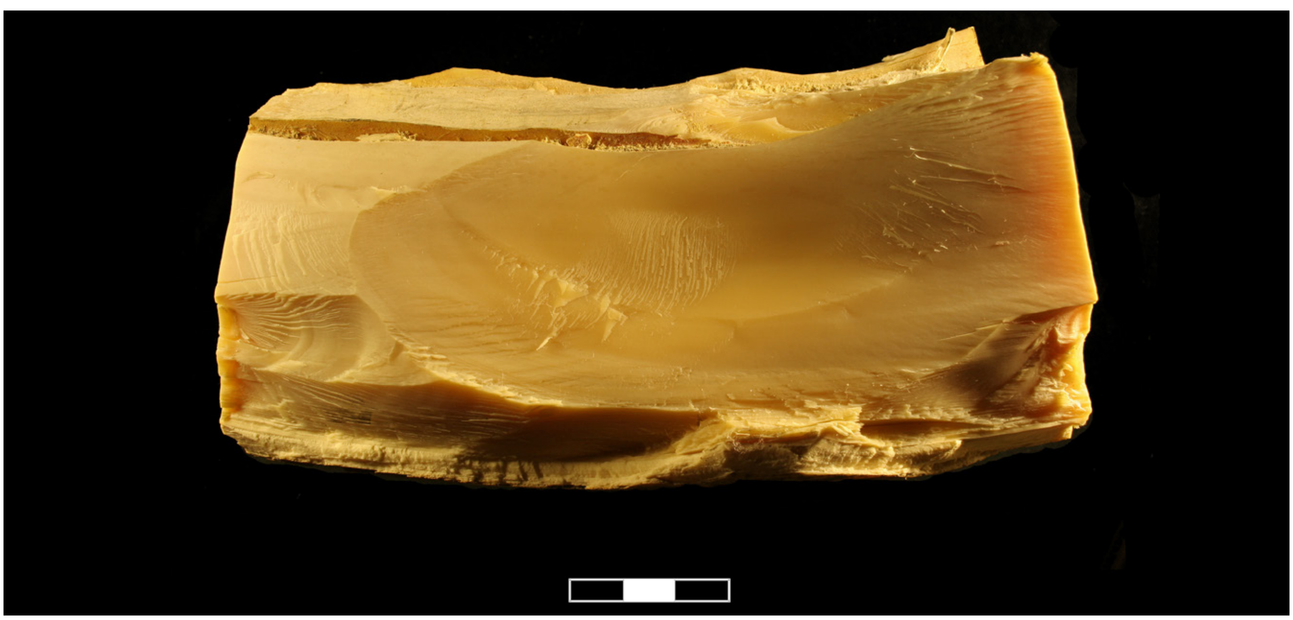

Fig. 13 – Ivory nucleus with the removal scar of a transverse flake, experiment carried out in 2004 at Murinsky Park, St-Petersburg, at −25°C.

Fig. 13 *– Nucléus d'ivoire avec le négatif d'enlèvement d'un éclat transversal, expérimentation réalisée en 2004 dans le Parc Mourinsky à Saint Pétersbourg par − 25°C.*

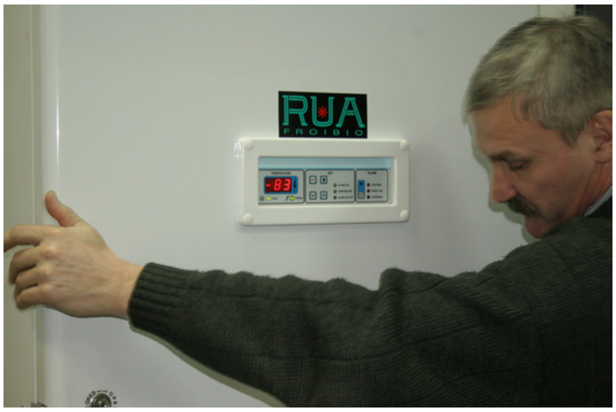

Fig. 14 – Vladimir Chouroun preparing a freezer-box ‘Ruainstruments CT322LV2755’ at the German-Russian Otto Schmidt Laboratory for Polar and Marine Research (OSL) at the Arctic and Antarctic Research Institute (AARI) in St. Petersburg.
Fig. 14 *– Vladimir Chouroun préparant un compartiment du congélateur « Ruainstruments CT322LV2755 » au Laboratoire germano-russe Otto-Schmidt pour la recherche polaire et marine (OSL), à l’Institut de recherche arctique et antarctique (AARI) à Saint-Pétersbourg.*

