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Pseudo-Heron's *cheiroballistra* a(nother) reconstruction: I. Theoretics

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BEFORE WE START...

> 'It is sometimes only too easy to find a solution to a fragmentary or corrupt passage by introducing conjectures founded on modern concepts of engineering which may run counter to the methods of ancient artificers. At other times it is hard to avoid forming a preconceived notion of a particular machine from a preliminary examination of its description and then forcing many details to fit this prejudiced view. Therefore an editor must respect what is known of the manuscript tradition and not resort to unfounded conjecture unless all else fails'.[1]

I think that there would be few better ways of beginning any investigation on such a difficult text as *'Heron, construction and dimensions of the Cheiroballistra'* than quoting Eric Marsden's precedent paragraph, a sensible and lucid approach to the problem. I shall try in the following pages to stick to it as much as possible.

It is now commonly accepted that, almost with total certainty, Heron of Alexandria was not the author of the *Cheiroballistra*.[2] That is the reason why I prefer to call our anonymous author Pseudo-Heron, rather than Heron. From now on, I shall abbreviate it to PH.

Ancient treatises usually began with an introductory section. This includes considerations about artillery, in general treatises, or more concrete promises about performance, when an individual weapon was described in particular: Philon wrote in his *Belopoeica* that his wedge-catapult would overcome every defect which flawed conventional catapults, and the anonymous author of the *Rebus Bellicis* claimed that his *ballista fulminalis* would shoot across the Danube. Unfortunately, PH's declaration of intentions – if it did exist – has not reached us, so we are not told what kind of weapon the *cheiroballistra* was or what it was intended for. In this context, I think that it is rather risky to state (beforehand, it seems) as Wilkins does that 'thus the machine described in the ms [the *cheiroballistra*], far from being of an obsolete, rare or experimental type, was established by Marsden as the standard arrow-firer issued to the Roman army from the time of Trajan onwards'.[3] I shall not deny that the standard Roman arrow-firers were metallic-framed, at least from Trajan onwards, but the *cheiroballistra* was only a member of the family – surely, the smallest one – and not the whole family. I am afraid that these words of Wilkins reflect an underlying desire to see the *Cheiroballistra* as a key treatise, just because it has reached us, via Byzantine compilations. If we analyze the artillery treatises that were grouped with the *Cheiroballistra* by the Byzantine scholars – Biton's 'Construction of War Machines', Heron's *Belopoeica* and, later, Philon's *Belopoeica* – we shall see that none of them were – by far – in the van of progress at the time: in fact all were already outmoded since the first century BC and that the *Cheiroballistra* is the most 'recent' one. The transmission of the classic texts seems to be, deplorably, as casual in the East as it is in the West. It depends rather more on the survival or availability of a book than in its paramount interest. Early mediaeval compilers would tend to copy every text related to their interests, but they could only choose from the surviving ones and not from the originally existing ones.

It could well be that the *Cheiroballistra* was a Greek translation of a Latin original. There is no direct or conclusive proof to support this, but some circumstantial arguments can be adduced: the words *cheiroballistra* and *kambestrion* are translation or adaptation of the Latin words *manuballista* and *(capitulum) campestris* [pl. *(capitula) campestria*], and the measurements seem to have been 'converted' from Roman units to Greek units by the simple expedient of making the equivalence one Roman digit (18.5 mm) = one Greek dactyl (19.3 mm).[4] The small difference of 0.8 mm can seem negligible at first sight, but it amounts to 12.8 mm in one foot. I have decided to employ Roman feet and digits instead of the Greek ones; it will make a somewhat lighter and smaller machine, but no important feature will be affected as a result.

The four main manuscript sources for establishing text and diagrams of the *Cheiroballistra* are the following ones:[5]

- M: Codex Parisinus inter supplementa Graeca 607 (foll. 56^{r}-58^{v}). Bibliothèque Nationale, Paris.
- F: Fragmenta Vindobonensia 120, olim 113 (foll. 12^{r}-14^{v}). Österreichische NationalBibliothek, Vienna.
- P: Codex Parisinus Gr. 2442 (foll. 68^{v}-70^{v}). Bibliothèque Nationale, Paris.
- V: Codex Vaticanus Gr. 1164 (foll. 106^{v}-108^{v}). Biblioteca Vaticana, Rome.

There are several editions of the Greek text, following in the main that made by Carl Wescher.[6] The first one is that of Prou, which also contained Latin and French translations.[7] Schneider also included a German translation with his edition and mischievous critical notes.[8] The latest, and more readily available, editions of the *Cheiroballistra* are those of Marsden and Wilkins.[9] Both include excellent English translations, but must be taken with some caution, because the edited Greek text is that 'corrected' by the authors, instead of just the original one, with the proposed changes appearing as footnotes.

Such relative abundance of good editions and translations excuses me from adding another one to the list. I shall, instead, summarize each section of the document and only turn in detail to the Greek text or the translations in case of disagreement with what has been published.

As I have already mentioned, the last monographic work devoted to the *cheiroballistra* is the long and detailed paper 'Reconstructing the *cheiroballistra*', written by Alan Wilkins.[10] It includes, besides a new edition and translation of the ancient text, careful tracings of almost all the relevant diagrams and, after a detailed analysis of each component, a proposal of reconstruction of the catapult and the kind of missile intended for it. As the latest work about the *Cheiroballistra* is Wilkins', it is unavoidable to take it as the guideline for my own paper. This could have been flattering for him, were it not the case that, after my own analysis of the subject, I disagree with most parts of Wilkins' reconstruction. It would be extremely unfair, nevertheless not to acknowledge the fact that I owe much, even the very knowledge about the existence of the *cheiroballistra,* to Wilkins. Constant negative references to his work in the following lines could be taken by superficial readers as a 'persecution' against him. That is not, of course, the case, because argument and counter-argument are basic to any scientific research. Anyway, I cannot help telling the things plainly as I understand and feel them.

It is now time to pass from all these first considerations to the set of instructions. The text of the *Cheiroballistra* is only that, a set of instructions for the construction of several components. Here they are.

THE COMPONENTS

1. The Case (Fig. 1)

The Case is described in the text as a *κανών* (which can be translated as a 'bar' or 'ruler' of an unspecified material, wood being the most logical choice here; thus the usual English translation as 'board') AB 3 ft 4 d (962 mm) long, $3^1/_2$ d (65 mm) wide and $4^1/_2$ d (83 mm) thick (Fig. 1.1). It must have a dovetailed groove 1 d (19 mm) deep, running longitudinally from A to Z, 2 ft 14 d (851 mm) long. All is concise and clear, but two of the paragraphs still seem to need some discussion.

The projecting block

The first one refers to the position of the projecting block XΨYΦ, 7 d (130 mm) long, which is left protruding from the lower surface of the case after removing 28 mm from the thickness of the board at both ends. The text says the following:

> 'Again, let the length AΘ, 1 foot 12 dactyls, of the Board AB be marked off, and the length AK 1 foot 1 dactyl; the remainder will be then KΘ, 7 dactyls. Again, let 1½ dactyls be marked off from the thickness of Board AB, and let it be cut along AK and ΛΘ so that the section KΘ remains at the original thickness, that is XΨYΦ.'

Obviously, 28 d (AΘ) – 17 d (AK) = 11 d and not 7, as appears in the text and, undoubtedly, there must be an error, and a very old one, as all the mss agree at this point.

Up till now, only two possible corrections have been apparently discussed: Schneider[11] (and, after him, Baatz[12]) changes AK *και δακτυλου* <u>*A*</u> (1 d) to *και δακτυλων* <u>*E*</u> (5 d) to reach 28 d – 21 d = 7 d, while Marsden[13] (and, after him, Wilkins[14]) reverses the positions of K and Θ on M's figure[15] and changes AK in the text for ΛK to reach 28 d + 7 d + 17 d = 52 d (which is 3 ft 4 d, the whole length of the case AB). In my opinion, the first proposal is palaeographically difficult to accept, and, as Wilkins[16] very sensibly points out, a carpenter would surely find it queer to mark off in such overlapping manner; and the second one, while fitting nicely, does so at the cost of changing both the text and the letters in the figure, which I deem excessive. In reality, by 1877, Prou[17] already saw that it would suffice to amend AΘ to ΛΘ for clearing up the paragraph, which would stand as follows:

> 'Again, let the length ΛΘ, 1 foot 12 dactyls, of the Board AB be marked off, and the length AK 1 foot 1 dactyl; the remainder will be then KΘ, 7 dactyls. Again, let 1½ dactyls be marked off from the thickness of Board AB, and let it be cut along AK and ΛΘ so that the section KΘ remains at the original thickness, that is XΨYΦ.'

I agree[18] with Prou's reconstruction, and my arguments are these: the original text is only altered at one point (i.e., ΛΘ for AΘ) with a correction palaeographically easy to accept while the rest is left untouched and making sense. Even if, as Wilkins claims,[19] it is true that the mss *usually* give the diagrams' reference letters in alphabetical sequence, the concordance between text and diagrams seems of major importance: in the case of the projecting block, the reading in the mss text is KΘ, in the same order that appears in the diagram, but, for example, in the Arch, the reading is ΘK, like that in the diagram. Furthermore, in M, P and V's diagrams, the block XΨYΦ is always placed nearer to A than to Λ.

To find out what the projecting block was intended for has been a puzzling problem for all previous reconstructors. Prou[20] uses the block for attaching his bizarre *klimakion* to its underside. Baatz just discusses the mistake in the mss text and places the block in his graphic reconstruction (rather unconvincingly) as a sort of hand-grip, without mentioning it.[21] Marsden and Wilkins[22] find it only suitable to fit the role of Vitruvius'[23] *chelonium* or *pulvinus*, which, in their opinion, supported the necessity of a stand for the *cheiroballistra*. Wilkins[24] adds that 'it must be remarked that cutting a long beam down from 4½ dactyls thickness to 3, just to create this small Block, seems unnecessary labour'. With our suggested change, the block is drawn forwards (Fig. 1.1), nearer to the point of balance and farther from the position suitable for a *chelonium*. In its new place, the block could equally fulfil the purpose of the wooden bearing placed by Wilkins under the case for a better attachment of the universal joint,[25] but it seems too long for that task. In my opinion, the controversial block is nothing but some kind of handle, very similar indeed to those of heavy crossbows, like the one shown in Figures 20–21 or in E. Viollet-le-Duc's drawings.[26] Incidentally, crossbow makers did not consider it 'unnecessary labour' to carve them from the stocks' wooden thickness.

The crescent-shaped fitting

The second conflictive paragraph is apparently clear and says 'Let a crescent-shaped [wooden, we suppose] fitting HB also be made and, bored in the middle with a quadrangular hole, let it be attached solidly to the end ΛB of the board AB, as in the diagram below'.

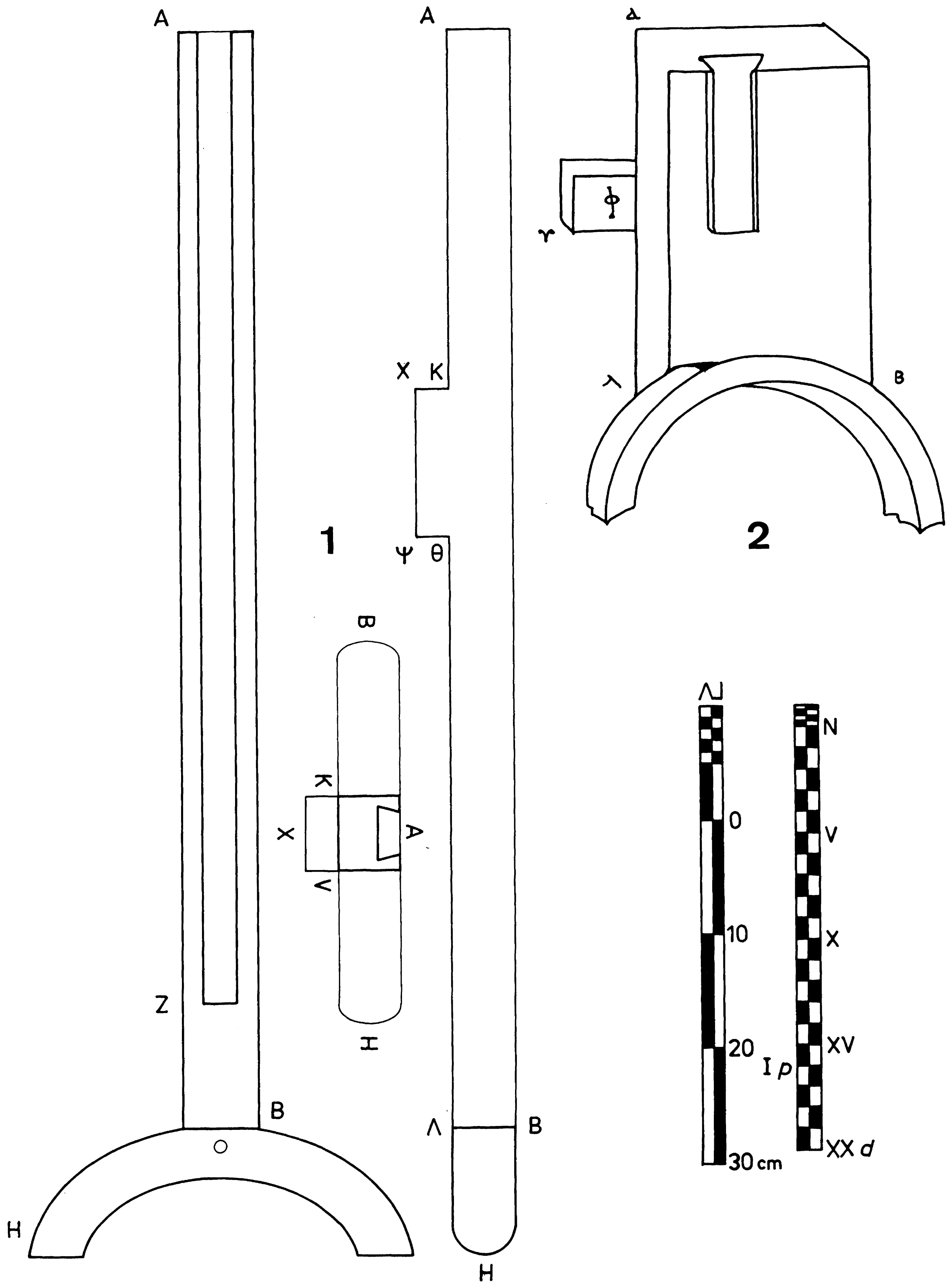


Fig. 1: 1. The case. Plan, front view and side view. 2. The case in P diagram.

Prou[27] saw no problem in placing this lunate fitting HB horizontally at the rear end of the case, and cocking his *cheiroballistra* by means of it, in the way that Heron's *gastraphetes* was. Schneider,[28] who cannot be suspected at all of having joined the 'horizontal' or the 'vertical' party (as he aimed to prove that the *Cheiroballistra* was not the description of a catapult's components at all!), reluctantly acknowledged that the case with the crescent-shaped fitting reminded him strongly of that of the *gastraphetes*.

Marsden had decided beforehand that the *cheiroballistra* was winched (and had a stand) and a horizontal placing did not fit inside his scheme, thus, without bothering to add a single argument on his behalf, wrote: 'The crescent-shaped fitment, HB, does not correspond to the withdrawal-rest (*καταγωγίς*) in the *gastraphetes* (on which, see Heron, *Bel*. W 77 f.). HB serves as a hand-grip which the operator uses when he wishes to raise, lower, or traverse the stock'. In his graphical reconstruction, the fitting is, naturally, vertically placed, but with only half of its supposed span. In Marsden's operative reconstruction, it was further reduced to a simple curved wire.[29]

Baatz argued that, in such a small catapult as the *cheiroballistra*, a windlass would be more of a hindrance than a help and that it was surely armed in the way the *gastraphetes* was. In his graphical reconstruction he, consequently, placed the crescent-shaped fitting horizontally at the rear of the case, but he provided it with lateral hand-grips like those in the *gastraphetes*, which are clearly absent from all mss diagrams.[30]

In Wilkins' opinion,[31] the mss diagrams show the case from the side, which would imply that the lunate fitting was vertically placed. In reality, those in M and V[32] are very inconclusive, as they can show the case either from above or from the side, because of, as Wilkins reminds us, 'the Roman draughtsman's principle that it was legitimate to turn parts through 90° to make them visible in a diagram'. The diagram in P (Fig. 1.2) is of more use: in it, the projecting block, even though turned 90º, stems clearly from the underside of the case, which means that it is seen from above and the fitting HB was horizontally placed. The position of the letter Λ in P and V's diagrams is not as decisive for this question as Wilkins thinks,[33] as it is also perfectly compatible with a view from above.

