Shooting out the slate: working with arrowheads made on thin-layered rocks.

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ABSTRACT
Although there are many archaeological and ethnographic evidences for the use of slate and similar rocks in the manufacture of lithics, they raised little interest among specialists, leading to a general ignorance of specific problems associated with these raw-materials. Starting from the study of several Neolithic and Chalcolithic slate collections of the Western Iberia, the mechanical properties of slate and its impact on knapping process has been defined; subsequently, manufacturing and use of slate and phyllite projectiles have been undertaken. The results show that the ease with which these materials break into sheets of uniform thickness and morphology would provide an ideal basis for a fast and easy manufacture of arrowheads. In addition, these projectiles have shown a penetration capability and resistance statistically equivalent to those made on more standard materials (i.e. flint or rock crystal). Therefore, slate and other rocks with a high degree of fissility would have been very attractive to prehistoric knappers endeavouring to make arrowheads.

Keywords: slate, arrowhead, experimental archaeology, archery, Projectile Technology

1. Introduction.

Slate, phyllite, schist or similar stones, have a medium hardness and a layered structure marked by cleavage planes (slaty cleavage, schistosity) that result in a high anisotropy and a splintery fracture with an unpredictable progression that somewhat hinders the control of the knapping process. As a result, these rocks were not traditionally rated as suitable raw material (Andrefsky, 1998; Odell, 2004) with the exception of, perhaps, the more "siliceous" varieties (Callahan, 1990; Whittaker, 1994).

However, that view is at odds with the importance accorded given to these raw materials during Prehistory. While it is true that a significant portion of these industries are polished, especially in the Arctic Regions of America and Europe (Clark, 1982; Mandelko, 2006; Zvelebil, 2006), where its use has persisted almost into the XXth Century b.C. (Ellis, 1997; Graesch, 2007), there are also references to flaked industries on foliated rocks in many archaeological sites with different chronologies across Europe (Ljubin and Bosinski, 1995; Baales, 1999; Olofsson, 2003), reaching special significance in certain areas of Western Iberia during Neolithic and Chalcolithic (Jorge, 1986; Enríquez, 1989; Marín, 2001) (Figure 1). Here, this raw material is subject of specialized work (Bradley et al., 2005), it is integrated into the exchange networks and makes part of the funerary offerings, along with prestige goods such as long flint blades or metal objects (Fábregas, 1991; Bueno, 1998).

Unfortunately, scholars have not paid much attention to the processes of production and use of flaked artefacts on slate and only valuable information has been gathered about the fabrication of polished objects such as spears, arrows or knives (Banahan, 2000; Morin, 2004; Graesch, 2007). We shall try to fill that gap by working with data derived from the study of slate and phyllite flaked industries from Western Iberia (Rodríguez, 2010). Also, shall characterize the mechanical properties of the slate and phyllite, specifically on the more fissile varieties, therefore, further in their mechanical properties from these typical of traditional materials, such as flint. Given the frequent use of slate/schist in the making of projectile points (Ellis, 1997), the process of manufacture and use of arrowheads has been reproduced experimentally. Thus, we aimed to define the specific knapping problems, identify particular technical solutions and also check if those projectiles made in rocks with a high degree of foliation and apparently less resistant to impacts, were competitive with their equivalents made of harder materials.

2. Physical attributes of slates.

Slate is a rock originated by regional scale metamorphism occurring at relatively low temperatures in clay sediments. It is a crystalline and microgranular material, whose main feature is the foliation or fissility, also known as "slaty cleavage": the separation of plates or sheets arranged parallely. The presence of these planes filled with mica and other minerals is generally less resistant will be responsible for the slate's fissility. Other allied processes can affect the mechanical characteristics of slate, causing irregularities and imperfections in its structure such as quartz veins and inclusions, crenulation cleavage and presence of microfractures or kink-bands.

There is some terminological confusion among archaeologists, who use interchangeably terms such as shale, slate or schist. On the other hand, terms such as "siliceous" or "silicified slate" have been used to mistakenly identify rocks as phyllite, shale or metamorphosed lutite and even lydite. In this paper, we deal with different types of slates (gray and black slate) and phyllites of Silurian-Devonian age from NW Iberia. Our choice has to do with the fact than the Chalcolithic site of El Pedroso (Zamora) is located in this area, and it is the studied site where the knapping of slate achieved more importance (Delibes et al., 1995; Bradley et al., 2005).

The petrographic characterization of these materials was done by XRD, XRF and thin section. The results showed the presence of certain elements, mainly Si, FeO and Ca, which often function as "cement" causing, too, a greater cohesion and hardness of the material and, ultimately, to a greater tendency to conchoidal fracture. On the contrary, the presence of Al, K and Cr, associated with mica-like sericite and muscovite present in the cleavage planes, tends to be related with more foliated materials producing a, sometimes very marked, splintered fracture.

There are many varieties of slate, differentiated by the degree of compaction of their internal structure, affecting their fissility, hardness and type of fracture. Despite this variability, there are a number of common features: a hardness of 3 to 5 on the Mohs scale and an elasticity coefficient rather high, making it very shock-resistant, especially if the impacts occur perpendicularly to the cleavage planes. Elastic waves and other forces advance much more easily along the softer sub-parallel layers of mica and other materials (Rodríguez and Calleja, 2004), fact that, while obvious, is important for the exploitation of this raw material. Aliste slates used during experimental reproduction of the projectile points were subjected to a test, employing an Equotip durometer, to measure the specific capacity of penetration of elastic waves in relation to the direction of the cleavage planes.

The Equotip is a device consisting of a piston that rebounds against a solid surface. The quotient of impact and rebound velocities of this piston will indicate the hardness of a material based on the Leeb hardness test (in a scale of 0 to 1000). The Equotip works in a similar way to the Schmidt Hammer (Aydin, 2009), although it has certain advantages such as the smaller diameter of its piston (3 mm.), allowing greater accuracy of measurement, or the automatic correction of the angle, which minimizes alterations in measurements caused by the gravity force. However, the most obvious advantage from our perspective lies in its low invasiveness (Aoki and Matsukura, 2008), allowing the use on archaeological materials (Mol and Viles, 2010).

Although less accurate than other devices, both Equotip and Schmidt Hammer can be used to measure beyond hardness, tensile stress or weathering degree (Aydin, 2009; Katz et al., 2000). However, the main interest of Equotip in our case is allowing us to observe the level of anisotropy, information that will be most useful when dealing with a strongly anisotropic material such as slate.