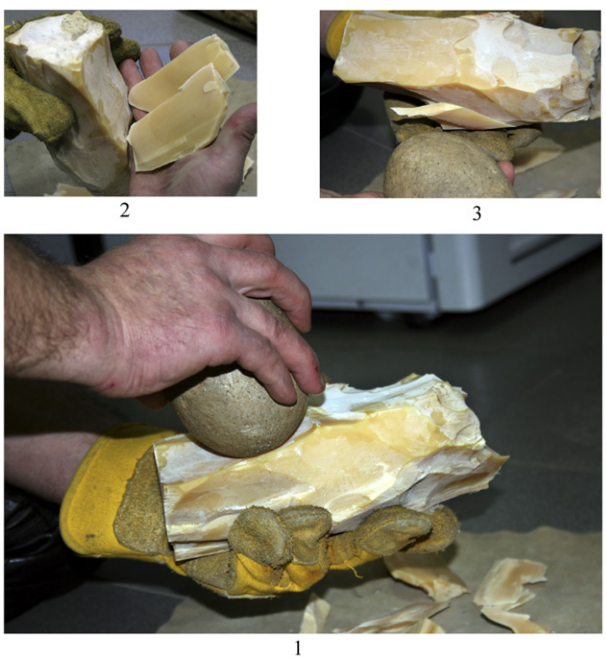

Fig. 15 – Knapping of frozen ivory using a stone hammer, experiment carried out in 2007.
Fig. 15 *– Taille de l’ivoire congelé avec un percuteur en pierre lors de l’expérimentation réalisée en 2007.*

Encouraged by this success and having received a kind invitation from the Russian-German Otto-Schmidt Laboratory for Polar and Marine Research we continued our experiments in an enclosed space. Thanks to the help of laboratory assistant Vladimir Charun and the equipment provided – the low temperature cabinet ‘Ruainstruments CT322LV2755’—in 2007 we managed to conduct a complete series of experiments with mammoth tusk ivory frozen at much lower temperatures, i.e. −30 to −80ºC (fig. 14).

Fig. 16 – Knapping of frozen ivory using an antler punch tool and a wooden billet, experiment carried out in 2007.
Fig. 16 *– Utilisation d’un punch en bois de cervidé et d’un percuteur en bois pour tailler de l’ivoire congelé lors de l’expérimentation réalisée en 2007.*

Fig. 17 – Knapping of frozen ivory using an antler punch tool and a wooden billet, experiment carried out in 2007.
Fig. 17 *– Utilisation d’un punch en bois de cervidé et d’un percuteur en bois pour tailler de l’ivoire congelé lors de l’expérimentation réalisée en 2007.*

In contrast to the previous studies, during which our main task was to determine the knapping abilities of the frozen tusks, during the series of experiments in 2007 great attention was paid to the modelling of technological processes revealed during the study of prehistoric ivory knapping technologies related to ivory industries of the Upper Palaeolithic of Eastern Europe and Siberia (Khlopachev, 2006). Results of these experiments fully met our expectations. At temperatures below −30°C it appeared to be possible to split wet tusk not only by direct percussion with hammerstones, but also by indirect percussion using antler punch tools. No special efforts were required to remove the flakes. It was necessary only to observe the same rules as for the knapping process of any other isotropic material.