Furthermore, the most usual form in which ancient artillery treatises show the case (alongside with the rest of the engine, of course) in their diagrams (when preserved) is seen from above and with its forward end up. Marsden[34] explains that a view from above with the two side-elevations directly placed at its sides was surely what a catapult designer understood as a proper working-drawing. If we look again at M's (and F's) first diagram with this idea in mind, the projecting block ΧΨΥΦ would be figured stemming from the underside of the left side-elevation (it does not appear in the right one, it is true) and the lunate fitting would be figured, horizontally laid, in the view from above and, maybe, in the side-elevations too, as the two small rectangles which are attached to their lower ends.

Wilkins has pursued his argument further in an updated version of his article.[35] He tries once more to prove that the diagram in M depicts the case laterally and brings forward one diagram of the *gastraphetes* in Heron's *Belopoeica*. In Wilkins opinion, the female dovetail in both diagrams (*gastraphetes* and *cheiroballistra*'s case) should be figured in the same way and, as this does not happen, it implies the absence of the female dovetail in the representation of the case in M. Unfortunately, for Wilkins' argument, the diagram of the *gastraphetes* he adduces in his support belongs to P and therefore is not comparable to an M's diagram to such a degree of detail. If we look at the corresponding picture of the *gastraphetes* in M,[36] we shall find that the female dovetail is figured identically (see the preceeding paragraph) in both *gastraphetes* and *cheiroballistra*.

Consequently, in his formidable working reconstruction, Wilkins places the crescent-shaped fitting vertically at the rear of the case, behind the windlass. He, like Marsden[37] earlier, seeks to identify it with the 'Griffrad' that Schramm recognised near the two catapults in cast 165 from Trajan's Column.[38] Perhaps it could be rather superfluous to add that a plain translation of 'Griffrad' would be 'wheel with handspikes': Schramm really meant that the pulling back of the slider was achieved in the catapults portrayed at the Column by means of a detachable wheel with four spikes, placed at the end(s) of the windlass.[39] In cast 165, the forward two spikes are obscured by the soldier's helmet, and the visible rear ones could thus not be Marsden's or Wilkins' vertical hand-grip.

My proposed reconstruction (Fig. 1.1) has the fitting placed horizontally at the rear end of the case. The quadrangular hole bored in its middle suggests strongly a mortise and tenon joint, but no tenon is described in the text. In the diagrams, the lunate fitting appears always below the letters Λ and B, and so must be understood as not included in the case's length, which implies that some mean of attachment is needed. I have left a rectangular tenon protruding from the case and passed a dowel pin through the crescent-shaped fitting and the tenon itself for securing the joint (Fig. 1.1). As I have said earlier, no diagram shows lateral hand-grips like those in the *gastraphetes* and, for that reason, I have not included them in my reconstruction; their absence is no hindrance for arming the weapon that way, as we shall see later. To finish with the fitting HB, its ends appear in M, F and V's diagrams as plainly cut, while P's (Fig. 1.2) exhibits strange notches; anyway, I have decided to make them rounded (Fig. 1.1), just to avoid bruising the belly.

2. The Slider (Fig. 2)

The slider is described in the text as another board, ΓΔ, with its cross-section in the form of a male dovetail, 3 ft (888 mm) long, about 2½ d (46 mm) wide and 1¼ d (23 mm) thick. Even in such a simple component, I diverge at one point from Marsden and Wilkins' reconstruction and, at another, from those of all my predecessors.

The length of the male dovetail

The slider ΓΔ, as given in the mss, is 2 d (37 mm) longer than the female dovetail AZ. Prou[40] and Baatz[41] left in their reconstructions this length of slider just protruding from the front of the case, but Marsden,[42] mirroring Heron's description of the *gastraphetes* slider, preferred to make the male and female dovetails of the same length and, therefore to leave the longer rectangular upper section of the slider overhanging the case's rear portion.

Wilkins,[43] even if he realized that Marsden had unduly lengthened it 4 d, maintained this overhang and tried to demonstrate its existence by putting the screws on the Greek text's translation. In his opinion, PH says that the dovetailed portion EΔ of the slider is of the same length as the corresponding groove AZ in the case and, consequently, 2 d shorter than the upper section ΓΔ of the same slider. This is not correct at all:

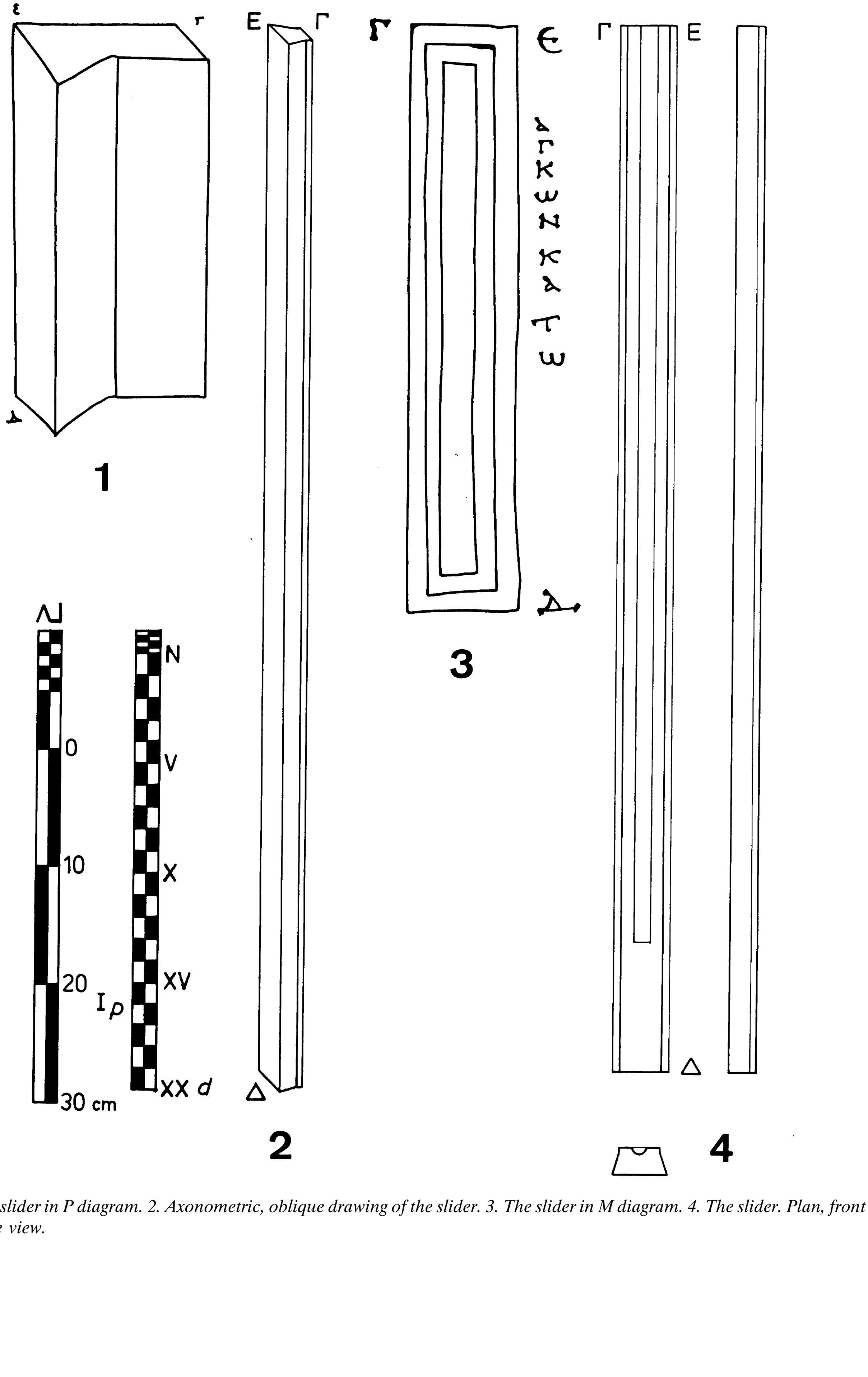


Fig. 2: 1. The slider in P diagram. 2. Axonometric, oblique drawing of the slider. 3. The slider in M diagram. 4. The slider. Plan, front view and side view.

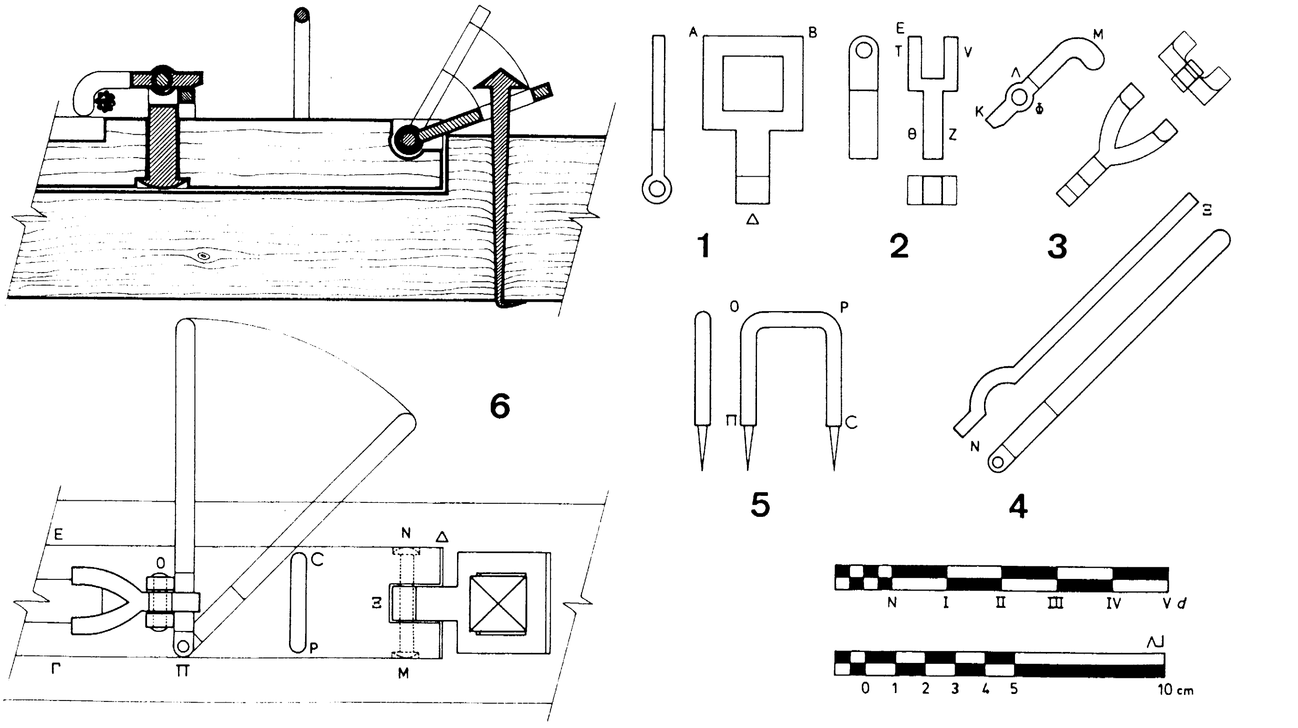


Fig. 3: 1. The 'handle'. 2. The fork. 3. The claw. 4. The trigger. 5. The pitarion. 6. Assembled trigger mechanism. Longitudinal section and plan.

what PH really says is that ΔE, the dovetailed underside of the slider, must 'be adapted to' or 'be suitable for' or even 'fit' AZ, the female dovetail of the case,[44] and nowhere can it be read that it must be of the same length.[45] Moreover, the mss diagrams (Fig. 2.1 and 3) do not show the slightest trace of such a prominent feature, as Wilkins admits.[46]

In my reconstruction, I have left the surplus length simply protruding from the front of the case, as in Prou's and Baatz's. This feature is indeed very helpful if one wants to achieve the complete pull-back of the slider using the stomach-bow cocking method.

The transversal cross-section

As far as I know, every other reconstructors of the *cheiroballistra* have chosen for their sliders a cross-section in the form of a 'T'. Prou and Baatz do not discuss this question.

Marsden and, after him, Wilkins choose for their case and slider a composite construction. Marsden[47] decides, again reflecting Heron's description, to understand ΓΔ as if it were only the rectangular upper portion of the slider, to which the dovetailed portion ΔE (if we want to designate two different boards, why then only three letters?), with an arbitrary width and 1 d thick, is later joined. The resulting slider has, therefore, a thickness of 2¼ d (42 mm). Wilkins takes this for good and affirms that 'the proportions and cross-section of Case and Slider are ideal for the attachment of side ratchet bars'.[48]

With respect to the composite construction, we must not forget that when ancient authors meant composite 'beams', they used to specify it clearly in the text, for otherwise the 'beam' was understood as solid.[49] Consequently, I think that the *cheiroballistra*'s slider was carved from a one-piece board (*κανών*) and that the overall dimensions given in the mss must be those of that initial board. Hence, the slider's thickness should be 1¼ d (23 mm), its maximum width, 'about'[50] 2½ d (46 mm), and its cross-section, trapezoidal, rather than T-shaped. This can be clearly seen when an axonometric, oblique drawing of the slider (Fig. 2.2) is compared with the diagram in P (Fig. 2.1). The diagram in M (Fig. 2.3) is less easily identified with my proposal, but it strongly resembles my drawing of the slider (groove for the missile included) as viewed from above.[51]

As no figure for the dovetail's angle is given in the text, I have, arbitrarily, reduced the width at the upper side of the slider to 2 d (37 mm) and given ¾ d (14 mm) for the channel (Fig. 1.4). I would like to add that a cross-section in 'T' enhances the slider's capability to accommodate a bigger missile in a broader channel, which could be misleading.

3. Trigger mechanism

In the 'chapter' describing the *cheiroballistra*'s bolt or trigger mechanism PH provides a full set of assembly instructions, alongside a diagram of the complete device. Such candy, as we shall see, is not as sweet as it may seem at first sight.

The slider is once more represented viewed from above in all the mss diagrams that depict the assembled trigger mechanism. It appears in the same configuration (more stunted, if possible) that we have previously seen at M,[52] but here the positioning of the trigger mechanism shows unmistakably that the flat upper section is narrower than the dovetail below it.

Leaving aside the discussion of the more or less astray interpretations of Prou[53] and Marsden,[54] I shall centre on Baatz's[55] and Wilkins'[56] ones.

PH's text starts talking about the mechanism's five components: An iron 'handle' ΑΒΓΔ, a fork with a quadrangular tenon ΕΖΘ, a claw ΚΛΜ, a trigger ('snake') ΝΞ and a goal-shaped handle ΟΠΡΣ. (Fig. 3.1, 2, 3, 4 and 5).[57] Our problems start when we realize that no measurement is given for any of them, except that the claw must have 'lengthwise an incision of 1d (19 mm)'. Let us see the assembly instructions:

The 'handle'

The 'handle' (*cheirolabe*) must be bored at its lower end Δ. The slider ΓΔ must also be bored, at ΜΝ with a round hole right through, and at Ξ, with a rectangular one. A pin, pushed through Μ, Δ (in the 'handle') and Ν, must establish a connection. It is easy to infer from the diagrams that Ξ is a rectangular slot cut at the rear end of the slider, but the distance from the line ΜΝ to Δ, the end of the slider, is not given in the text.