We used the Equotip on the main varieties of slate and phyllite present in the studied assemblages: forty readings were made on each sample, distributed according to their orientation with respect to the cleavage planes (perpendicular, oblique and parallel to the cleavage planes) (Figure 2). In every case, there is a significant direct relationship between the rebound of elastic waves and the inclination with respect to the direction of the schistosity or cleavage planes. Resistance is much higher when impacts are made perpendicular to the cleavage planes so that, the penetration of a mechanical force applied will be much less if done in this direction; exactly the opposite happens when impacts occur in a parallel orientation, where the rebound is drastically reduced. In this sense, several authors have studied and reproduced experimentally the fracture parameters of rocks with a high degree of planar anisotropy (Lérau et al., 1981; Gatelier et al., 2002; Aydin, 2009), and all observed a relationship between fracture parameters and structural anisotropy, because the fracture propagation occurs mainly along the cleavage planes.

3. Projectile manufacture.

The technological analysis of the El Pedroso assemblages shows that the primary goal in the reduction of slate blocks was to obtain sheets of appropriate thickness to elaborate arrowheads (Figure 3), so the experimental protocol focused first on reducing slate blocks to get blanks with a suitable thickness, regardless of shape or size. To tackle the same problems confronting prehistoric knappers, the use of the same raw material was an obvious priority. Different varieties of slate and phyllite were collected, using them according to the frequency with which they were worked at the site. The material presented different degrees of compactness, cementation and weathering, a variability that is present in the local quarries as well.

The techniques used during experimentation were direct percussion with hard and soft hammer, indirect percussion and pressure flaking. The experimental reduction of slate and phyllite blocks clearly showed the importance of cleavage planes during the knapping. However, that incidence changes in rock's attributes: those more compact and cemented varieties will not display so much difference when struck in parallel or perpendicular directions to the cleavage planes. Thus, perpendicular percussion is only feasible on these harder varieties, for the force of the blow easily overcomes the internal planes (Figure 4, A), resulting in conchoidal or subconchoidal fractures; consequently, the technical gestures and chaînes opératoires will be closer to those found on raw materials like flint. However, on those rocks with a pronounced slaty cleavage a splintery fracture with an uncontrolled progression will take place or, if the blank is too thick, a rebound of the shock waves will hinder the fracture initiation. If the impact occurs in a parallel direction, the progression of waves will be facilitated, but softness of the material in that direction causes a rapid destruction of the striking plane (employing cortical platforms could diminish that), something particularly evident in bipolar percussion.

The best results were obtained by a careful percussion in an oblique direction to the foliation planes (between 35 and 50º) (Figure 4, B). Precisely these oblique angles had been defined by various authors as the most favourable for achieving a more effective split of the slate blocks (Aydin, 2009). No marked differences between hard and soft hammer were observed in the flakes obtained. The use of a not too heavy hammer is critical to avoid fractures and cracks in the material. On the other hand, the impact should be executed further to the interior of the striking platform, lest the cornice collapse.

Indirect percussion would have been another alternative for the reduction of the slate blanks. Again, this technique was applied both in a perpendicular and parallel direction to the cleavage planes. The results were disappointing in the first case (as happened with direct percussion), while the latter was particularly effective during the early stages of reduction, especially on thicker blocks. The fact that the parallel reduction does work with indirect percussion is due to the impact occurring against a smaller number of cleavage planes, thus concentrating the energy of the blow (more like a wedging initiation) and facilitating the initiation and propagation of fractures (Figure 4, C). Nevertheless, in less thick nuclei (3 cm. or less), parallel reduction is less suitable, as there is a high probability of an early termination of the fracture. It is safer hitting this type of cores on an oblique angle to the cleavage planes (Figure 4, D), slightly smaller than in the direct percussion (15 - 40°).

The number of sheets obtained experimentally from blocks varied depending on raw material and technique. Slate blocks between 500 and 1000 gr. of weight reduced by direct percussion have provided between 15 and 20 sheets apt for the manufacture of projectiles, while similar blocks reduced by indirect percussion have exceeded the 30. Indirect percussion, them, has proved the most effective technique, producing a greater number of sheets and causing less destruction of the blocks. However, due to limitations evidenced by each technique (mainly to do with the thickness of the available blocks), is probable that various methods would have been used along the reduction process according to the specific needs of each moment.

The products have a variable morphology and size according to the technique used and the reduction phase to which they belong. Those made by direct percussion on harder varieties of slate usually are similar to those obtained on more traditional raw materials: distinct faces, bulb of force and lenticular or triangular transversal sections. In varieties with a marked fissility, the products display a longitudinal and transverse quadrangular section with a small variation in thickness over the entire piece. The shape of these sheets also tends to be rectangular, as well as trapezoidal or triangular. Along with these, a large number of fragments and small splinters are also obtained.Generally, these pieces do not have the features on which lithic specialists have traditionally based their classification categories and they may have gone unnoticed in the archaeological record. In this sense, the very morphological distinction between cores and flakes is complicated, being necessary to pay attention mainly to size criteria. Likewise, it can be hard to distinguish between dorsal and ventral faces in flakes: both have a rectilinear or extremely irregular delineation without the presence of bulb or percussion waves; it is also difficult to differentiate the flake's platform as it has not a greater thickness, and is not easy to detect the stigmata of the technical process, as the point of impact.

Likewise, it is very difficult to venture the kind of specific technique that was used in the manufacture of a particular product, unless there are obvious stigmata of the tool used on the surface, as other authors already noted (Graesch, 2007). Although the products obtained by direct percussion usually have a greater thickness than those produced by indirect percussion, this feature is useful as a discriminator only statistically.

The ideal thickness of a sheet for the realization of a projectile varied, in our experiments, between 2 and 7 mm. When sheets are too large, we break them with smashing percussion using a soft anvil. Subsequently, preforms are configured by direct or smashing percussion, giving a morphology that is already close to the final form, which will be achieved by retouching. However, percussion can be omitted, resorting only to the retouch for the final configuration. Both methods have been documented in the studied assemblages (Rodríguez, 2010) and have also been described during the manufacturing process of "ulus" (polished knives) as well as polished arrows (Morin, 2004; Graesch, 2007).

The retouching technique employed on the slate and phyllite must be necessarily the pressure. Gestures differ: in the case of shale and siliceous slate are quite close to those used on flint or other cryptocrystalline materials. However, on the varieties with a high level of cleavage, the gestures employed are quite specific. Thus, on flint or obsidian the pressure flaker is situated on the very edge, pressing inward and downward; with the slate, however, to avoid indenting the pressure must be applied further inside the piece (about 2 or 3 mm. from the edge) and must be exerted only downward, in a similar way to the abrupt retouching on other rocks. Depth of retouch can be controlled, to some extent, with hand pressure on the piece, while its angle by shifting the distance from the edge (which is lower in abrupt than in simple retouch) and the inclination of the piece itself.