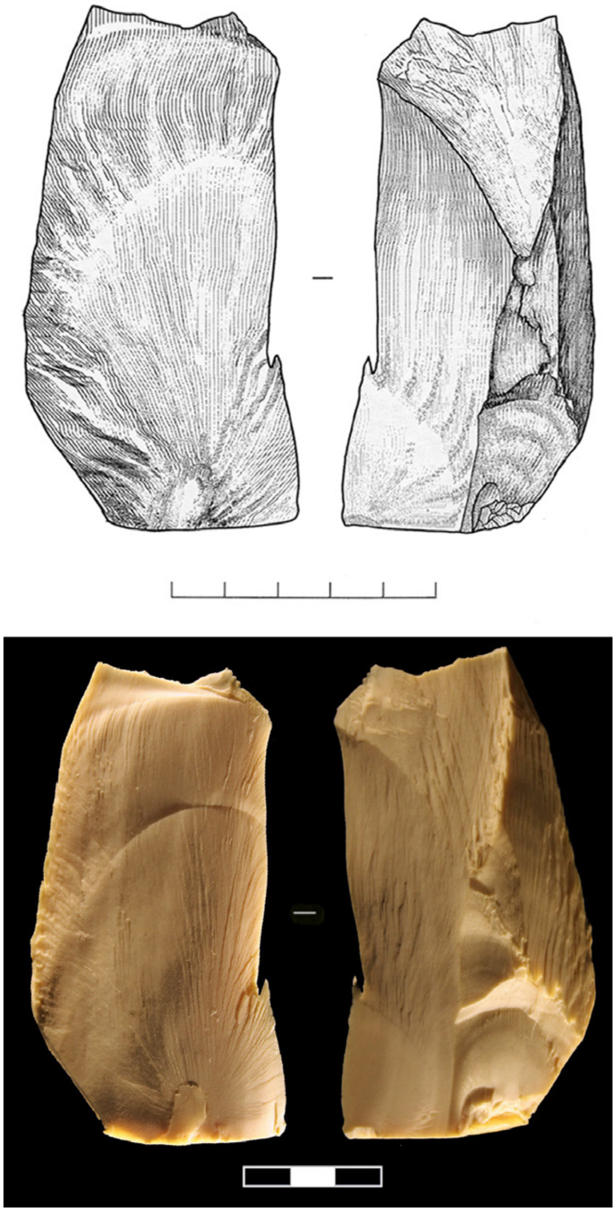

Fig. 18 – Transverse flake removed from an ivory tusk frozen up to −40°C, experiment carried out in 2007.
Fig. 18 *– Éclat d'ivoire transversal détaché d'un bloc d'ivoire congelé à env. − 40°C, expérimentation réalisée en 2007.*

Experiments have shown that removing tusk flakes is best performed from an acute platform angle, using hard and heavy hammerstones (fig. 15). Grooves, cut on the surface of the tusk, are one of the simplest and most convenient way to create a striking platform for the removal of flakes, regardless of their direction. In cases in which the groove is not wide enough, which makes it difficult to apply an accurate blow to the edge of the groove plane, it is more convenient to use an antler punch and a heavy stick (fig. 16 and fig. 17). All the ivory flakes produced in this way exhibited the same features on their ventral sides as is the case for knapped stone: compression waves, fissures, bulb of percussion (or a non-conical initiation), etc. (fig. 18 and fig. 19). For the removal of large and long blade-like flakes, one stroke, as a rule, is not enough; it is necessary to apply several successive strokes to the same point. Traces of such a step-by-step development of the fracture plane (cleaving) are well read on the ventral surface in the form of large, wavy, smooth steps shifting into each other (fig. 20). A significant quantity of waste by-products is produced in the course of mammoth tusk knapping at temperatures below −30 °C, such as small (1-2 cm) and very small (less than 1 cm) chips (fig. 17). As a result, in the location in which tusk knapping is carried out a heap of small tusk chips of varying sizes and forms, similar to the so-called 'production places', which are well-known in Palaeolithic archaeology as 'flintknapper places' ('concentrations'). We were able to identify similar 'concentrations' stemming from tusk knapping thanks to a planigraphic analysis of tusk knapping waste distribution at a distinct number of Upper Palaeolithic sites: Khotylevo II dated to 23,000–21,000 BP, Timonovka 1, Suponevo, Eliseevichi 1 dated to 15,000–