The 'handle' seems to assume two different forms in the diagrams: when it is depicted detached, it resembles a 'T'[58] and, when assembled, a laying 'H'. I think that the lower horizontal branch of this 'H' could simply be a representation of the rectangular slot Ξ and, so, I have consequently retained the 'T' form which, incidentally, makes narrower the rectangular slot Ξ and debilitates less the slider at this critical point.

Finally, I agree with Wilkins when he says that the 'handle' was not used as such[59] (because it is always depicted in the diagrams as being narrower than the slider and thus has no room inside for accomodating more than one finger), but I differ from him in the kind of connection proposed for the 'handle'. Wilkins fix it rigidly in an horizontal position[60] (which fits nicely his theory of a winched *cheiroballistra*); however, in my opinion, it must swivel around the horizontal axis ΜΝ for two reasons: first, if a rigid connection was sought, why then bore a circular hole for a circular pin? Second, the 'handle' is clearly depicted at every 'assembled' diagram in an upright position[61] (Fig. 3.1 and 6).

The fork and claw

The claw must be bored at Φ, and equally the fork's twin ends ΤΥ. A (round) pin must be inserted through ΤΦΥ, so that the claw can swivel around it. After measuring ΔΟ, 5 d (93 mm) long, on the slider, a hole must be drilled at Ο and the rectangular tenon of the fork driven inside it, so that the fork stays firm. If Δ is the slider's rear end, the hole for the fork-claw ensemble can be placed with total security. The fork's tenon is described in the mss as *τετράγωνος*, which can be translated as 'square' as well as 'quadrangular' (rectangular), I have preferred the latter meaning, that will redound to the immobility of the union. I have made the tenon cross the slider's whole thickness and be clinched at its lower end. (Fig. 3.2, 3 and 6). Incidentally, the forked claw is the only tell-tale fact which confirms us that the *cheiroballistra* is an arrow-shooter.

The trigger

The trigger ('snake') ΝΞ must be bored at its end Ν, and the slider correspondingly at Π, so that a pin is driven through both holes and riveted in such way that the trigger can turn freely around it. Π is marked at 4 d (74 mm) from Μ, we must assume from the diagrams that this Μ is the left side of the boring for the handle's pin, but we are not told how long from the end of the slider Μ is. Let us guess a little:

The position of the fork holding the claw, at 5 d (93 mm) from the end of the slider, is known. The trigger must be, obviously, placed behind it. If we position the trigger just adjacent to the fork and give it a minimum width of, say, ⅓ d (6 mm), then Π will push Μ(Ν) to a distance of ⅔ d (12 mm) from Δ (Fig. 3.6), which does not seem very much in view of the fact that it must hold the whole strain of the machine, but I am afraid that it is the maximum that can be achieved.

About the form of the trigger Schneider remarks: 'The *δρακόντιον* exhibits in the figure a curvature which in that *σχαστηρία* (the trigger in Heron's *gastraphetes*) doesn't exist and which would be superfluous'.[62] If the curve in the trigger is placed horizontally, as in Marsden and Wilkins'[63] reconstructions, it is almost unavoidable to agree with Schneider, as it would make the same work being just straight (like it seems to be in Baatz's reconstruction).[64] Notwithstanding, a remarkable feature in both Marsden and Wilkins'[65] reconstructions (Baatz's is no more than a sketch) is the thickness that the trigger must assume in order to lock the claw adequately. In Heron's *gastraphetes*, the 'block', a portion of the slider (at the rear end) left higher than the rest, allowed for a lighter trigger, as Marsden[66] pointed out, but there is no such thing in the *cheiroballistra*. I think that the 'snake' is pictured in the diagrams as viewed from its side, just like the claw is and, thus, its 'hump' must be placed vertically, with the purpose of locking the claw's tail firmly, without an increase in its thickness (Fig. 3.4 and 6).

The 'pitarion'

The last paragraph in the description of the trigger mechanism is an utter mess: 'And again, having marked ΞΡ from the handle <ΑΒ>ΓΔ, we bore at Ρ, and again, having measured from there 4½ dactyls (83 mm), as ΡΣ, we bore at Σ, and thus we lower <the *pitarion*> into the board ΓΔ, which is in the first chapter. Here it is.'

The text is explaining where the *pitarion*'s[67] two tenons, Ρ and Σ, have to be placed on the slider. No figure is given for the distance ΞΡ but, on account of the reference to the 'handle', we must suppose that Ξ is the quadrangular hole at the rear end of the slider. Reading word for word, we could understand that the distance ΡΣ between the two tenons amounts 4½ d (83 mm), which would make the *pitarion* even wider than the case!

Wilkins tries to put a little order in the confusion by making ΞΡ = ΞΣ = 4½ d.[68] This places the *pitarion* clearly forward of the fork-claw, but, contrary to what Wilkins supposes, this is not supported at all by the mss diagrams: the *pitarion* in M's (assembled) one certainly interrupts its 'crossbar' at the fork-claw (with the purpose of not obscuring them). However, it would be completely impossible to discern whether it passes fore or aft of the fork-claw were not the insertion points for the 'legs', Ρ and Σ, placed clearly behind even the trigger. The diagram in P shows the 'crossbar' complete, but the original colour washes substantially blur the clear picture traced by Wilkins in his line drawing.[69] Anyway, the *pitarion* 'legs' insert again clearly behind the fork-claw and the trigger: the medieval copyist was forced to enlarge the left 'leg' just to make this clear![70]

Based on the diagrams, I have placed the *pitarion*, as appears in my reconstructed drawing (Fig. 3.6) behind the fork-claw and the trigger, approximately halfway between the last one and the point Ξ. I am not fond at all of changing numerals in the text, but

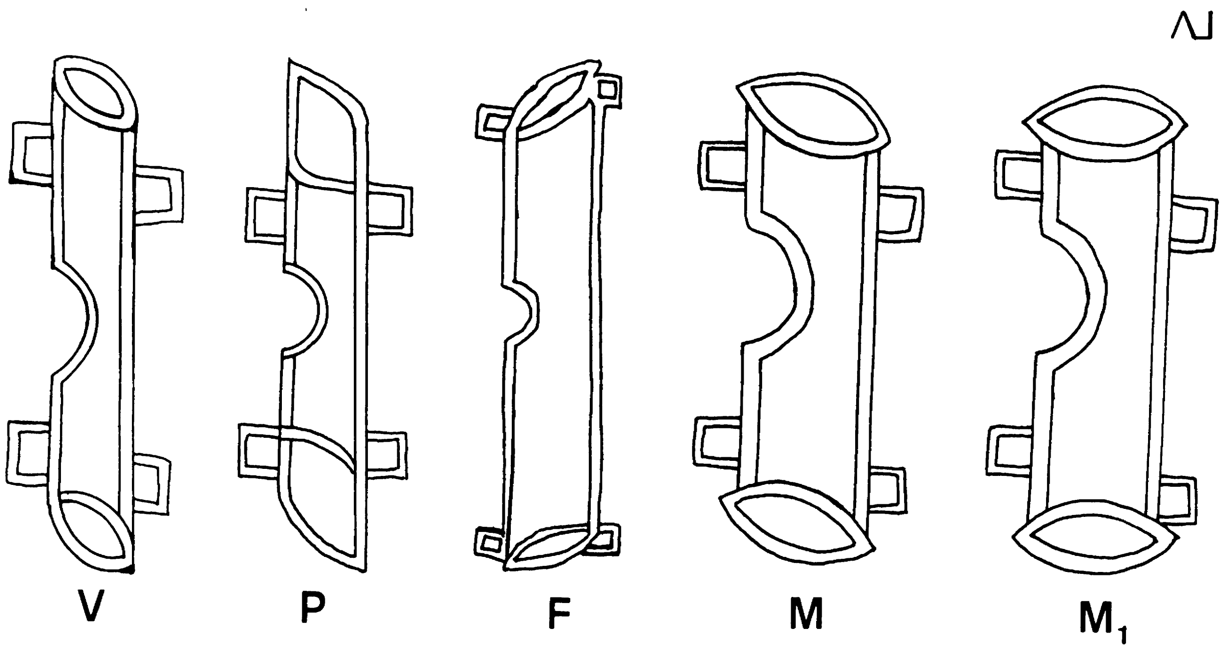


Fig. 4: Comparison of the field-frames in the diagrams of the four main manuscripts.

nevertheless if we would change ΔC d (4½ d = 83 mm) for AC d (1½ d = 28 mm), then PΣ would fit inside the slider's width. Even making ΞP = ΞΣ = 1½ d, it would provide a position for the *pitarion* noticeably equal to the one I have proposed earlier for it. This is clearly unsatisfactory, but is the best I can get out of the paragraph.

The *pitarion*, as Wilkins declares, is a very useful handle to push the slider forwards.[71] In my reconstruction it is still possible to press down the rear of the claw with one finger while grasping its 'crossbar'. In the place I have proposed for it, the *pitarion* not only does not foul the trigger, as Wilkins fears, but it provides a useful limit for its travelling arch.

4. Field-frames

The field-frames (*kambestria*) are one of the few *cheiroballistra* components whose relatives, belonging to different but related machines, have been archaeologically attested. This circumstance will provide us with valuable clues to the interpretation of text and diagrams, but can also be a little misguiding, if we go too far in assigning to it the *cheiroballistra* characteristics of catapults that were clearly different.

One *kambestrion* is composed from two rings, held apart by two iron bars. The bars (one of them exhibiting a curve in its central portion) are 10½ d (194 mm) long,[72] a little more than ⅔ d (12 mm) wide and must have 'a thickness so that they are not easily bent'.[73]

The rings have an inner diameter of 2 d (37 mm), a width of 1 d (19 mm) – thus, their external diameter is 4 d (74 mm) – and the same thickness as the bars. I think[74] that the word *εὖρος*, which I have translated as the 'inner diameter', specifically denotes the inner span of hollow things, and for this reason only appears in the text linked to the rings and *pitaria* of the field-frames and to the bronze washers. It appears here clearly differentiated from *πλάτος*, which denotes 'width' elsewhere.

Each bar must be set at a distance of 3½ d (65 mm) from its companion and must have two *pitaria* (with the same width and thickness of the bar, but with an inner breadth of ⅔ d (12 mm)) attached to it.

This is as far as the mss text goes. Nevertheless, there are still two crucial questions to be solved before any reconstruction of the *cheiroballistra*'s *kambestria* is attempted.

The palintone position

Since the first tentative reconstruction, everyone has agreed on the *cheiroballistra*'s palintone character,[75] no matter what was exactly understood by 'palintone'.

In the earlier stone-throwing *ballistae*, the palintone position (the enlargement of the arc travelled by the arms) was achieved mainly thanks to the special design and individuality of the half-springs,[76] which, by the way, bear a clear resemblance to the *cheiroballistra*'s field-frames.

Up until now, six real *kambestria* have been found. Three belong to medium-sized *ballistae* (Orsova,[77] Lyon[78] and Sala[79]) and have their bars placed offset, in a very similar way to the palintone half-springs. The other three belong to small *manuballistae* (Gornea)[80] and have their bars radially set.

Even if it were beyond doubt, which is not the case,[81] that the bars in the Gornea field-frames were originally radially set, this would not forcibly imply the same for the bars in the closely related *cheiroballistra*'s ones, as Wilkins thinks.[82] We have already seen that the mss text does not give any clue to solve this question, but what about the diagrams?

The field-frame bars are clearly offset in P (Fig. 4.P) and even the 'rings' assume a form identical to that of the palintone half-frames' hole-carriers. At first sight, things are not so clear at V, F and M (Fig. 4.V, F, M). Let us examine the, in appearance, less 'palintone' of all them, the diagrams in M.

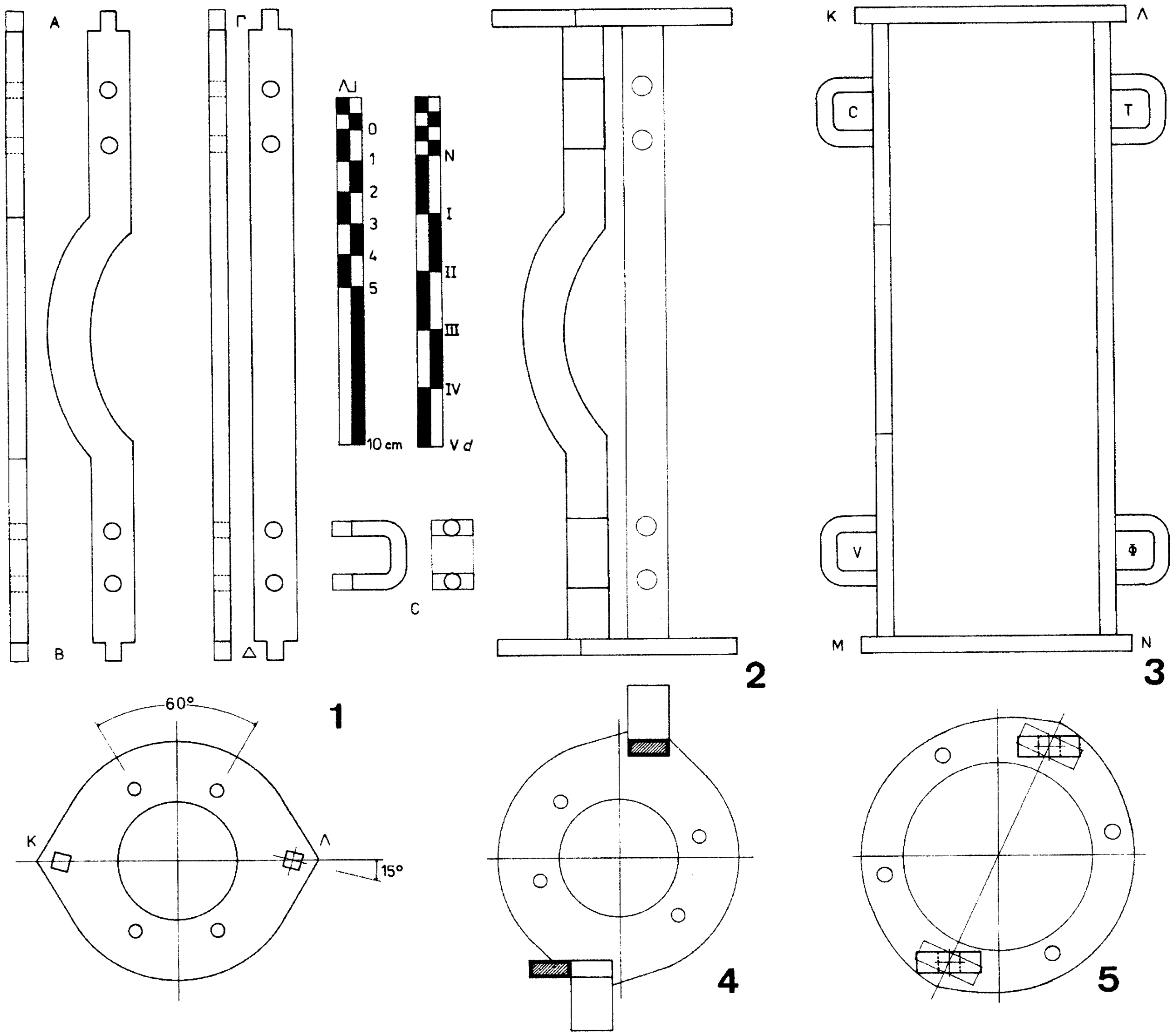


Fig. 5: *Field-frame. 1. Components. 2. Front view. 3. Side view. 4. Mid cross-section. 5. Mid cross-section of the Gornea field-frame, with the bars offset.*

Wilkins simply dismisses the shape of the rings in M as 'the common failing of drawing ellipses with points' (instead of circles), but, in my opinion,[83] there is more to it than that: it is true that all the circles in M's diagrams are depicted as pointed ellipses, but where this is done (the washers and the arms) the ellipse is always placed with its long axe perpendicularly set to the longitudinal axe of the figure. In M's *kambestria*, the ellipses are set obliquely to the bars (Fig. 4.M), had they followed the general rule, the diagram would have looked noticeably different (Fig. 4.M_1). Therefore, I conclude that in all the main mss diagrams, the *kambestria* bars are depicted offset and this condition must be observed in the reconstruction.[84]

The inner diameter of the rings

The figure of 2 d (37 mm), given by all the mss for the inner diameter of the *kambestria* rings, has been deemed as clearly insufficient (and, thus, corrupt) by all previous reconstructors (except Prou, who thought that the *cheiroballistra* was propelled by steel springs, and Schneider, who believed that the *kambestria* were not artillery components at all).[85] I think that there is no reason to change it.