The consolidation of thinner parts of the edge by abrasion and scraping is not possible on slate. This action, almost essential on flint or quartz to avoid accidents, is very unwise on slate: its low hardness leads to a fast grinding of the area, thus difficult the retouch by eliminating the necessary angle. Ridges created by previous removals cannot be taken as a guide for new removals either, in this way a denticulated, pseudo-scalar and always marginal retouch takes shape.

In spite of that, it is much easier to get straight and aerodynamically well-balanced faces with slate. The reason lies on the straight morphology of the sheets and its virtual absence of thickening, saving the trouble of performing flat retouch series and making possible to get fully operational arrowheads only from a marginal retouch, which in other rocks would be just the first phase of projectile configuration. Thus, the total time of manufacture of projectile points in slate and phyllite with a high degree of fissility was always below 15’, much less than that when using chalcedony, opal and rock crystal (an average of 45’).

4. Experimental shooting of slate projectiles.

The scarcity of experimental programs testing the use of slate projectiles (Holmerg, 1994), led us to design an protocol with two main objectives: evaluate the effectiveness of projectiles made on fissile rocks in terms of impact resistance, stability and, above all, penetration capacity and determine their performance compared to those made on other materials.

A set of 51 projectiles of different materials, morphologies and sizes was created (Table 1, Figure 5), the significance of each variable being determined by its importance in the archaeological contexts. Thus, the collection is dominated by points made on raw materials present in the lithological environment of the studied sites, being those manufactured in Silurian-Devonian gray and black slates the most numerous, followed by other local raw materials.

The arrowheads were inserted in industrial shafts of cedar wood 81 cm long and 8 mm. thick. The hafting was achieved by three systems: lamb gut casing, vegetable fibres hardened with birch resin and mastic: a mix of animal glue and ochre. The use of ochre as a binder in adhesives is well known(Wardley, 2005; Lombard, 2007) and had a special interest in our case because the grinding of this oxide was recorded in some of the studied sites (Rodríguez, 2010).

A modern bow 62" long and 32 pounds of tension was used, and the target was a 45 kg gutted pig held approximately 50 cm. above the ground. Two additional shots (PT1, PT10) were made against a 5 mm. thick wood panel covered with a tanned goatskin. The purpose was testing effectiveness both against a living body and protective devices such as shields or breastplates. The use of an eviscerated carcass greatly improves the penetration of the projectiles, by avoiding the resistance exerted by internal pressure and bowels. The nature of targets has been unequally appraised by different authors (Bergman and Newcomer, 1983; Flenniken, 1985; Sisk and Shea, 2009). We believe that this fact has no direct impact on our experiment, since the aim was not to measure the penetration of the projectile in absolute terms but comparing the piercing capability of slate and phyllite arrows against those made in other materials.

Shooting distances ranged between 8 and 20 meters, which would be within the usual range for hunting and warfare (Petrequin and Petrequin, 1990; Bartram, 1997). The depth and position of each shot were recorded to see if a lower penetration or a rebound were caused by the skeletal structure or by the particular density of the muscular tissue. A total of 213 shots were made with the 51 projectiles. The maximum number of shots per projectile was 10, with a mean at 4.17. Of these, 36 (16.90%) missed the target, while 23 (10.79%) rebounded; to these we must add the two projectiles fired at a target composed of wood and leather, which got through it completely. Thus, the experimental program ended with a total of 154 shots that penetrated the target (a success rate of 71.62%). The impacts reached a maximum depth of 18.5 cm.; those with a lower penetration (4 cm. or less) are located mostly on the fore part of the animal where they hit its bone structure or heavy muscle masses. The deeper impacts (more than 8 cm.) are located in the middle section, most shots slipping through the intercostal spaces (Figure 6).

The resulting average penetration rate (hereafter APR) of the projectiles was analyzed statistically and checked against the quantitative and qualitative variables considered in our performance (Table 2), in order to see if any of those significantly affected the projectile effectiveness. Several non-parametric tests were run (Kendall’s Tau Rank Correlation and Spearman’s Rank Correlation Coefficient) with the aim of defining the level of relationship among quantitative variables and the APR reached for different projectiles

The test results show a correlation between various variables and the APR that could be euphemistically described as discrete; in most cases this correlation is negative, while in others, namely the L/W Index, there is a positive correlation. The statistical analysis shows that there is a different level of correlation among several of the variables and the APR: L/W Index, Tip Cross-Sectional Perimeter (TCP), Width and, to lesser extent, the Distal Angle seem to play a leading role; in fact, all these variables had been previously defined as conditioning factors (Odell and Cowan, 1986; Hughes, 1998; Sisk and Shea, 2009). However, we must reiterate that none of the variables considered in this experimental program exhibits a degree of correlation good enough to be considered a decisive factor in explaining, much less predicting, the APR of a given projectile, as observe in the regression plots (Figure 7).

Regarding to qualitative variables, we conducted a non-parametric analysis of variance based on the Kruskal-Wallis test. The results show an Asymptotic Significance well above 0.05, and, therefore, we concluded that no statistical evidence endorses the existence of significant differences among raw materials based on APR or Penetration in the first shot (Table 3). Also, statistical analyses were conducted to determine whether there was a significant correlation between the variables considered and the number of ricocheting arrows. As in the previous case, results showed that both quantitative and qualitative variables, including raw material (Table 3), did not have a clear impact on the number of bounces. However, certain variables (again the L/W Index and the TCP) showed a comparatively higher relative correlation.

As for the resilience of the projectiles, the level of fractures was relatively high, fundamentally as a result of an intensive use: a total of 28 projectiles (54.90%) were broken; however, in 6 occasions (11.76%) the fracture would not involve the discard of the piece for, in some cases, it reaches the highest penetration after taking one such fracture. The greatest percentage of fractures occurred in the phyllite, followed by quartz and black slate while chalcedony and crystal are at the opposite extreme. However, if we relate the level of fracture and discard to the intensity of use, the results become fairly balanced and black and gray slate have equal or even lesser fracture rates than their quartz and chalcedony counterparts. Moreover, if we consider the percentage of projectiles whose fracture has involved discard, the gray slate stands as the second most effective material (Table 4).

5. Conclusions

Despite its a priori unattractive features for knapping and its low hardness in comparison with flint, slate and other fissile rocks as phyllite or schist have been widely used for manufacturing tools during prehistory and up to the last century. This has not prevented, however, that these materials went quite unnoticed among specialists.