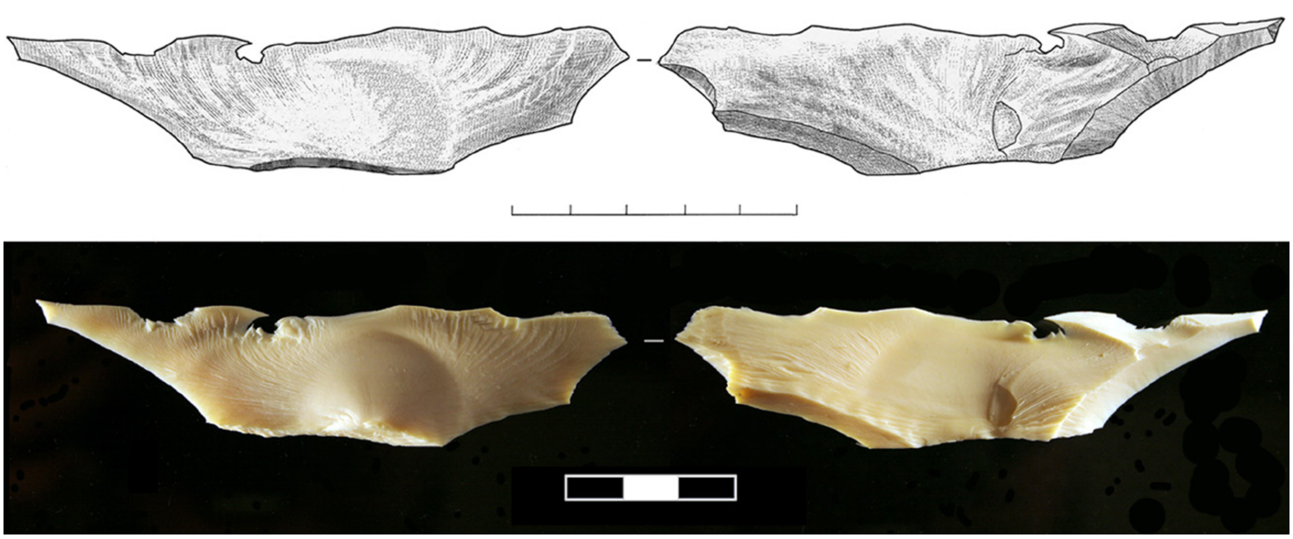

Fig. 19 – Transverse flake removed from an ivory tusk frozen up to −40°C, experiment carried out in 2007.
Fig. 19 *– Éclat d'ivoire transversal détaché d'un bloc d'ivoire congelé à env. − 40°C, expérimentation réalisée en 2007.*