I shall deal with this question as it deserves in the following section, but this is the most convenient place to refute adequately one of Marsden's objections. He, rather obscurely, argued that if the bars were 3½ d apart, then they would not fit rings with an inner? diameter of 2 d.[86] Let us remember that the external diameter of the rings is 4 d, that neither the rings depicted in the mss diagrams nor those belonging to the archaeological *kambestria* (not even those of the Gornea ones) are externally perfect circles, but more or less pointed ellipses and that the bars are offset placed. The conclusion is that there is no problem to fit the bars in the rings (Fig. 5.4).

Proposed reconstruction (Fig. 5)

Without the clues provided by actual *kambestria*, and specially those from Gornea, it would be extremely difficult to reconstruct those of the *cheiroballistra* from the text and diagrams alone. Notwithstanding, it is very important to remember always that only technical solutions should be borrowed, the dimensions of different machines are not interchangeable (no matter how similar the machines seem to be, or how logical the interchange could appear), otherwise, there would be an enormous risk of reconstructing some other catapult or a strange hybrid under the name of *cheiroballistra* (a Gornea*ballistra*!).

Accordingly, I have kept the bars' dimensions to that given in the text. There is no information about the curvature in one of the bars, so I have arbitrarily chosen for it a length of one third of the bar and a rise equal to the bar's width. I have not considered the structurally necessary tenons to be included in the length of the bars, for the same reason that the tenon for the lunate fitting was not included in the case's length (Fig. 5.1).

As I have proved earlier, the *cheiroballistra*'s field-frames' bars must be offset and the rings must adopt the form of pointed ellipses, but, to what extent? Unfortunately, there is no indication in the text or diagrams about this. In my reconstruction, the increase in length (Fig. 5.1) from the initial circle at the long axis of the ellipse is marked by the positioning of the bars, which I have, arbitrarily, rotated 15°, just to fit the difference in length of the *klimakion*'s bars, as we shall see later (see 'The arc travelled by the arms'). Each ring has the customary four holes for the locking pins[87] (Fig. 5.1, 2 and 4).

It also seems to be a rule that in all the preserved field-frames, the lower pair of *pitaria* is larger in height and width than the upper one.[88] A exception to this rule is the Sala *kambestrion*, in which the missing four *pitaria* were at least of the same height.[89] In the *Cheiroballistra*, text and diagrams definitely speak of four equal *pitaria* at each field-frame.[90] I suppose that the figure given for their internal breadth is also valid for their internal height. At this point of the study, it is barely a surprise to discover that PH has forgotten to tell us at which exact points of the bars the *pitaria* must be inserted. The diagrams show them closer to the rings than to the middle of the bars, which is sensible and attested by all archaeological finds, but, whether half a digit lower or higher, is again anyone's guess (Fig. 5.1, 3).

5. Washers and levers

Four light bronze cylinders, with a height of 2 d (37 mm), an inner diameter of 1⅓ d (25 mm) and a thickness equal to that of the *kambestria* bars must be made, with circular flanges, ⅔ d (12 mm) wide and the usual thickness, attached at 1¼ d (23 mm) from their upper ends. Each cylinder must have two slots, diametrically opposed, at its upper side into which rectangular (iron?) bars, 3 d (56 mm) long and ⅔ d (12 mm) high must be slotted (Fig. 6.1, 2).

Everybody (except Prou) identifies the cylinders with the standard catapult washers and the bars, with the levers. A lot of washers, of all periods and sizes, have been found by archaeologists. All the *modioli* are made of bronze, except those belonging to the Lyon field-frame, which are made of iron. They seem to gradually develop a higher profile from the older to the more recent ones (Hatra, Pityus, Volubilis), which also exhibit a torus under the slots for the levers.[91]

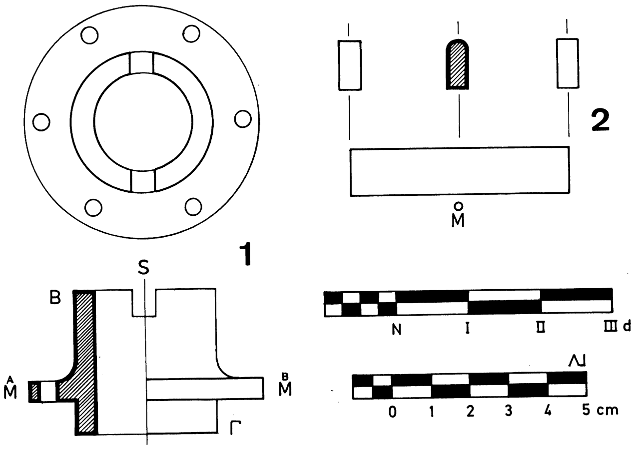


Fig 6: *1. Washer. 2. Lever.*

The mss do not say anything about the holes around the washer's flange for the locking pins, but they are almost a commonplace. Small *modioli* exhibit very few (four to six) holes, consequently, I have decided to bore only six holes on my *cheiroballistra*'s washers (Fig. 6.1).

No figure is given in the mss text for the thickness of the levers. I have decided to make them of the customary 'same thickness of the bars'. A rounded profile must be given to, at least, the central portion of the lever which overhangs the hole in the washer, if one wants to avoid chafing the spring cord badly.

The thickness of the field-frame bars

As I have already mentioned, PH assigns to the *kambestria* bars 'a thickness so that they are not easily bent'. This riddle becomes a real trouble because this thickness is subsequently systematically referred to all along the *Cheiroballistra* text.

Attempts have been made by previous reconstructors to fill this notorious gap but they are nothing but intelligent guesses. The proposed thicknesses are, moreover, always on the high side,[92] concordantly with the strains posed by their over-enlarged springs. However, the *Cheiroballistra* text furnishes, in my opinion, enough information to fix within very narrow limits this missing thickness.

We have been told that the inner diameter of one *modiolus* is 1 ⅓ d, and that of the hole in the field-frame ring in which it must fit, 2 d. Therefore, it is easily deducible that the wall thickness of the *modiolus* is ⅓ d (6 mm) or, better, a little less, to allow it a freer rotation inside the hole, say, ¼ d (5 mm). As we have also been told that this same thickness of the washer's wall must be 'equal to that of the bars', then we have here the solution to our problem: the thickness of the bars must lay between 5 and 6 mm.

The inner diameter of the washers

This is one of the main points in my argument. Let us remember that the figure given by PH for the inner diameter of the *kambestria* rings (B d = 2 d) have been refuted by previous reconstructors as inadequate and corrupt because of its smallness. Marsden proposed 3½ d (ΓC d), Baatz rectified it to 3 d (Γ d), and finally, Wilkins realized that these corrections were palaeographically unsound and sought to reconcile his assumed wider diameter and palaeography by turning what the mss text clearly says is the inner breadth to outer diameter (but we have already talked about the respective meanings of *ευρος* and *πλατος* earlier) and then changing Β d (2 d) to Ε d (5 d).[93]

Consequently, they continue the inner diameter of the washers that appear in the mss text (ΑΓ d = 1⅓ d) cannot be right. Marsden suggests 2⅓ d (ΒΓ d), Baatz accepts it and add 2½ d (ΒC d) as another possibility, and Wilkins simply adheres to this, this time without regard to the palaeographical difficulties.[94]

What happens with the levers, then? Marsden leaves untouched the length which PH marked for them (Γ d = 3 d), with the result of clumsily short levers in respect to the washers and the total impossibility of using the spanner for twisting the springs. Baatz also retains the length of 3 d, but the ensemble gains in appearance as he makes the external diameter of the washer of 3 d, too; anyway, it is again impossible to use the spanner. Wilkins once more realizes this problem and, therefore, dares to do what his predecessors seemed afraid of doing: to recover the much needed overhang by lengthening the levers, leaning on the handy palaeographical excuse of the repetition (ΓΓ d = 3⅓ d).[95]

Summing up, although the practical use of only slightly wider springs is attested from the archaeological record (Ephyra 6 = 34 mm, Elginhaugh = 35 mm[96]), the search for a powerful weapon has forced almost everybody to alter the spring diameter given by PH, after which, it is unavoidable to change the inner diameter of the *kambestria* rings and the length of the levers. This means the modification of three perfectly interrelated figures given in the text, which should be under little or no suspicion of being altered (all three at the same time) by careless copyists in all the manuscripts (there is no reading variants at these points), which stem at least from two different first copies of a supposed original.[97] I think that, in any event, this heavy 'emendation' of a quite coherent ancient text is plainly excessive. Marsden had decided beforehand that 'Heron of Alexandria's second artillery treatise, the Cheiroballistra, provides the description of a very powerful, torsion, arrow shooting engine'.[98] If a spring diameter of 1⅓ d (25 mm) did not fulfill his expectations, even if the *cheiroballistra* was 'little more than a toy',[99] nothing authorizes him or his followers to change the text numerals at will: due to the total lack of information about the machine's purpose, the power output should be the conclusion, not the premise of our reconstruction work.

6. The 'arch'

The *kamarion* is a long (iron?) strut, with an arch in its middle and forked ends, let it be ΑΒΓΔΕΖΗ (Fig. 7.1). The length of the main body, ΓΕ, is 1 ft 7½ d (435 mm), the inner span of the arch, ΘΚ, 5 d (93 mm). The length of the long tenons, Α and Ζ, is 4 d (74 mm) and, that of the short ones, Β and Η, 2 d (37 mm). The distance between the tenons, measured by their inner sides, is about 3½ d (65 mm). The thickness (of the whole *kamarion*, or only of the tenons?) is the same than the field-frames bars.

Only one real 'arch' has been up till now found, the Orsova one.[100] It belongs to a machine substantially bigger than the *cheiroballistra*, a medium sized *ballista*. Unfortunately, its four tenons are broken, but it is clear that they were flattened so as to reduce their thickness almost to a sixth of its original value. The best preserved of them showed a rectangular hole and part of a second one, of the kind usually intended for receiving metallic retaining pins.

With the help of the Orsova *kamarion*, the reconstruction of the *cheiroballistra*'s one does not seem a great problem (Fig. 7.1). Baatz chose the easy way in his graphic reconstruction[101] and did not flatten the tenons, the rectangular holes for the pins being thus left in a vertical plane. At first sight, there is not a great difference between Wilkins 'arch'[102] and mine, but there are, anyway, some remarks to be made.

The final phrase of the text's instructions is a little ambiguous in its sense, as it is not clear if it assigns a thickness 'equal to that of the bars' (5–6 mm, as we have seen earlier) to the whole *kamarion* or only to its tenons. I have decided to make the 'arch' and its tenons of this same thickness. No indication is given in the mss text for the *kamarion*'s vertical thickness. In the Orsova one, it approximately doubles the horizontal one and I have kept this proportion in my reconstruction.

The distance between each pair of tenons, measured by their inner sides, must be about 3½ d, says the mss. Wilkins, very sensibly, keeps exactly this distance,[103] but I think that the tenons have to be inserted through the *kambestria*'s *pitaria* (see the section, 'Assembling the components') and, therefore, I must adhere to Marsden's opinion when he says 'that 'about 3½ d' is even more appropriate than a straightforward '3½ d' would have been'[104] if PH wanted to indicate that the tenons should fit the field-frame bars, which are set 3½ d apart. The distribution of the rectangular holes, intended for iron pins, in the tenons corresponds also to the positions of the *pitaria*.

7. The 'ladder'

The *klimakion* is another long, composite strut. It is formed by two (iron?) bars, which have a width (height) at their middle points of 2 d (37 mm) and of 1¼ d (23 mm) at their ends. One of the bars, ΛΜΝΞ, is 1 ft 8 d (444 mm) long, thus shorter than its companion ΟΠΡΣ, which is 1 ft 10 d (481 mm). There are tenons, ΛΒ, ΝΓ, ΟΔ and ΡΕ, at each of their ends. The thickness... of each one of them must be 2 d (37 mm).

The bars must be spaced at three equidistant points and quadrangular holes bored at Τ and Υ (the central ones), while circular ones must be bored at Φ, Χ, Ψ and Ω. A cross-piece – 3 d (56 mm) long (not counting its tenons) and 2½ d (46 mm) wide – must be inserted in the central holes of the two bars and two rungs – of the same dimensions than the cross-piece – in the side ones. The distance between the two bars is, therefore, 3 d, measured by their inner sides. All the tenons must be riveted, so that the bars are joined firmly.

Finally, four T-clamps, ς, ς, ς, ς must be riveted on the bars, two on each one, at either side of the cross-piece. They must be 3 d (56 mm) long, 1 d (19 mm) wide and suitably thick. They must be bored down the middle and be 2½ d (46 mm) apart from one another.

The tenons

A difficult phrase is the only reference to the *klimakion*'s four tenons in the mss text. In M, P and V, it can be read: '*πάχος δὲ ἕκαστος* (*ἕκαστον* in F, *ἑκάστου* amended Vincent) *τῶν* ΛΒ ΝΓ ΟΔ ΡΕ *τόρμων ἔστω δακτύλων* Β'. It could be straightforwardly translated as: 'the thickness of each one of the tenons ΛΒ ΝΓ ΟΔ ΡΕ must be 2 d (37 mm)'. Notwithstanding, the philologist M. Vincent, and after him, C. Wescher and R. Schneider, felt

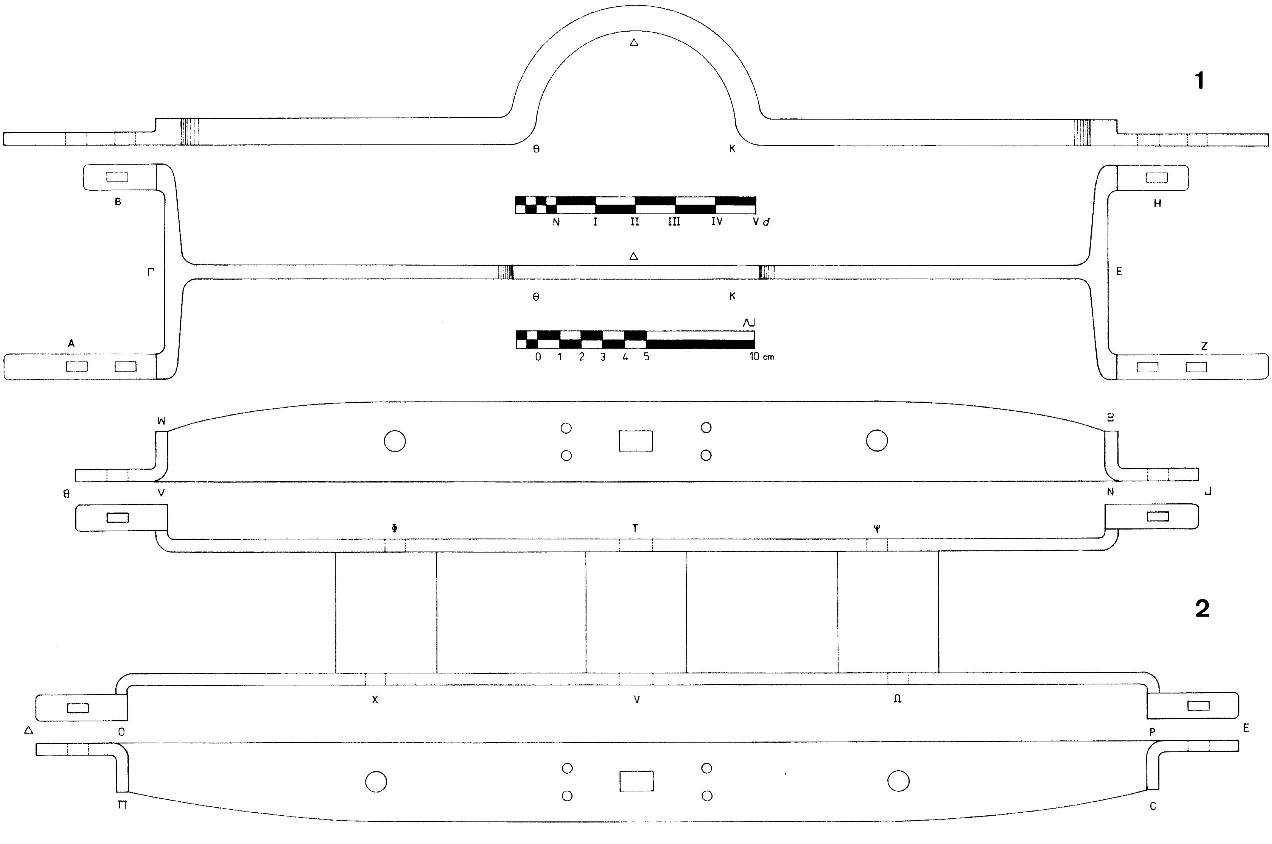


Fig. 7: *1. The 'arch'. Side view and plan. 2. The 'ladder'. Side views and plan.*

that there was a gap in the text at this place and that the preserved part should be read: 'the thickness... of each one of the tenons ΛΒ ΝΓ ΟΔ ΡΕ must be 2 d'.