This paper has approached to the mechanical properties of slate and phyllite with a high degree of fissility, assessing the effect that internal cleavage planes would have on the knapping of these materials. The experimental manufacture and shooting of projectile points made on fissile rocks has shown, on the one hand, the existence of specific technical gestures and chaînes opératoires, which would have required some technical adaptation but, at the same time, would have led to a quick and easy manufacture of ideal blanks for making projectiles, due to the ease of this raw material to separate into sheets with a straight section and a regular thickness so that it must be added the ease of configuration of the points, being sufficient, in most cases, a marginal retouch to obtain a fully operational arrowhead.

On the other hand, the launch of the projectiles made on fissile rocks and the comparison those made from other raw materials, confirmed the initial hypothesis, namely that slate and phyllite projectiles were perfectly competitive with their equivalents made of cryptocrystalline rocks with conchoidal fracture.

Summing up, despite the somewhat coarse aspect of these arrowheads casting doubts over its functionality, arrows on foliated rocks display a level of effectiveness and strength comparable to those made on other “more traditional" raw materials. This fact, coupled with their quick and easy fabrication, makes slate and phyllite projectiles an ideal choice as part of a strategy to minimize energetic costs.

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Figure 1. Map of Western Iberia with the location of El Pedroso and other archaeological sites where lithic industries on slate, phyllite or schist are recorded.

Figure 2. Variation on the values of slate and phyllite hardness as recorded by the Equotip when applied at different angles with respect to the cleavage planes.

Figure 3. Dimensions of the slate artefacts of El Pedroso according to the reduction phase to which they belong. Percentage of sheets with a suitable thickness for making arrowheads (2-7 mm.).

Figure 4. A, B: Direct percussion perpendicular (only possible on harder varieties of slate) and oblique to the cleavage planes; C, D: Indirect percussion parallel and oblique to the cleavage planes.

Figure 5. Experimental projectiles made on slate, chalcedony, phyllite, rock crystal and quartz.

Figure 6. Examples of the lower and highest penetration (perforating the chest) reached by the experimental projectiles.

Figure 7. Scatter plots and regression line showing the correlation between arrowhead's main quantitative variables and the Average Penetration Rate (APR).

Table 1. Experimental projectiles.

Table 2. Spearman's Rank Correlation Coefficients and Significance Levels for the Average Penetration Rate (APR).

Table 3. Kruskal-Wallis Test of APR, number of Ricochets and Penetration reached with the first shot according to the raw material.

Table 4. Incidence of fractures among the experimental projectiles.

Table 1

CODE	RAW MATERIAL	TIPOLOGY	WEIGHT (gr.)	L (mm.)	W (mm.)	T (mm.)	DA (º)	TCP	HAFTING[a]	APR (cm.)
CA01	Chalcedony	Concave	22,66	28,5	13,6	4,6	57	28,71	M	10,49
CA02	Chalcedony	Tanged	22,41	22,7	18,1	5,2	56	37,66	V	4,24
CA03	Chalcedony	Triangular	23,80	29,1	17	6,6	62	36,47	V	4,52
CR01	Rock Crystal	Concave	19,40	29,2	16,8	4,6	61	34,83	M	9,06
CR02	Rock Crystal	Triangular	22,01	32,8	15,5	5,3	63	32,76	M	5,98
CR03	Rock Crystal	Convex	23,58	25,8	17,2	5,8	43	36,30	V	4,89
CR04	Rock Crystal	Concave	21,92	38,1	15,4	5,2	46	32,50	M	5,49
CR05	Rock Crystal	Concave	21,44	28,6	15,2	3,9	53	31,38	M	5,59
PI01	Phyllite	Barbed-and-tanged	24,35	33,7	27,1	4,9	65	55,07	M; V	3,54
PI02	Gray Slate	Concave	21,82	29,4	15,6	3,5	70	31,97	M	3,66
PI03	Phyllite	Tanged	26,56	43,8	26,2	3,6	63	52,89	V	5,50
PI04	Gray Slate	Concave	28,08	36,2	21,6	4,6	64	44,16	M	3,00
PI05	Gray Slate	Barbed-and-tanged	25,42	35,8	27,9	4,5	62	56,52	M; V	5,12
PI06	Phyllite	Concave	23,95	34,8	18,1	3,6	44	36,90	M	8,96
PI07	Phyllite	Concave	22,82	37,3	20,1	4,2	65	41,06	M	6,29
PI08	Gray Slate	Concave	26,05	32	24,5	3,2	64	49,41	M	1,00
PI09	Phyllite	Concave	24,34	30,6	25,6	4	66	51,82	M	4,30
PI10	Phyllite	Barbed-and-tanged	24,53	34,9	29,6	3,3	56	59,56	M	4,82
PI11	Phyllite	Barbed-and-tanged	29,56	42	34,6	4,9	56	69,89	M	6,61
PI12	Gray Slate	Tanged	24,01	37	25,1	4,3	55	50,93	V	5,29
PI13	Black Slate	Concave	27,88	32,1	19,1	5,6	54	39,80	M	11,33
PI14	Gray Slate	Tanged	26,56	36,9	24,2	6,4	57	50,06	M; V	5,88
PI15	Black Slate	Concave	22,88	41,2	16,5	3,9	58	33,90	M	9,40
PI16	Gray Slate	Concave	28,98	31,7	18,1	7	53	38,81	V	3,49
PI17	Gray Slate	Tanged	23,81	34,1	18,2	5,1	64	37,80	M; V	5,64
PI18	Black Slate	Concave	23,63	27,7	13,8	5,7	52	29,86	V	5,85
PI19	Gray Slate	Concave	24,75	37,6	21,8	5,8	57	45,11	M	5,43
PI20	Gray Slate	Straight	30,27	33,3	29,5	6,2	66	60,28	M	3,00
PI21	Black Slate	Concave	23,99	38,6	25	4,8	56	50,91	M	4,89
PI22	Black Slate	Barbed-and-tanged	22,52	36,4	22,1	3,3	56	44,69	M	5,62
PI23	Black Slate	Concave	24,88	33,2	16,4	4,5	55	34,01	M	4,50
PT01	Phyllite	Barbed-and-tanged	30,31	50,1	39,6	3,5	64	79,50	G	-
PT02	Phyllite	Barbed-and-tanged	24,39	42,1	27,1	3,4	64	54,62	G	3,16
PT03	Phyllite	Concave	25,29	49	26,2	3,9	54	52,97	G	3,50
PT04	Gray Slate	Barbed-and-tanged	25,91	45,3	31,5	4,6	59	63,66	G	-
PT05	Black Slate	Tanged	28,84	44,4	24,2	5,8	46	49,77	G	5,76
PT06	Gray Slate	Tanged	24,42	47	30,3	6,4	67	61,93	G	3,80
PT07	Phyllite	Concave	27,51	50,4	39,8	6,1	65	80,52	G	2,24
PT08	Gray Slate	Concave	28,66	57,4	27,2	4	58	54,98	G	4,90
PT09	Gray Slate	Tanged	26,38	44,5	27,6	5,5	70	56,28	G	6,83
PT10	Gray Slate	Tanged	45,97	62,4	31,9	6,8	70	65,23	G	-
PR01	Rock Crystal	Composite	19,92	-	-	-	-	-	M	3,82
PR02	Quartz	Composite	20,94	-	-	-	-	-	M	3,30
PR03	Quartz	Composite	21,38	-	-	-	-	-	M	3,00
PR04	Rock Crystal	Composite	25,57	-	-	-	-	-	M	3,24
PR05	Rock Crystal	Composite	23,70	-	-	-	-	-	M	4,15
PR06	Rock Crystal	Composite	22,04	-	-	-	-	-	M	3,91
BP01	Quartz	Composite	20,04	-	-	-	-	-	M	3,46
BP02	Quartz	Composite	20,04	-	-	-	-	-	M	3,50
BP03	Quartz	Composite	22,08	-	-	-	-	-	M	5,00
TE01	Quartz	Composite	20,51	-	-	-	-	-	M	7,00