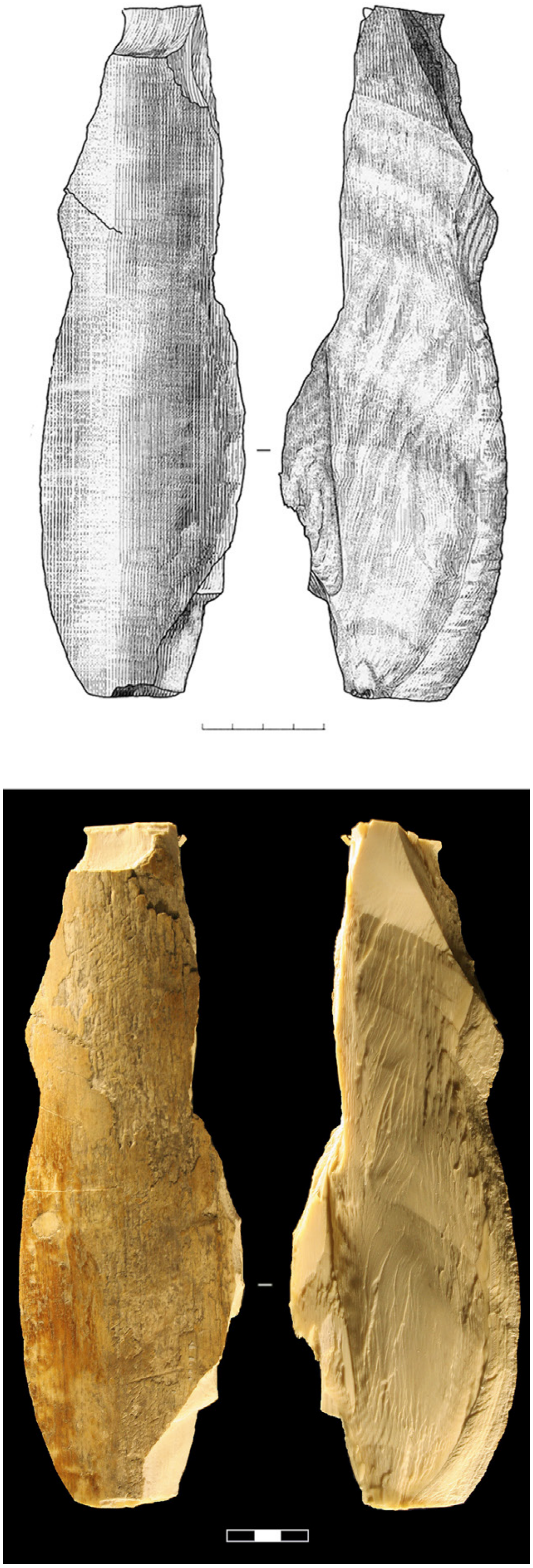

Fig. 20 – Ivory blade-like flake the removal of which required a few strokes with a hammerstone. The tusk was frozen up to −40° C, experiment carried out in 2007.
***Fig. 20** – Éclat laminaire d'ivoire dont le détachement a nécessité quelques coups de percuteur. La défense était congelée à −40°C, expérimentation réalisée en 2007.*

12,000 BP (Khlopachev, 2006). We had the opportunity to investigate such a production place at the Upper Palaeolithic site of Yudinovo. The initial treatment of the mammoth›s tusk was carried out in the south-eastern area of the space between the dwellings of the settlement. The place of primary processing of the tusks was a concentration of tusk knapping products across an area encompassing 1.5–2 m^2. This concentration consisted of 306 elongated flakes, large and medium-sized flakes, several dozen fragments of narrow lamellar removals, as well as 13 pieces of solid tusk with traces of knapping and three tusk cores with regular narrow lamellar flake negatives 10–25 cm long and about 2.5 cm wide.

As regards nuclei (cores) from the tusk, the shape and proportions of the narrowest lamellar spalls indicate that these were removed from the frozen naturally wet mammoth tusk with help of the punch technique from striking platforms in the form of a small step (cut) at the edge of the end face of the tusk.

In the 2007 experimental programme we paid much less attention to antler knapping, but the results of several experiments have convincingly demonstrated that wet antler changes its properties under low temperature conditions in a similar way to mammoth tusks.

It should be emphasised that while doing these experiments it was desirable to split the frozen antler of the reindeer or the mammoth tusk as quickly as possible, within five to ten minutes after removal from the refrigerator, as the surface layer of the bone nucleus heated up sufficiently quickly and lost its fragility.

It was found that at temperatures below −40°C wet tusk fragility is further enhanced. The nature of the splitting causes the tusk to resemble ebonite. With even more significant cooling (−60ºC and below) the tusk becomes too fragile: individual chips crumble during removal (fig. 21).

A quite 'comfortable' knapping of wet tusk can be carried out at a temperature between −30 and −40°C without great effort (without the use of enhanced blows). It is possible to remove both large blades (in association with deep and large grooves) and flakes in a longitudinal or transverse direction (fig. 18 to fig. 20; fig. 22). There is only one simple rule, which is determined by the anisotropic qualities of the tusks and which is extremely important and indispensable for successful knapping: the ventral side of any removal having a platform on the lateral surface of the tusk or on its end should be tangentially oriented relative to the structure of the tusk growth cones.

It is impossible to conduct controlled knapping on the plane transverse to the longitudinal axis of the tusk. This creates a very tangible discomfort and significantly limits the freedom of action of the knapper in the formation of both striking platform and flaking surface. There is no

Fig. 21 – Ivory blade-like flake split into three pieces, removed by a single stroke from a mammoth tusk frozen up to –60ºC, experiment carried out in 2007.
Fig. 21 *– Éclat laminaire d'ivoire, fragmenté en trois morceaux, dont le détachement a été fait en un seul coup sur un bloc congelé jusqu'à − 60°C, expérimentation réalisée en 2007.*