Prou was the only one who had no problem to accept 2 d as the thickness of the tenons,[105] but, in any case, it seems too much. The thickness of the bars is not given in the text and, from Vincent onwards, the phrase has been restored as follows: 'the thickness <of each of the bars must be (2 d, ½ d, equal to that of the above mentioned bars?). The length> of each one of the tenons ΛΒ ΝΓ ΟΔ ΡΕ must be 2 d'. Wilkins' witty proposal[106] of just changing the end of the phrase from '*δακτύλων* B' = 'of two dactyls' to '*δαχτυλου* B' = 'of ½ dactyl' must be rejected, because in the short *Cheiroballistra* text the numeral 'B' is never employed to denote '½'. It always means '2', and '½' is consistently written in all the mss as 'ς' or '*ἥμισυ*'.

The mss diagrams of the *klimakion* are the most disappointingly obscure of all the set. Nevertheless, the tenons are depicted in them as flat and surely rotated 90°. It would be acceptable to make them 2 d long, ⅔ d wide and of the standard thickness.

As Wilkins remarks,[107] it is impossible to pass the tenons of the 'ladder', which are 3 d apart, trough the *pitaria* in the *kambestria*. I have no defence at this point, to solve the problem I have just conjured up folds at the ends of the bars (to set the tenons apart enough) (Fig. 7, 2) from the very same place from which Wilkins conjures up his 18° turn of the tenons.[108]

The cross-piece and the rungs

The mss text, once more, does not give a figure for the thickness of the cross-piece and rungs. The 'standard' thickness (⅓ d – ¼ d) seems to me this time a little scarce, so I have chosen ½ d for them.

The cross-piece ΤΥ has posed no problem in former reconstructions. The width of its tenons can be, say, one third from the total (Fig. 8.2). A very different matter are the rungs ΦΧ and ΨΩ: Marsden just reproduced the cross-piece, but with round tenons; the undesirable result is that, with such form, the rungs would revolve freely. Baatz proposed to make the rungs cylindrical, but, as they are 2½ d wide, they would protrude awkwardly from the (at their most) 2 d wide bars. Finally, Wilkins provides each rung with four tenons to immobilise it, but the mss text distinctly mentions only one tenon (and one hole, in the corresponding bar) at each side of the rungs, and the diagrams confirm this.[109]

I think that the trouble with the rungs can be solved by means of a small hocus-pocus. The mss text says that both *klimakion*'s bars must be bored at three equidistant points. If we understand this as 'divide each bar in four equal parts', the result is that the round holes of both bars will not coincide, but will be ½ d apart (measured at the axes) from one another. This happens because one bar is 2 d shorter than the other. Consequently, the tenons are displaced from the central axis and the rung will not revolve (Fig. 7.2 and 8.1).

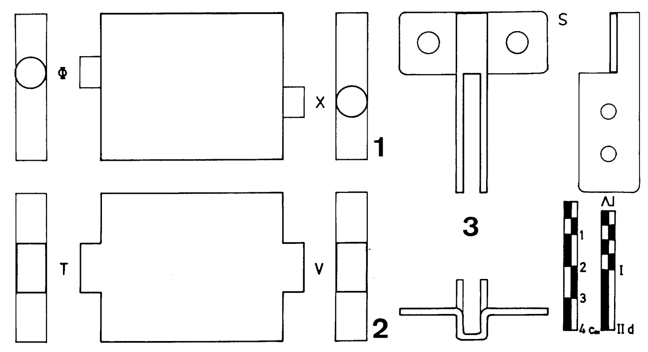


Fig. 8: *Additional componenets of the 'ladder'. 1. Rung. 2. Cross-piece. 3. T-clamp.*

The T-clamps

These are undoubtedly the worst depicted pieces of the worst depicted *cheiroballistra* component in the mss diagrams. The dimensions given in the text seem to describe rectangular elements, but they have a clear T-form in the diagrams. This form is completely logical, because the clamps join the case to the 'ladder' and as much contact surface as possible must be afforded by them. Marsden, Baatz and Wilkins[110] have worked out the meagre information available, successively improving it, but there is no way of knowing what PH's T-clamps really looked like.

Following upon Wilkins' design, I have developed my own T-clamps (Fig. 8.3). They are worked from iron sheet, 2 mm thick, which saves weight and working expense while maintaining their strength. The distance between the clamps given in the text is the same as the width of the cross-piece and so I agree with Wilkins that it has to be measured across the case, but with my T-clamps design, there is no need to carve mortises for them out of the case, thus reducing its resistant section.

8. The arms

Each arm is composed of a (wooden?) *frustum* of a cone and a hooked (iron?) bar welded[111] to an (iron?) ring.

The cones are 11 d (204 mm) long, their ends are ½ d (9 mm) thick and, their bases, 1 d (19 mm) thick. They have quadrangular grooves along their lengths and tenons in their ends.

The bars have, as we have said, rings welded on and they must fit the grooves and tenons in the cones. The hooks at their ends are ½ d (9 mm) high.

Perhaps the text is uncomplete and breaks off abruptly without giving the length or cross-section of the bars, as everybody thinks, but I must remark that, in the logical descriptive sequence followed in all the *Cheiroballistra* chapters, the length of the bars should have – at least – been given before the height of their hooks, which is not the case.

Marsden proposed a total length for the complete arms of 16 d, which left the iron bars protruding 5 d from the hard wood cones. He understood the 'tenons' as pins passing through holes in cone and bars. Baatz accepted Marsden's reconstruction and suggested that the cones should be made of bronze. Wilkins lengthens the arms to 17½ d, interprets the tenons as dovetails in the grooves and states that only bronze cones would resist the strain imposed by the machine.[112] One of the Wilkins' wooden cones certainly broke while testing his catapult, but what does it exactly prove?

All the components in a machine are unavoidably interrelated. If we do not respect the dimension given in the mss text for the spring diameter,[113] we can hardly expect that the arms, for example, will work perfectly[114] and we should blame nobody – neither PH, nor the mediaeval copyists – but ourselves for it.

Marsden and Wilkins need longer arms to exploit to the best their thicker springs, but the cones are only 11 d long and this cicumstance, as we have seen, results in Marsden's iron bars protruding 5 d, and Wilkins' ones, 6½ d, from the ends of the cones. I think that the *cheiroballistra*'s arms are very cleverly designed to work as composite-built cantilever beams: the wooden cones will work compressed and the iron bars, tensioned. To achieve a correct functioning, both bar and cone must work in unison. If the bar is noticeably (125 mm) longer than the cone, its independent bending will add a moment to the shearing stress already suffered by the cone at its weakest point, what will surely prove to be too much. Not to mention that Marsden and Wilkins have doubled the spring diameter given in the mss text, which means to increase sixfold its power output.[115]

The mss diagrams do not show the bars as protruding excessively from the cones. Even if we measure on M's diagram, which is not to scale, the distance does not reach even half of that proposed by Wilkins.

The dimensions given in the *Cheiroballistra* are noticeably refractory to the application of any of the wooden-framed engines' modular systems of proportions. Anyway, I think that the arms of the *cheiroballistra* fit into the palintone modular system. It could, of course, just be chance, but we must not forget that the *cheiroballistra*, although an arrow-firing catapult, is a palintone. The module of a catapult is equal to the diameter of its spring, but it is usually mentioned by the treatise writers as the diameter of the hole in the hole-carrier. This was no problem in wooden-framed engines, because both dimensions could be made equal in them, but in iron-framed ones, the diameter of the hole is always bigger (= diameter of the spring + two times the thickness of the washer) than that of the spring. If we retain, in any case, the diameter of the hole as the module in the *cheiroballistra* (2 d), then the thickness at the base of the arm should be ½ D = 1 d, which is the thickness given by PH, and the length of the arm, 6 D = 12 d; this is just 1 digit longer than the cone, and would accommodate without problem the ½ d high hook and the tenon at the end of the cone.

What about those troublesome tenons at the narrow ends of the cones? Wilkins discards, rightly I think, Marsden's solution as improbable and highly debilitating for the iron bars, but I am afraid that his proposal to interpret the tenons as dovetails in the cones' grooves is even more far-fetched.[116] No matter how oblique the sides of the grooves at P and V's diagrams may seem, PH definitely wrote that the grooves must be quadrangular. The word 'dovetailed' was undoubtedly in his glossary and he would have had no problem in using it, as in the description of case and slider, had he considered it appropriate. In my opinion, the tenons must be taken just at their face value, that is, a tenon must be left protruding from each cone's small end, carved out from the same piece of wood (Fig. 9.1). If both tenon and iron bar are tightly bound by a wrapping cord, then bar and cone will be attached at two points, the ring and the tenon, and will work in unison, as required (Fig. 9.3).

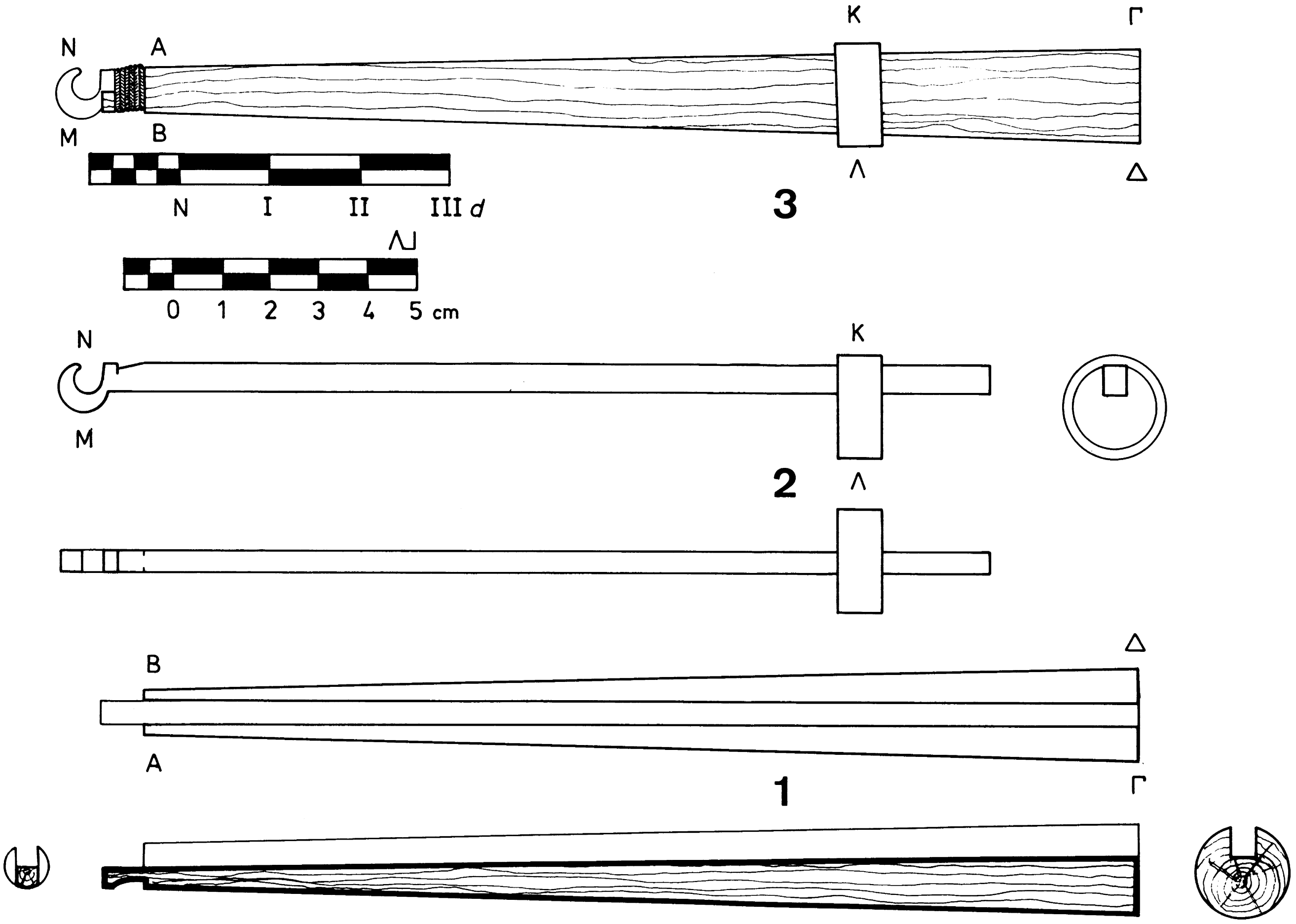


Fig. 9: *The arm. 1. 'Cone'. Front view, longitudinal section and side views. 2. Bar with ring. Plan, front view and side view. 3. Assembled arm. Plan.*

Finally, it is unnecessary to add metal tabs to the arms if one wants to prevent them from being pushed or pulled out of the springs, as Wilkins does:[117] the ring (made as thick as necessary) will hinder the first and the tapering base of the wooden (rough) cone, the second (Fig. 9.2, 3).

ASSEMBLING THE COMPONENTS

It is a pity that the only surviving instructions for the construction of a metallic framed catapult are those of so small a one as the *cheiroballistra*. Moreover, the machine does not seem to follow any of the given modular lists of dimensions stemming from the calibrating formulae, which implies that the instructions cannot be used (except, perhaps, in a very broad structural sense) for the construction of a bigger machine, like the ones figured in Trajan's Column or for the completion of the many parts missing from archaeological artillery finds.

Whether complete or uncomplete, the *Cheiroballistra* text lacks the smallest hint about how all the described components should be assembled, and this is its worst draw-back. There are some clear points: the slider must be inserted in the case; the 'ladder' must be attached to the case at some uncertain point; the two field-frames must be held apart by the two struts, the 'arch' above and the 'ladder' below; washers and levers must be inserted in the field-frames' rings to receive the rope-springs, and finally, the arms must be placed in the springs.

The frame

If it is easy to deduce that both field-frames must be inserted one on each side of both struts, to find out in which concrete position they must be inserted has always been quite a problem. I shall not unnecessarily lengthen this chapter by discussing all previous reconstructors' proposals, but I shall only quote Baatz's statement of the problem: 'the two field-frames differ in that one is the mirror-image of the other. As we do not know which of the frames is to fit which side of the weapon, there are eight possibilities for mounting each field-frame on the forked ends of the transverse struts.'[118]

If such a question had not been solved in the Hellenistic machines by the diagrams and descriptions in the Artillery Treatises, we could still have resorted to actual catapult frames: the Ampurias and Caminreal ones.[119] Although their wooden stanchions and hole-carriers have perished long ago, the iron plating perfectly preserves their structure and dimensions.