[a] Hafting adhesive: Mastic (M); Vegetal Fibres (V); Gut (G).

Table 2

Variables	Correlation	Significance
Length	-,031	,852
Width	-,369[b]	,023
Thickness	,008	,961
L/W Index	,433[a]	,007
W/T Index	-,072	,667
L/T Index	-,303	,064
Weight	-,090	,541
Distal Angle	-,303	,065
TCP	-,372[b]	,021

[a] Correlation significant at 0,01 Level; [b] Correlation significant at 0,05 Level

Table 3

Test Statistics (a,b)

	APR	Penetration 1^{st} shot	Ricochets
Chi-Square	6,940	,599	2,983
df	5	5	5
Asymp. Sig.	,225	,988	,703

a Kruskal-Wallis Test
b Grouping Variable: Raw Material

Table 4

Raw Material	Broken Projectiles		Fractures causing discard			Accidents vs. Number of Shots	
	N	%	N	% Fractures	% Projectiles	% Fractures	% Discards
Quartz (6)	4	66,67%	3	75,00%	50,00%	25,00%	18,75%
Chalcedony (3)	1	33,33%	1	100%	33,33%	8,33%	8,33%
Rock Crystal (9)	2	22,22%	1	50,00%	11,11%	5,41%	2,70%
Phyllite (11)	9	81,82%	8	88,89%	72,73%	25,00%	22,22%
Black Slate (7)	4	57,14%	4	100%	57,14%	8,70%	8,70%
Gray Slate (15)	8	53,33%	5	62,50%	33,33%	12,12%	7,58%
TOTAL (51)	28	54,90%	22	78,57%	43,14%	13,15%	10,33%

Figure 1
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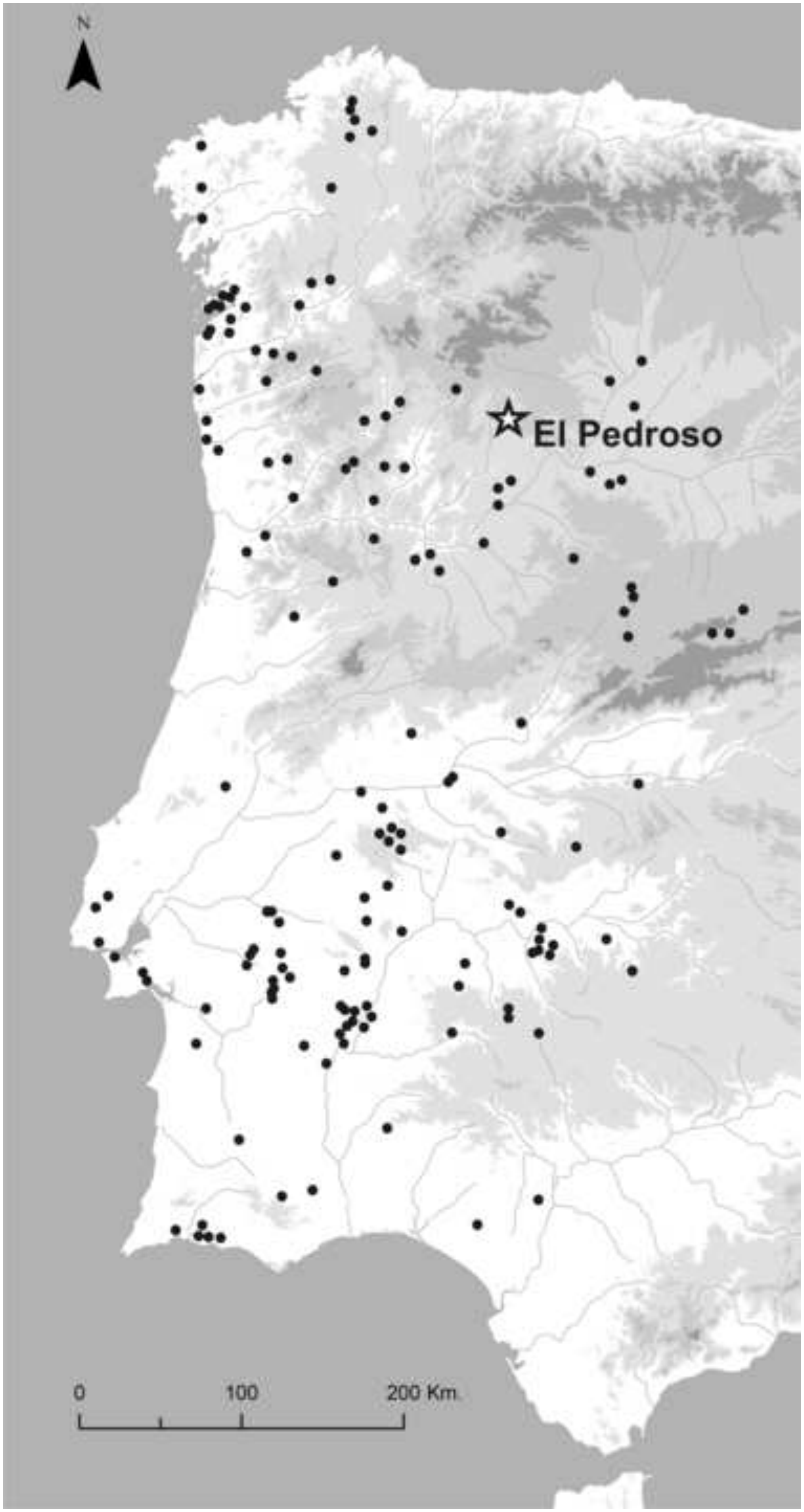