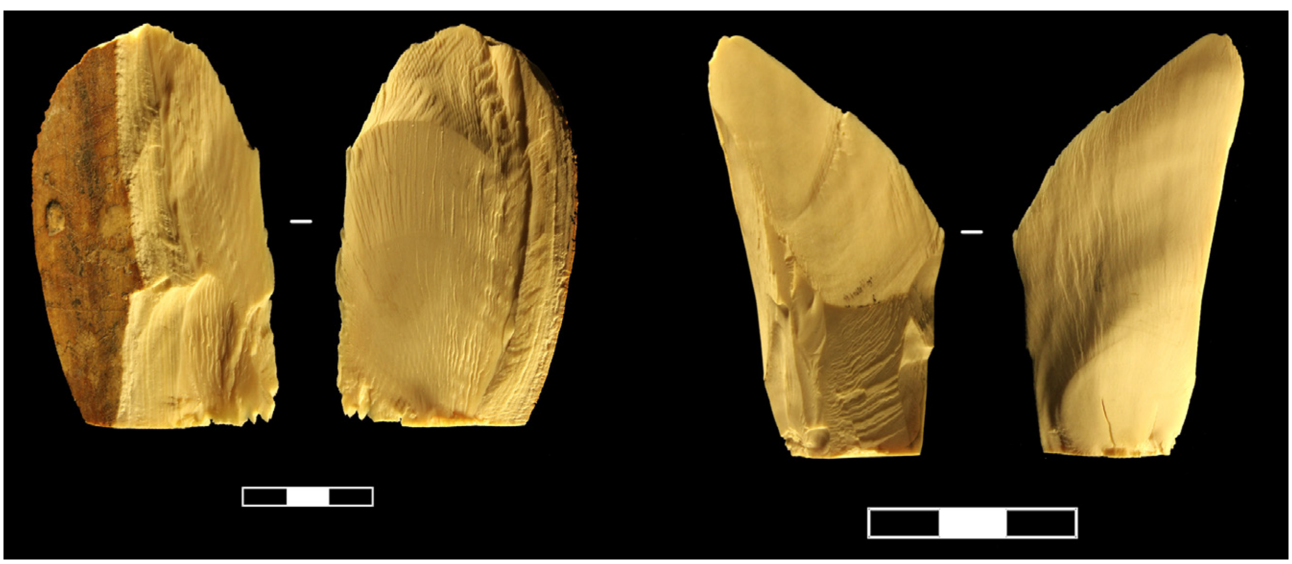

Fig. 22 – Elongated ivory flakes removed by percussion from frozen ivory, experiment carried out in 2007.
Fig. 22 *– Éclats allongés en ivoire détachés d'un bloc d'ivoire congelé, expérimentation réalisée en 2007.*

doubt that this circumstance is the reason why a considerable part of the known technologies for splitting tusk have, as was the case, two stages of manufacture: precore preparation in warm conditions and flaking of the cooled tusk.

Both phases of processing (in warm and cold conditions) can be observed on the transverse flake from the mammoth tusk found by N. K. Vereshchagin in the course of his studies of the Berelekh location (fig. 23, no. 1).

There is reason to believe that the systematic removal of flakes from the rounded lateral surface of the tusk or antler without preliminary preparation is possible when using adzes or chisels having a strong, sharp and solid