With the later all-metal framed engines our lack of information is dramatic. To fill the gap in the *Cheiroballistra* about how to assemble the components of the frame we have only a hand-

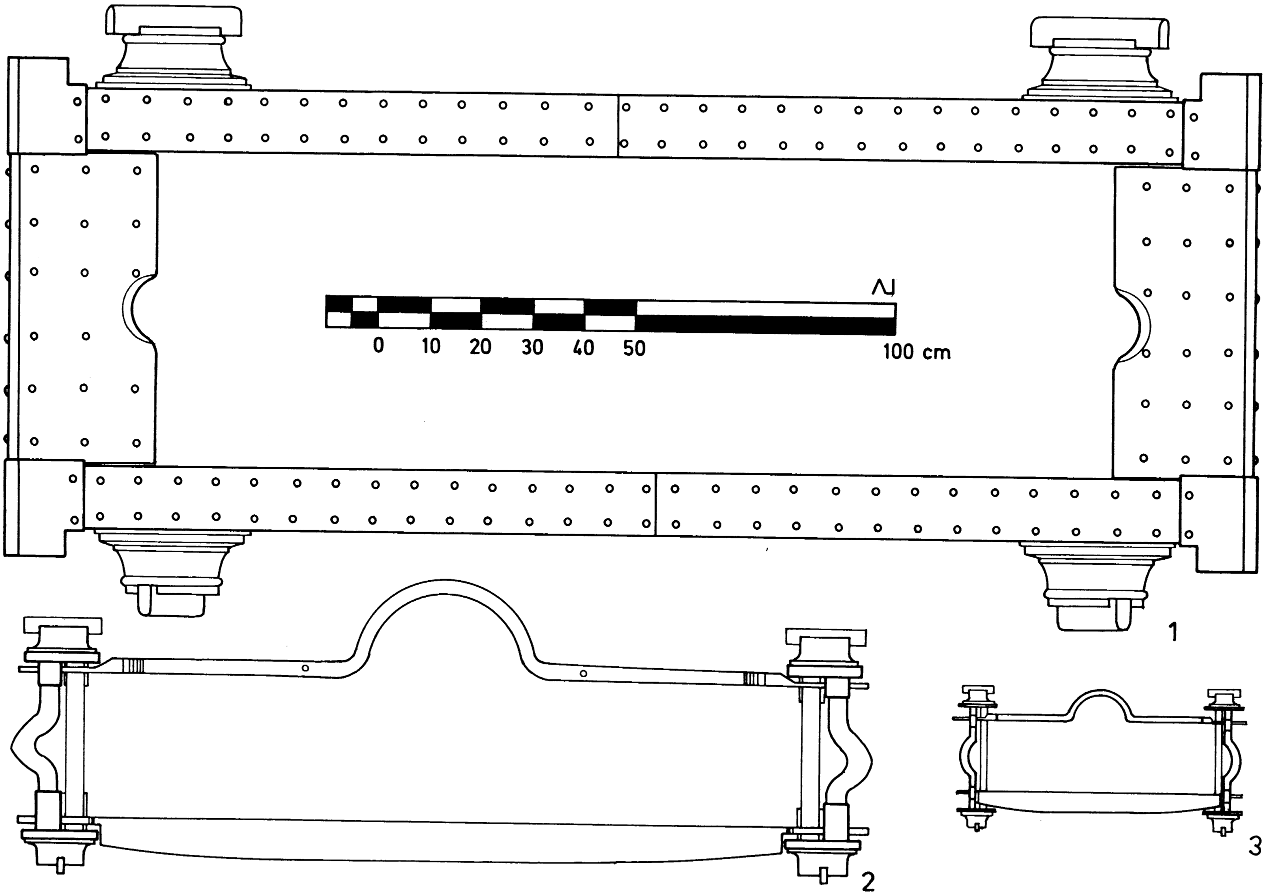


Fig 10: *Late ballistae frames, front view. 1. Hatra (after Baatz). 2. Orsova. 3. Cheiroballistra.*

ful of imprecise non-professional descriptions and even less (and by no means more explicit) graphic representations.[120] The actual remains of metallic frames consist only of detached components, without immediate clues about their relative positions. An archaeological find like the above-mentioned Spanish ones would be, therefore, most useful, but do we not have already one?

In 1972 the bronze plating of a complete frame was discovered in Hatra (Iraq), belonging to a medium sized stone-throwing *ballista* (Fig. 10.1). In his account of the find,[121] Baatz mentions superficially 'the two half-round openings in the side-stanchions'. Well, if we compare this frame with, say, the Ampurias one, we shall soon realize that the openings are not cut at the sides of the frame and rearwards, as they 'ought' to be, but at the front and inwards. In other words, it seems as if the former side-stanchions had been turned 90° and had now become 'front-stanchions'. It cannot be doubted that the Hatra engine was fully functional,[122] and, moreover, its mid-III[rd] century AD date makes it roughly contemporary of the all-metal frames' components mentioned in the precedent sections. Consequently, I think that in Roman Imperial catapults (at least, from Trajan onwards) the semi-circular recesses for the arms were placed at the front of the frame and looking inwards.[123]

The vexed question about the positioning of the two field frames is finally solved and, if we place them this way, it will come out that the four *pitaria* are placed just as to be inserted in the forked ends of both struts.

One archaeological find helps to confirm this theory: that from Orsova. There an 'arch' and a field-frame, both belonging to the same machine, were discovered.[124] Unfortunately, the four tenons of the strut were broken, but the forked pairs are separated by the exact distance as to accommodate inside the field-frame's upper *pitaria.*[125] I think that there is enough information to attempt a theoretical reconstruction: tenons of different lengths in each pair, like those of the *cheiroballistra*, would fit marvellously the offset bars of the field frames and, if we add another symmetric field-frame, four washers and an imaginary 'ladder', the Orsova metallic frame's general dimensions can be restored with some confidence (Fig. 10.2). The curves of the front bars bulge noticeably from the sides of the frame and this image is strongly reminiscent of the rounded projections that are represented at the sides of some of the catapults figured in Trajan´s Column. These side-extensions are inconsistently depicted as continuing either the line of the 'arch' (Fig. 11, cast 105) or the line of the 'ladder' (Fig. 12, casts 163–4), but they are always placed at the middle of the field frames.[126] In my opinion, these examples from the Column also support my theory about the positioning of the field-frames.

I am well aware that I have just transgressed some of Wilkins' main commandments, which can be summed up as: 'passing the

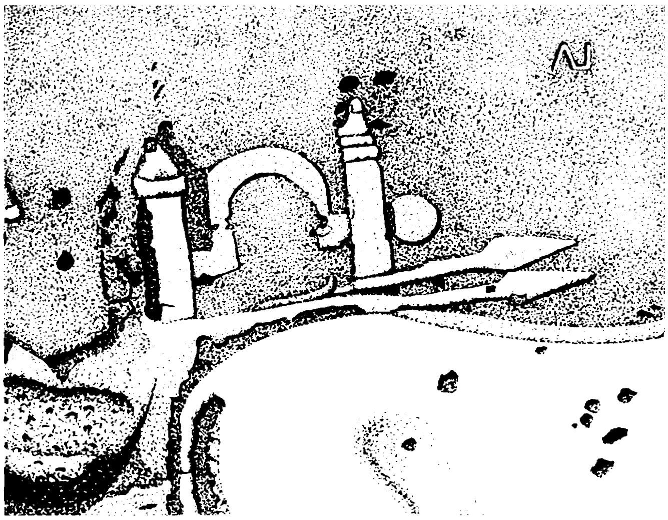


***Fig.11:** Ballista on Trajan's Column. Scene XL, Cast 105.*

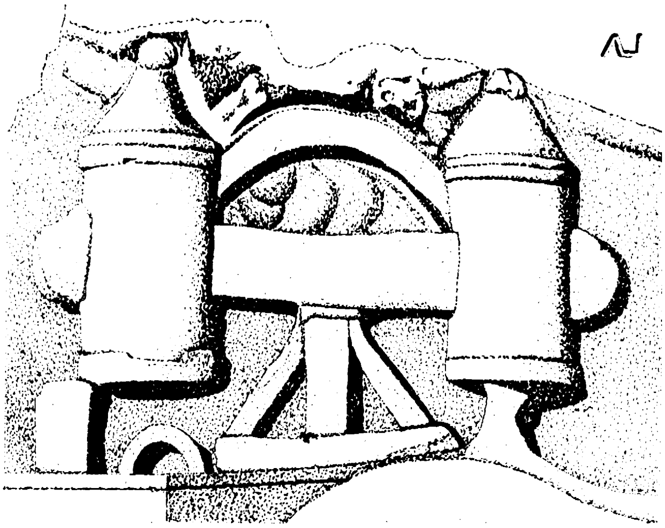


***Fig. 12:** Ballista on Trajan's Column. Scene XLVI, Casts 163–4.*

Ladder or Arch tenons through the Π Brackets is ruled out'[127] and I am, therefore, obliged to discuss all his arguments before going on. Let us thus return to the *cheiroballistra*.

Wilkins proposes in his reconstruction to let the four tenons of the two struts just rest against the inner faces of the field-frames' rings. To make an effective union, he imagines pairs of heavy bronze locking rings.[128] His reasons for it can be summarized as follows:

1. 'The tenons have lost so much thickness... that unless they are sandwiched between such (flat) adjoining parts they will be easily bent.'

The tenons are not so weak as Wilkins thinks, but I agree completely with him in that they must be 'sandwiched' if one wants a solid and rigid enough frame.

2. 'If, for the sake of argument, the Ladder tenons were somehow inserted through the *pittaria* on the Field-frame Bars, then the Case and Slider would be lifted higher, and to avoid scraping along the Slider the Bowstring would have to be much higher than halfway up (the) Frames...'

Wilkins represents this argument very convincingly in his Figure 9. Against it, I need only to show my Figure 14, which attains the same result by a completely different way. I am afraid that, as there are so many imprecise points in the *Cheiroballistra*, Wilkins' and mine will surely not be the only choices available.

3. 'Passing the Ladder or Arch tenons through the Π Brackets is ruled out'.

As I have already said, I must admit that Wilkins is right when he says that the 3 d apart bars of the 'ladder' are not in the best position to pass their tenons through the lower *pitaria* of the field-frames. This is the weakest point in my reconstruction.

The same objection is easier to refute in the 'arch'. If the thickness of the field-frame bars was left to the choice of the constructor, then it was impossible to give a exact figure for the distance between the tenons of the 'arch' and the 'about 3½ d' given by PH is the best way to explain that the tenons must clear the bars, which are set also 3½ d apart. Even if, as I think, the missing figure for the thickness in the bars is implicit in the text, the distance between the tenons of the 'arch' amounts to only 4 d.

4. 'No holes are drilled through the P Brackets or the Field-frame Bars... To return to the P Brackets, on most of the known examples there is a lack of precision, almost carelessness in their construction in that pairs on opposite sides of the Bars can hardly be described as exactly matching in size and/or alignment...It may therefore be concluded that the way the P Brackets functioned did not require such accurate construction.'
'I have interpreted the Π Brackets as frames to retain pair of wedges...'

Wilkins makes a bull's-eye when he identifies the strangely non-matching *pitaria* of the archaeologically attested field-frames as wedge-frames. In my Figure 13 I attempt to show the system that I think was employed to fix the tenons of the 'arch' (Fig. 13.1) and the 'ladder' (Fig. 13.2) to the *pitaria*. If the Π brackets are perfectly squared and matching one another, the tenon is inserted touching the upper side of the *pitarion* and a pair of hardwood wedges securely fill the rest of space available inside it; finally, iron pins are driven in the tenon's rectangular hole(s) to secure the joint laterally. The workmanship exhibited by the Imperial artillery components so far discovered is by no means astonishing, and the pairs of *pitaria* are habitually irregular and non-matching, but there is, obviously, no problem in employing bigger or smaller wedges or just inserting wooden or iron pieces over or under the tenon, until the correct position is achieved.[129]

A front view of the reconstructed frame of my *cheiroballistra* can be seen in Fig. 10.3, drawn to the same scale that those of the

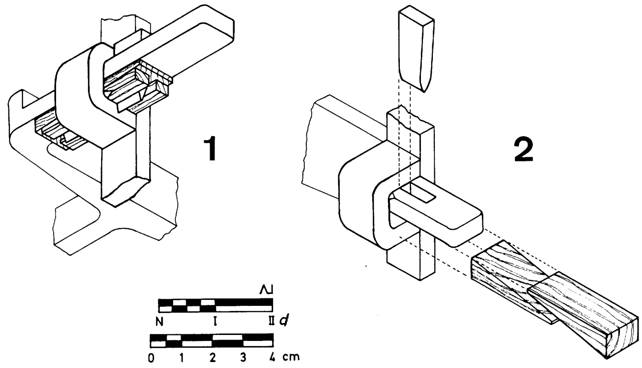


Fig. 13: 1. Proposed method of fixing one of the 'arch's' front tenons into one of the field-frame's upper pitaria. 2. Idem of one of the 'ladder's' front tenons into one of the field-frame's lower pitaria.

Orsova and Hatra machines, for comparative purposes. The small size of our catapult is readily apparent, even more if we take into account that the other two were not particularly large.

The arc travelled by the arms

There is a well-known principle in torsion artillery: the wider the arc travelled by the arms when pulled rearwards, the more of the energy stored in the springs is used. The above discussed proposal for assembling the frame would be of no use if the position suggested for the field-frames would hinder the movement of the catapult's arms. I shall show that this does not happen.

Of the three known 'big' *kambestria*, the crucial horizontal cross-section by their middle is available only for the Orsova and Sala examples. I have drawn them in Figure 16, alongside a Hellenistic palintone half-spring of the same 'module' for comparison (Fig. 16.1). I have hypothetically reconstructed the arms of the Sala (Fig. 16.2) and Orsova (Fig. 16.3) catapults using the same modular palintone proportion that I have used for the *cheiroballistra* ones. The Orsova field-frame performs quite well in that position (it matches the 68° arch travelled by the arm in the older palintone half-spring), but the Sala counter-stanchion is too wide and stops the arm too soon, even though the poor resulting 38° arc is comparable to that of a standard Hellenistic euthytone arrow-shooter.[130]

As I have already said, I doubt that the Gornea field-frame bars were originally set radially. I think that the holes in the rings and the tenons in the bars could become rounded and loose after the derusting and were, perhaps, replaced by the restorer in the position he deemed more 'logical' (see my n. 81). If the former is not too hard to swallow, then the bars can be rotated without problem within the narrow ground given by the rings' surface until a more than acceptable off-set palintone disposition is achieved (Fig. 5.5). The 61° arc travelled by the arm in the off-set field-frame (Fig. 17.2) is, of course, bigger than the 38° arc in the radially set one (Fig. 17.1).

In the *cheiroballistra*, it is logical to think that the missing longitudinal separation between the off-set field-frames' bars, not the transversal one, which is given in the text, must be dictated by the difference in length between the tenons of the struts. There seems to be, however, one problem: that difference amounts to 2 d in the 'arch' tenons, but only to 1 d in the 'ladder' ones, if I have correctly interpreted the shape of the last one. I have decided to keep the separation of 1 d[131] in my *kambestria* bars (Fig. 5.2); the long tenon of the 'arch' protrudes almost half a digit in excess (Fig. 14),[132] but the short one fits perfectly (Fig. 15, top). The 69° arc travelled by the *cheiroballistra* arm is as good as that of the Orsova one (Fig. 17.3). I consider it useful to compare the relative sizes of the arms corresponding to the *cheiroballistra* and to the Gornea *manuballista*, because the last one has the same 'module' that has been arbitrarily chosen by Baatz and Wilkins for their reconstructions of the *cheiroballistra*.