Figure 2

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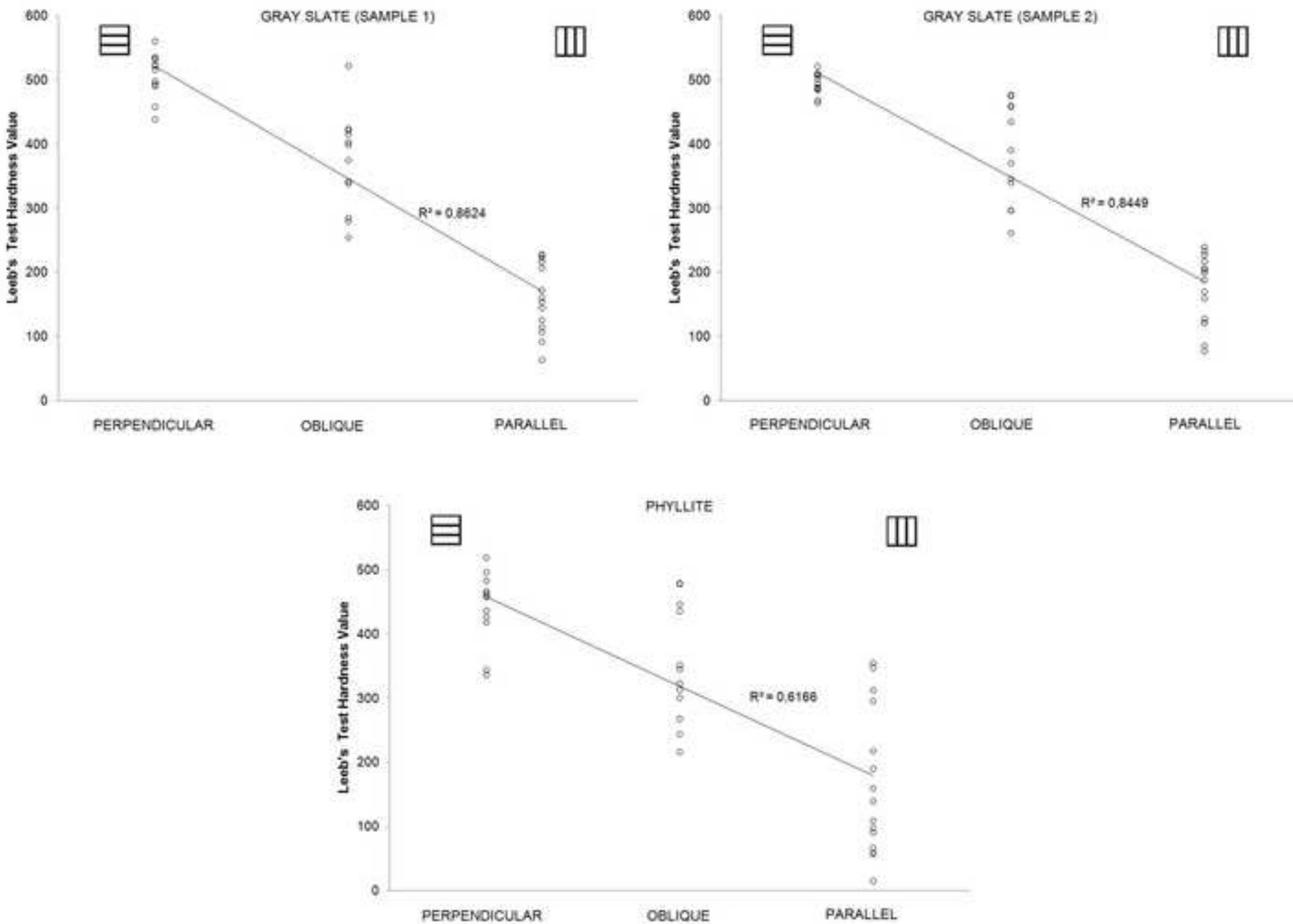

Figure 3

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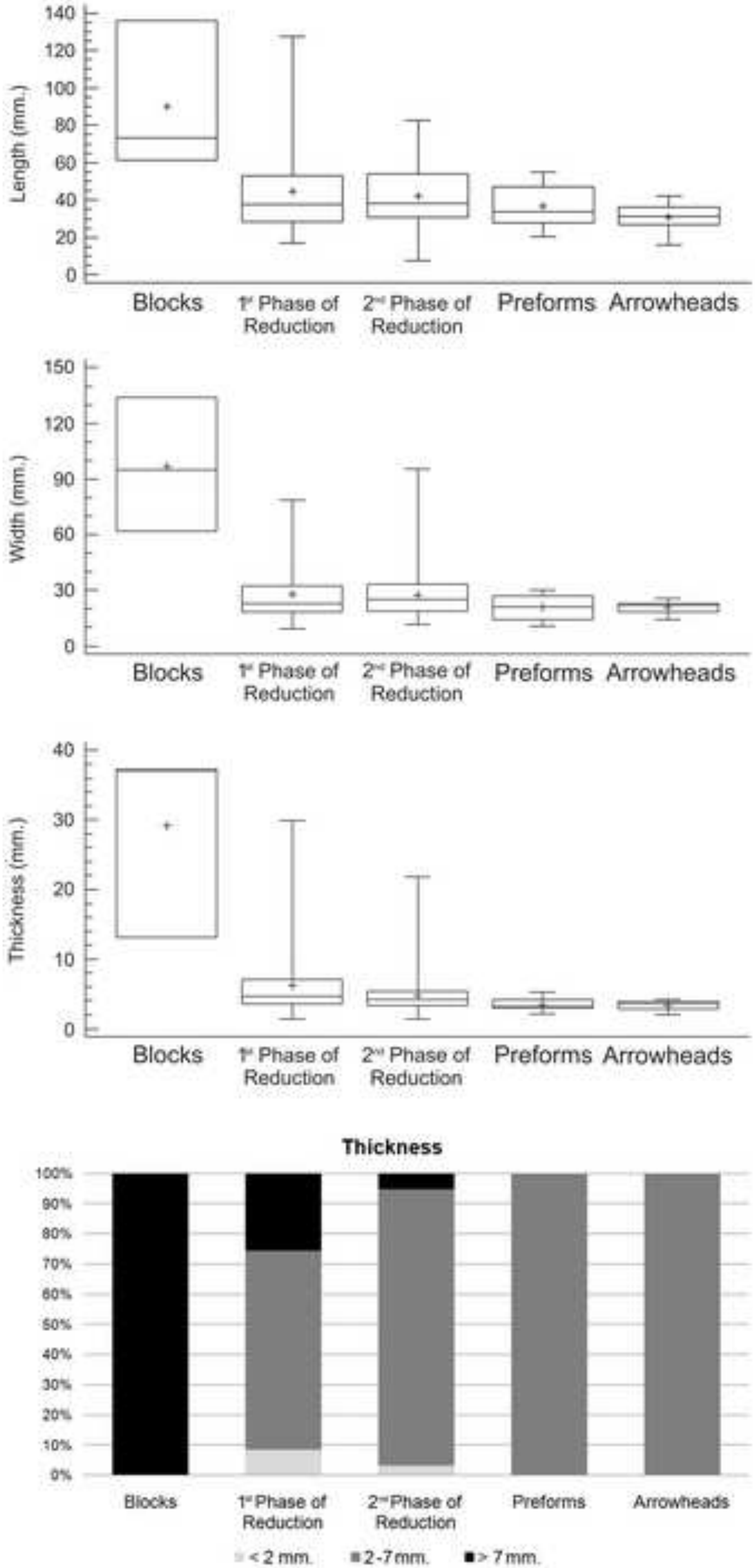