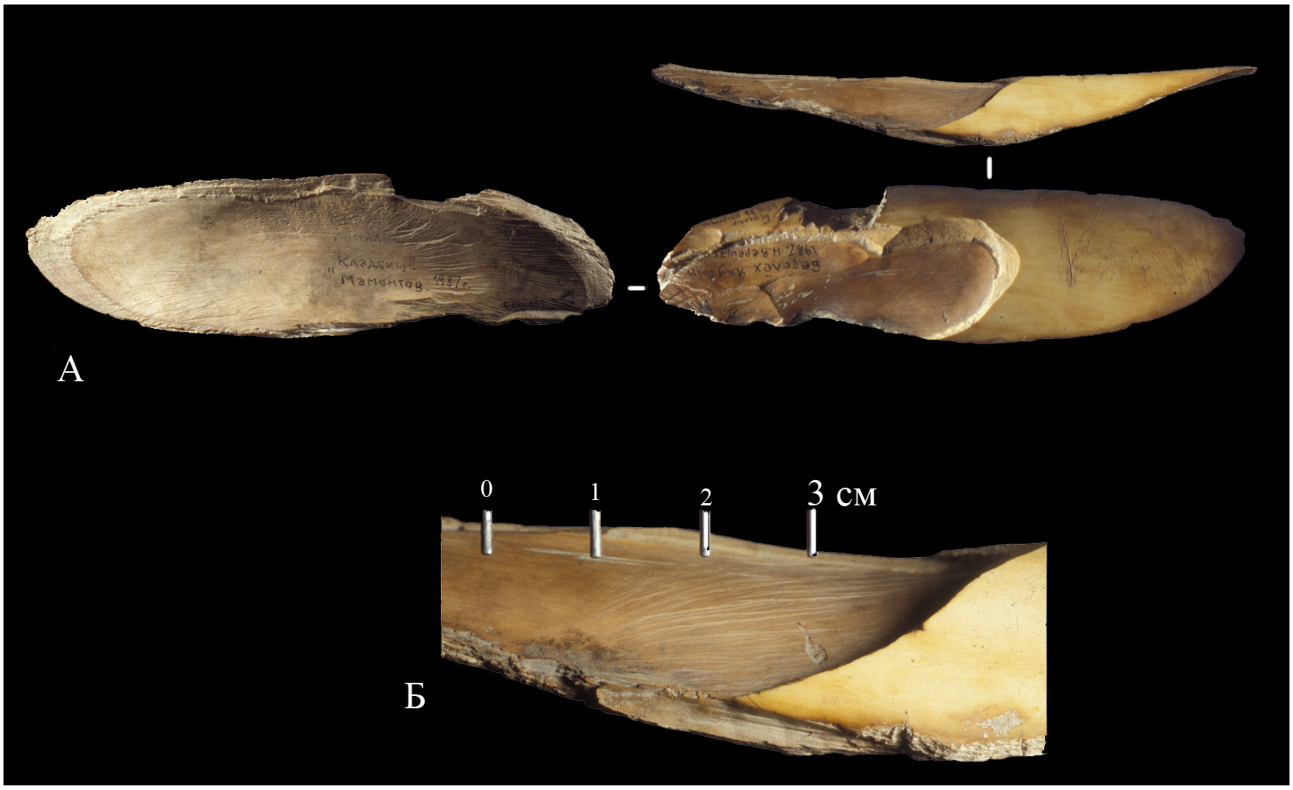

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Fig. 23 – 1: transverse ivory spalls; 2: transverse removal scar on an ivory spall. Berelekh, Upper Palaeolithic site.
***Fig. 23** – 1 : chutes d'ivoire transversales ; 2 : négatif d'enlèvement transversal sur chute d'ivoire. Berelekh, site du Paléolithique supérieur.*

Fig. 24 – Transverse ivory spall. Zhokhov Mesolithic site.
Fig. 24 *– Chute d'ivoire transversale. Zhokhov, site mésolithque.*

working edge. This does not mean the recognition of the correctness of the reconstruction of the tusk splitting model proposed by S. A. Semenov in 1957 (Semenov, 1957) and refuted by A. K. Filippov in 1983 (Filippov, 1983). When using direct percussion, blade and flake production from the rounded lateral side surface of the tusk is therefore almost impossible. However, it is possible that the treatment of the lateral surface of the tusk by breaking off small chips with a chisel or an adze is quite feasible.

Signs that are characteristic of the flakes made of moist, strongly cooled tusk or antler are:

– the smooth texture of the ventral surface, especially in the bulb of the percussion field and on a half or one third of the proximal part of fracture propagation;

– well-expressed, but at the same time rather thin radial 'beams' (fissures, hackle marks) dispersing in different directions from the impact (contact) zone point.

– Rather well-expressed, but smooth and plane shock wave (cracking ripples, compression waves).

– The proportions identical to proportions of the flake received when knapping flint of average quality.

In addition, intentional knapping of frozen mammoth tusk can be indicated by the presence, among the knapping products, of very large massive flakes with very small linear or almost pointwise impact platforms (fig. 23 and fig. 24), as well as narrow, thin and long blade-like flakes or blades, the removal of which from antler or tusks in dry form at positive temperatures is impossible.

The described methods of preparing raw materials for processing are almost certainly not an exhaustive list of such prehistoric techniques. And we still have to decipher the pages of the ancient history of the development of technology for processing bone, antler and tusks (Girya, 2015).

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