From the time Prou[133] launched the theory there have always been researchers who think that all the palintone engines (the *cheiroballistra* included) had inward swinging arms,[134] instead of the usually attested outward configuration. Furthermore, they see in this circumstance the first reason for the development of the low wide frames. The theoretical results of an inward positioning of the arms, measured in sheer degrees of arc travelled by them, are certainly encouraging (Sala: 66°, Orsova: 125°, my *cheiroballistra*: 112°), but two crucial questions remain to be solved: first, the real advantages of an inswinging configuration should be tested on real machines, preferably against a conventional catapult of the same calibre. Second, there is no ancient description, diagram or sculptural representation of an 'inswinger' (Prou had already observed[135] that there are no arms depicted on Trajan's Column catapults and took this as a proof that they were 'inswingers', but it is clearly a far-fetched conclusion, given the shortcomings of the Column as a reliable source[136]).

Incidentally, I think that the arms, in their travelling forwards after the releasing of the bowstring, would surely hit the bulges of the field-frames with their metallic front edges (the bars with rings attached). This would undoubtedly make a very characteristic noise. Seneca (but surely still referring to wooden-framed engines) in fact writes that catapults made some noise when shot: *'nam ballistae quoque et scorpiones tela cum sonitu expellunt'*.[137] But it is Ammianus Marcellinus who much more clearly establishes the fact (and this time, there is little doubt about which kind of machines is he referring to): *'alii machinarum metu stridentium praecipites acti'*, *'tormentotumque machinae stridebant sine iaculatione ulla telorum'*, *'locabant etiam artifices tormenta muralia, in funestos sonitus proruptura'*, *'tum aptatae ligneis sagittis ballistae, flexus stridore torquebantur, creberrima spicula funditantes'*.[138] Ammianus employs the same word for defining the noise emitted by elephants: *'adiectis elephantorum agminibus, quorum stridore...'*.[139]

The attachment-point of the frame on the stock

When, after much discussion, a suitable proposal for assembling the frame has been achieved, then we arrive again at another thorny question: at which point of the case must the frame be attached? This problem has gone, apparently, unnoticed previously; the other reconstructors (except Prou, but he is of no use here) seem to have simply thought that 'the more forward the frame is attached, the better will be the result'. However, can we place the frame at any point we desire on the case? The answer is 'no'. The point is marked by the position of the arms when retracted, the length of the arms and the length of the bow-string (i.e. the distance between the hooks of the arms, when splayed). If my hypothesis for the length of the arms in the *cheiroballistra* is

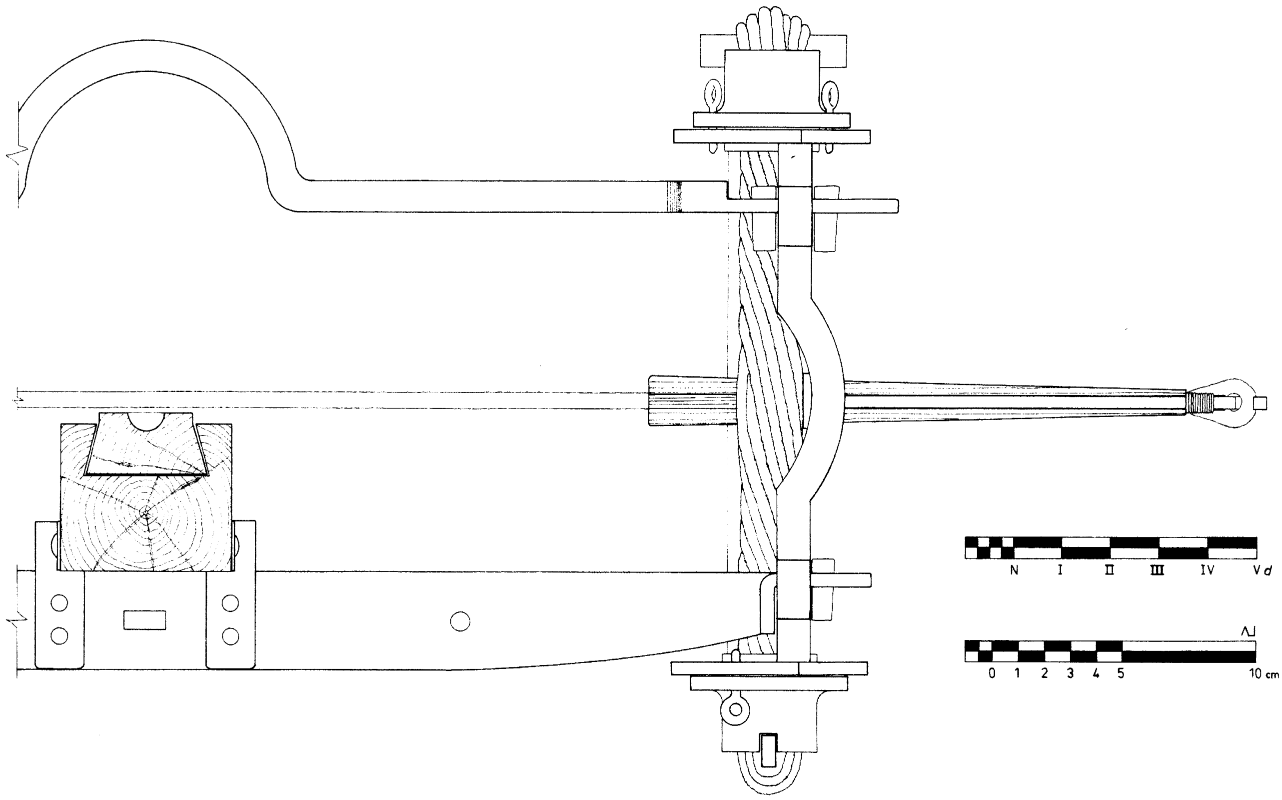


***Fig. 14:** Partial front view of the assembled cheiroballistra.*

accepted, after holding the bow-string with the claw – the slider kept in fully retracted position – the frame must be slid forwards along the case, until the arms reach their hindmost position, and then, be fixed there: this will be the maximum power that the catapult can develop. The outcome of the operation in my reconstruction is that the frame must be placed at some 1 d ahead of the projecting block ΧΨΥΦ (the handle), leaving just room enough for introducing the hand between both them (Fig. 15).

Missing parts

Wilkins has based most of his reconstruction on the basis that there are some important components missing from the preserved *Cheiroballistra* text.[140] As I have said earlier (see section 8, 'The arms'), I do not think that it can be categorically stated that this text has reached us incomplete, at least in respect to the list of components. A specialist writer, like PH, would not have normally bothered to mention such obvious elements as the springs or the bowstring, let alone the sundry bolts, pins, and the like, but there is, however, a vital component not described in the text, without which the weapon cannot achieve a minimal functionality: something to keep the slider fixed in position after cocking the catapult.[141]

Marsden and Wilkins propose straight side-ratchets as retaining devices for their machines' sliders.[142] Such elements, imported from Heron's description of the *gastraphetes*, do not appear in the *Cheiroballistra*. In my opinion, straight ratchets must be discarded, because the pawls should have appeared in PH's detailed description and diagram of the trigger mechanism. A circular ratchet, like the one employed by Marsden in his final working reconstruction,[143] would undoubtedly have not affected the trigger mechanism, but it must work unavoidably associated to a winch, which, as we shall see in the following section, only adds extra weight to an already functional machine. Moreover, I have already said (see 'The handle') that if the *cheirolabe* was designed to remain fixed in an horizontal position (to receive the rope of the windlass) then it would not have appeared in the mss diagrams represented in an upright position.

The possibility that the 'handle' could swivel around the axis MN suggests a much more simple solution to keep the slider fixed in retracted position. Prou realized that a simple *'bouton'*, a kind of nail, fixed on the case was enough to retain the *cheirolabe* and Baatz adhered to it (without crediting Prou with it, as usual).[144] I agree with them in this matter and, consequently, I have used a nail as the most straightforward and simple retaining device, perhaps so simple that PH did not consider to mention it (Figs 3.6 and 15).

We have seen in the section about the frame that the locking rings contrived by Wilkins are superfluous and, in the preceding lines, that the pawls and side ratchets were not present on the *cheiroballistra*.[145] The reconstructions proposed by Marsden and Wilkins also have a winch and a stand, but does the *cheiroballistra* really need them to be operative?

The stomach-bow theory

The answer is 'no'. This is the adequate place to refute Wilkins' remaining objections to the handling of the

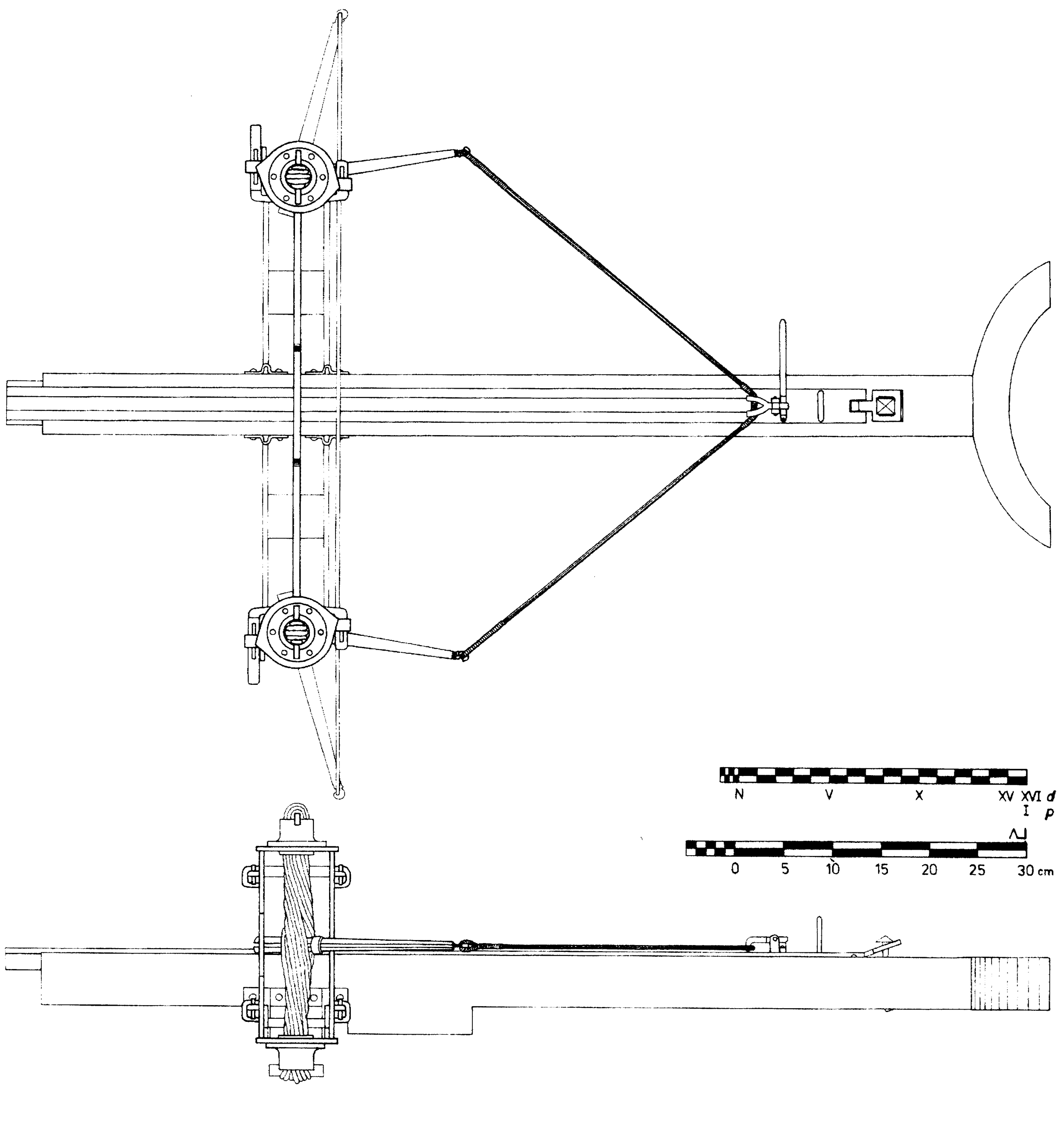


Fig. 15: Plan and side view of the assembled cheiroballistra.

cheiroballistra as a stomach-bow. 'It is easily demonstrable that this machine is not a *gastraphetes*. It is partly a question of weight and point of balance, and of the enormous force required to pull back the arms'.[146]

Well, my actual reconstructed machine weighs complete only 9 kg,[147] very far from the 22.8–27 kg of Wilkins' machine and at a distance from the 12.24 kg of Digby Stevenson's one. The mediaeval war-crossbows weighed between 8 and 10 kg, had the point of balance at their foremost place and were, if properly protected, very effective weapons, even in long battles lasting several hours.

In my reconstruction, the centre of gravity is not placed so far forward as in other reconstructions and, furthermore, it coincides with the handle below the case (the projecting block ΧΨΥΦ) (Fig. 15). I think that the *cheiroballistra* could be easily shot in the same position as the mediaeval crossbows: one 'horn' of the lunate fitting tucked under the right armpit and the left hand holding the handle, the elbow resting against the body. Of course, any light weapon will be undoubtedly easier to operate, aim and shoot with the advantage of a stand, but the stand involves a significant loss of mobility which, we must not forget, constitutes the main inherent advantage of any light weapon.

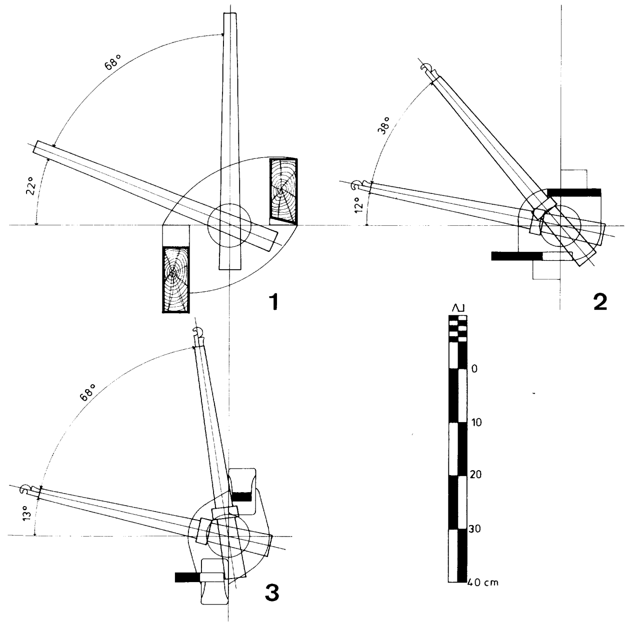


Fig 16: *Arc travelled by the arm. 1. Wooden palintone half-spring. 2. The Sala field-frame. 3. The Orsova field-frame.*

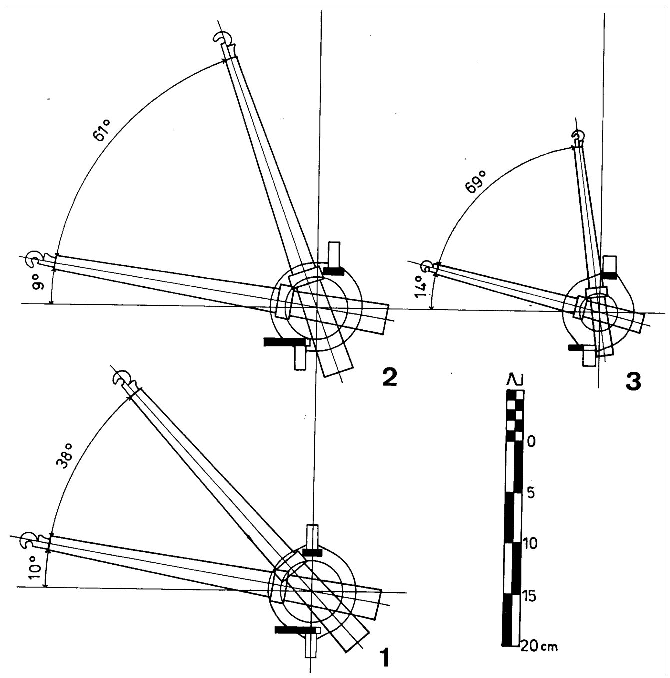


Fig. 17: Arc travelled by the arm. 1. The Gornea field-frame, radial. 2. The Gornea field-frame, offset. 3. The cheiroballistra field-frame.