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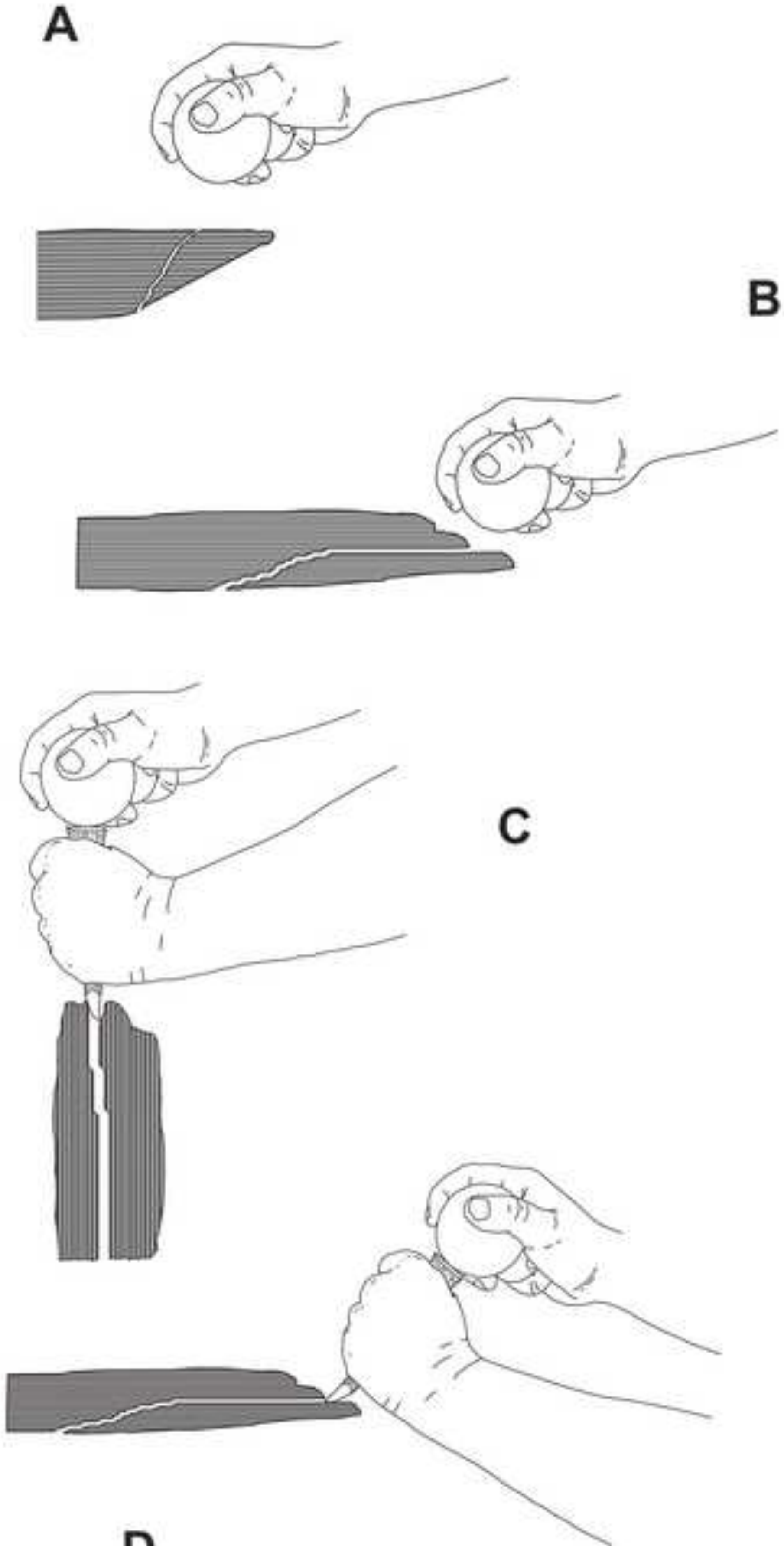

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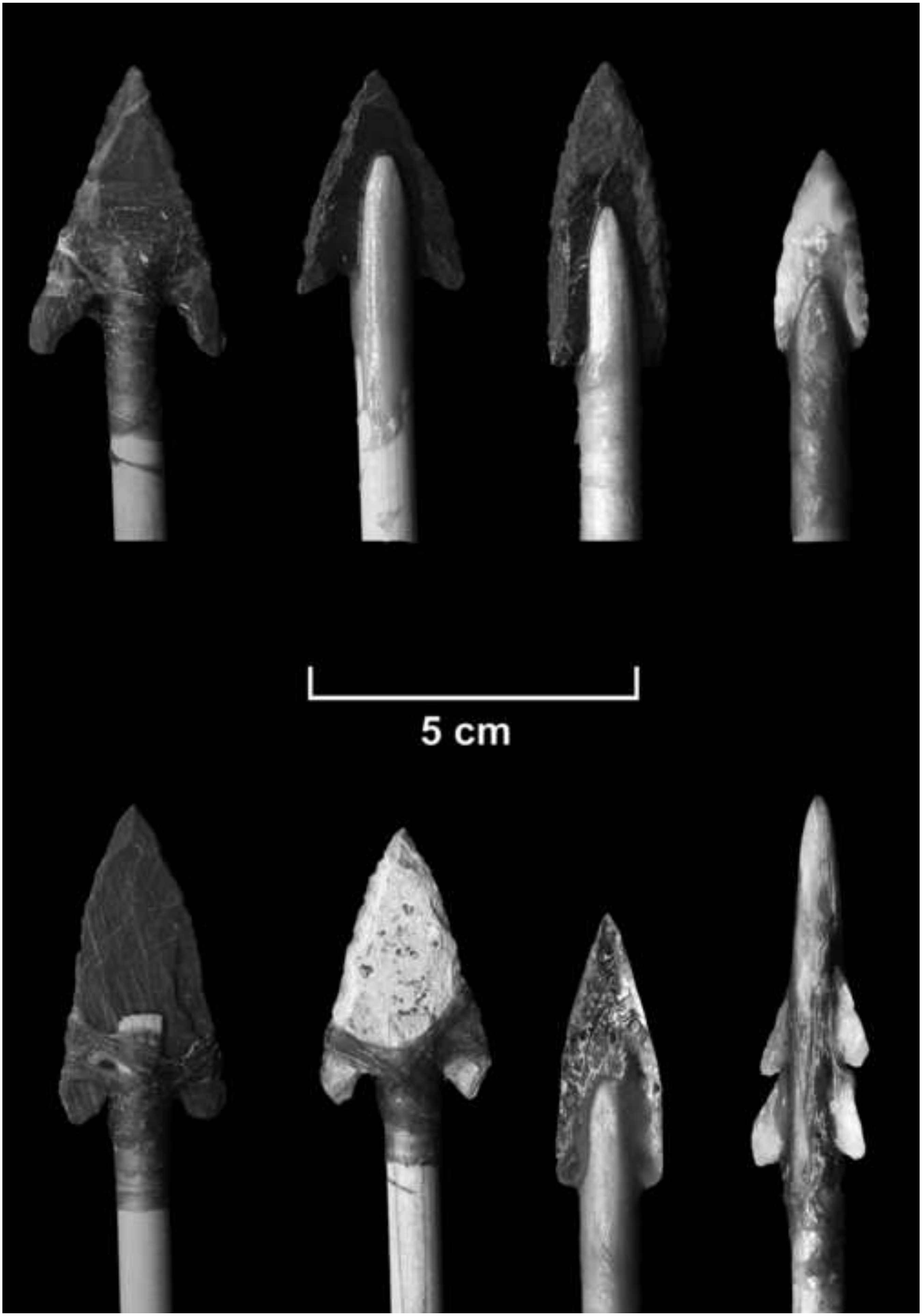

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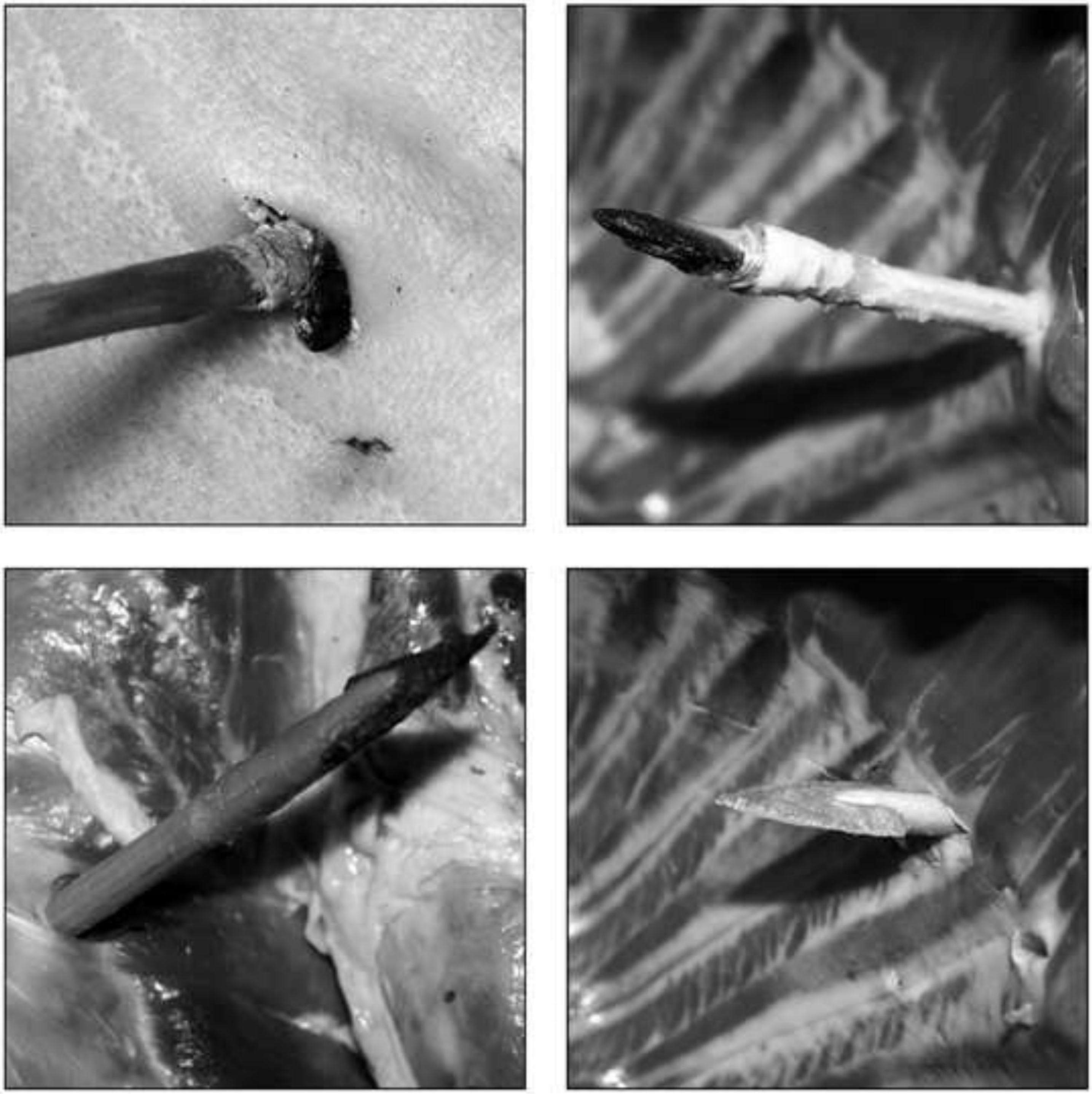

Figure 7

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