This is the reason why the heavy crossbows or early muskets were never furnished with a stand or only with a simple fork.

It is beyond doubt that my *cheiroballistra* will never achieve the astonishing output of Wilkins' machine, but with its 1⅓ d thick springs there is no problem cocking it by hand, without concourse to a windlass or ratchets of any kind. The handles present at both sides of the *katagogis* in Heron's *gastraphetes* are not necessary for the arming of the *cheiroballistra*, as both arms can effectively help the push, simply grasping the projecting block in the case.

Wilkins[148] also states that since 'the *cheiroballistra* has the same spring-diameter as the old One Cubit or Two-span catapult' it was the intended replacement for the latter and, thus, winched. In my opinion, it is clear (see 'The inner diameter of the washers') that the real spring-diameter of the *cheiroballistra* is only half of that of the Two-span. The rest of the proposition comes from Vegetius' well-known assertion: *'Scorpiones dicebant quas nunc manuballistas vocant'* (they used to call scorpions what are now called hand-*ballistae*).[149] Marsden had certainly prepared the path when he pointed out: 'Large scorpions were probably three-span, lesser scorpions one-cubit arrow firers'.[150] The connection (given the equivalence *cheiroballistra* = *manuballista*) with Vegetius' assertion seems apparent and Prou already indicated it.[151] Unfortunately for this clear picture, Ammianus writes: *'Scorpionis autem, quem apellant nunc onagrum'*[152] (the scorpion, which is now called the wild-ass). Vegetius, as well as Ammianus, consistently calls the mangonel 'wild-ass'. He surely presented his *Epitoma* to Theodosius I between the years AD 388 and 391 and as Ammianus read the first 25 books of his *Res Gestae* in AD 390 or 391,[153] their works were therefore contemporary. It is impossible to ascertain which of them is right, but, for this very same reason, Vegetius' assertion can only be taken with a pinch of salt.

Finally, on the other hand, Vegetius always places the *manuballistarii* alongside with other light (archers, slingers, crossbowmen) mobile offensive troops,[154] which he would surely not have done if the *manuballistae* were nailed to the ground by their stands.

THE MISSILE

'Scorpiones dicebant quas nunc manuballistas vocant; ideo sic nuncupati, quod parvis subtilibusque spiculis mortem inferunt' (they used to call scorpions what are now called hand-*ballistae*; they were so named because they inflict death with tiny, thin darts). This phrase in Vegetius' *Epitoma*[155] led Prou and Wilkins, as we have seen in the preceding section, to suppose that the *cheiroballistra*, equated to the *manuballista*, was the successor of the old *scorpio*, but there is yet more to discuss in relation to it: whichever was the old name of the *manuballista*, it shot 'tiny, thin darts'.

Marsden ventured that the *cheiroballistra* 'shot an unpleasant little bolt about twenty-one dactyls (405 mm) long, I estimate, and perhaps about three-quarters of a dactyl (14.5 mm) thick'.[156] It is hardly surprising to read later that he dismisses Procopius' *ballistra* as a small machine simply because it shoots a bolt of the same size he has arbitrarily established for the *cheiroballistra*, even if Procopius tells us that the machine was big enough to need at least two men at the winch for pulling the slider back.[157]

Wilkins seems to have finally dismissed his initial proposal of a 461 mm long bolt and now advocates for a shorter, 263 mm long, one, both constructed to the likeness of the Dura-Europos ones.[158]

I do not think that either a 405 mm long bolt, nor even a 263 mm one can be properly defined as 'tiny and thin'. Searching in

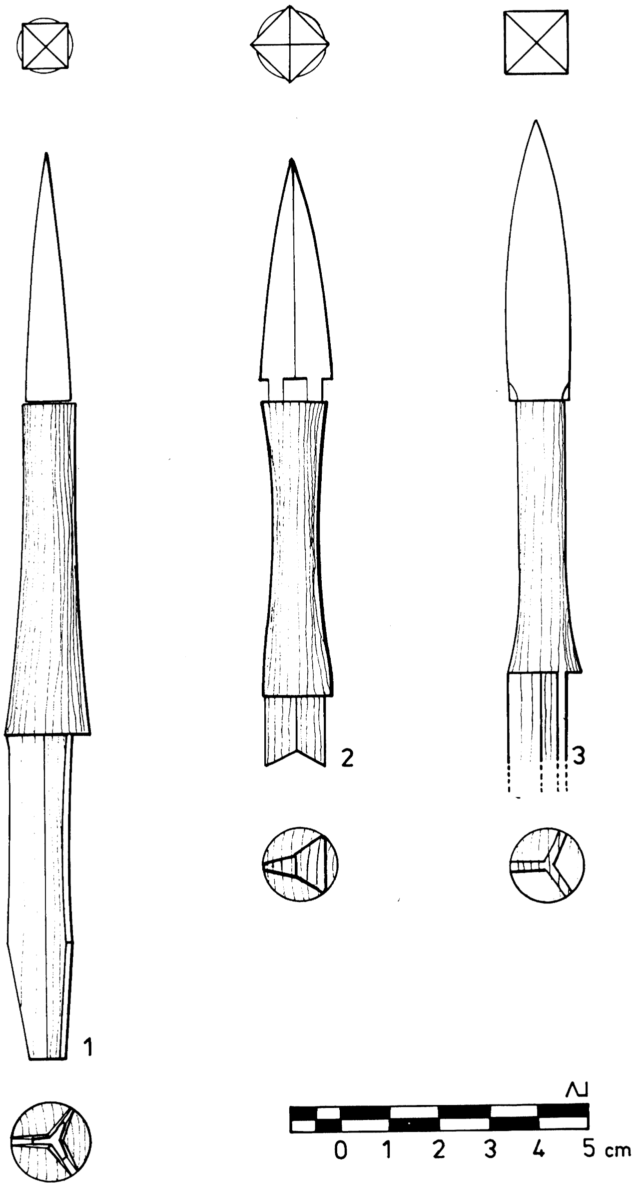


Fig. 18: *Small Augustean catapult bolts. 1 Qasr Ibrim. 2. Vindonissa (after SIMONETT). 3. Haltern (after DAHM & SCHRAMM).*

the archaeological record for something smaller, I have only found three suitable candidates. All of them are, of course, Roman, but they belong to the Early Principate. This fact must not be at all discouraging, because small crossbow-like torsion engines were in service since the Hellenistic times (Ephyra) and later (Elginhaugh).

The first quarrel comes from the fort of Premnis or Primis (Qasr-Ibrim), in Nubia.[159] Its full length is of about 185 mm (Fig. 18.1). The wooden (cherry or cherry-laurel[160]) part is 133 mm long, 67 for the shaft and 66 for the tail, and is fairly complete, except for one of the three vanes which has split along its length. The corresponding iron heads seem to be a little too thin for the shaft, perhaps due to the acute shortage of all kind of supplies that the Roman garrison suffered. I have had replicas of the Qasr Ibrim quarrel made and they weigh 25 g (15 g, head; 10 g, shaft).[161]

The second one was found at the fort of Vindonissa (Windisch, Switzerland) in 1911.[162] The wooden (cherry[163]) shaft is 60 mm long, but only a stump – 15 mm long – survives from the tail and, thus, the reconstruction of Simonett – with a notch at the end – is somewhat dubious (Fig. 18.2).[164] The bolt, in its present estate, weighs 40 g, 30 of them corresponding to the iron head.

The third example – or, rather, a group of three and portions of other seven – was recovered in 1902 at the fort of Haltern (Germany).[165] Two different sizes ('calibre') were recognized by Dahm, from which I shall only discuss the small one here.[166] The wooden (maple) shaft is 55 mm long and, once more, only a pointed stump – around 20 mm long – survives from the tail with the beginning of the three vanes still clearly discernible. Dahm thought that this form of the tail was an original feature of the bolt, but Schramm, after a closer examination, dismissed this idea and stated that the tail's vanes had parallel sides and ended in a straight cut.[167] (Fig. 18.3). The weigh of the iron head – without the tang – was determined as 16 g.[168]

I think that the differences between these three bolts are more apparent than real: leaving aside the sizes of the heads, the shafts are very similar in dimensions and shape, especially those of Qasr Ibrim and Haltern. The Qasr Ibrim one is the only which preserves its tail intact enough to allow for a reliable reconstruction to be made, and it is, approximately as long as the shaft is. I have not examined the Haltern and Vindonissa quarrels myself, but it is easy to see that their tails could have been considerably longer and even that the cross section given to the tail of the Vindonissa bolt could be just a misinterpretation of one possessing three vanes, due to a deficient state of preservation.

Schramm opined that the Haltern quarrels were only the surviving foreparts of conventional, composite-built, long catapult bolts and not missiles in their own right. He has been, subsequently, followed by Baatz, Wilkins, James and Taylor. In my opinion, the Qasr Ibrim/Haltern/Vindonissa quarrels were not used to form composite-built bolts, due to morphological factors.

Schramm proposes that the vanes of the tail were just tenons intended to be inserted in corresponding slots cut into the front of a softwood main body.[169] James and Taylor[170] apply Schramm's hypothesis to the Qasr Ibrim shaft without apparently noticing some incongruous features: a) the complexity of the triple bladed tail seems 'puzzling' to Schramm, James and Taylor,[171] but it is a clear aerodynamical arrangement; b) if the vanes were in fact tenons, carving them with a symmetrical tapering section would be not only superfluous, but even an obstacle,[172] we are facing again another aerodynamical disposition; c) the width of the vanes taper inwards at some 17 mm from the rear end,[173] this feature would be once more needless work in the tenons of a foreshaft, but is nearly imperative to fit the tail snugly inside the 'claw' of any arrow-shooter.

Wilkins thinks that the composite shaft mirrored some arrows found at Dura-Europos, i.e. with the main body made from a hollow reed.[174] The long, tapering tail would then be suitable, but the presumed foreshafts should, in that case, have exhibited a deep peripherical rabbet to stop the borders of the cane – which, otherwise, would slide forwards and 'swallow' them – but they do not have such feature.[175]

On the other hand, Schramm's main objection to the mere existence of short catapult bolts – apart from the 'fact' that ancient writers did not mention bolts shorter than 668.4 mm – is their supposed inability to fly straight and far or even to be shot by the machines without risk.[176] Whatever tests he carried out to sustain his first assumption,[177] it is false. Wind-tunnel tests made by Foley, Palmer and Soedel proved that quarrels of the kind we are here discussing – even with the short tail reconstructed by Schramm – have an extremely small ratio of mass to drag, less than half of that owned by a Dura-Europos bolt, for example. It means that the short quarrel will lose its initial kinetic energy slower than the other missiles and it will achieve the longest range to a given initial velocity.[178] Thus the Qasr Ibrim/Haltern/Vindonissa bolts fly well and far and, as I have experimented with my own machine, they also fly straight.[179]

The second assumption seems, at first sight, more plausible: if the bolt is not long enough to protrude from the narrow shooting aperture in the wooden frame of an 'old style' catapult when fully wound – we must not forget that all the quarrels are Augustan in date – there is an inherent risk of it being ricocheted against the frame and backwards if mis-shot.[180] But, reading between the lines, these hazardous experiments with short bolts seem to have been carried out on Vitruvian three-spans and it is clear that neither the length of the slider nor the power output of the springs would be barely suitable for the missile, whose tail would surely become smashed just with the impact of the bowstring, thus foreshadowing an erratic trajectory. Everybody knows how dangerous it is using inadequate ammunition in any kind of shooting weapon.[181]

Wilkins, in his turn, objects that such light missiles – even lighter than war arrows – will not develop enough kinetic energy for an effective impact.[182] If we go to the formula of the kinetic energy – $e = m \times v^2$ – we shall see that it is proportional to the mass, indeed, but also to the square of the velocity. Consequently, I think that the 'muzzle' velocity is the critical factor in a missile, more than its mass, and, to a given catapult power, the lighter the bolt, the higher will be its initial velocity. Moreover, the fact is that Roman legionaries actually manufactured such 'featherweight' missiles and their 'bodkin' heads speak strongly in favour of their use in war.

Are these missiles suited for the *cheiroballistra*?

Baatz has already once suggested that they are of the kind that could have been used for it.[183] He has also proposed to use the old formula of the palintone stone-throwers to the later palintone arrow-shooters and calculate in this way the weight of the missile they could shoot.[184] Thus, $M = \frac{1}{100} \times (\frac{D}{11})^3$.[185] M is the weight of the missile in Attic minas (1 mina = 436.6 g) and D, the spring-diameter in dactyls (1 dactyl = 19.3 mm). This formula is only valid for springs with the proportions stated by Philon (the height, without counting the levers, must be nine times the thickness) and a correcting factor must be applied to differently proportioned springs.

The result for my *cheiroballistra* is highly disappointing: 8.35 g (corrected), just a small pebble! What happens if the same formula is used on Wilkins' machine? The (corrected) result for it is 31.56 g, well under the real weight effectively shot by it: 92 g. If we scale up the value calculated for the *cheiroballistra* in the same proportion, we shall reach 24.34 g, encouragingly similar to the weight of the Qasr Ibrim bolt.

AN HYPOTHETICAL RECONSTRUCTION OF THE GORNEA *MANUBALLISTA*

Every investigation has its by-product. The Gornea field-frames bear witness to the existence of several kinds of *manuballistae* besides the *cheiroballistra*, in case it was a real weapon. After endeavouring to make a reconstruction of the latter, it is really tempting to try to do the same with the Gornea *manuballista*.

The dearth of information is evident and the problems with the *cheiroballistra* seem trifling compared to this. We have only the field-frames,[185] but the Volubilis washers[186] could be adapted to them with just a small enlargement and trimming their flanges (the rings in the Gornea *kambestria* are really very narrow), and the dimensions of the arms could be estimated, following my assumption about the use of the modular system (see section 8, 'The arms'). Nothing more, so to complete a design for a working machine it is unavoidable to borrow the missing dimensions from the nearest relative: the *cheiroballistra*. The resulting hybrid is, no doubt, unauthentic, but worthwhile to have a look at (Fig. 19).

The frame is very squat, in particular the springs. One wonders whether they were specifically designed to shoot at short range, like the *brachytonoi* of Archimedes in Syracuse.[187] Anyway I have provided the 'arch' with a pair of holes, like the Orsova one, and used them to create an 'horizon' with an adjustable sighting bead, in the way suggested by Wilkins.[188]

The squatness of the frame makes a case of reduced thickness necessary, only 2½ d, to keep the bowstring right in the centreline. The 'ladder' is inserted on the case near its forward end, as a result of the greater length of the arms. I have furnished the case with side ratchets, to help the operator in the process of cocking a machine twelve times more powerful than the *cheiroballistra*. In spite of the valiant efforts of Digby Stevenson to prove the contrary, I agree with Wilkins that only with the aid of a winch can the best performance be obtained from such thick springs (54 mm).[189] As I have stated in 'The stomach-bow theory', it is my opinion that the name *manuballista* clearly indicates a portable weapon and, therefore, excludes the use of a stand. The Gornea catapult should be manageable by its sole operator. The 12.24 kg of Stevenson's *cheiroballistra* surely correspond to the weight of my reconstruction of the Gornea *manuballista* without its windlass and are in the very limit of the bearable. To keep the burden at this limit, I have made the windlass detachable, like the ones belonging to mediaeval heavy crossbows. The small catapult could also be cocked in the same way as those crossbows were,[190] the stock in an upright position and the end of the slider held between the operator's feet. We should not forget that the Gornea field-frames were recovered from two angle-towers of a small permanent fortification[191] and, perhaps, this kind of heavier *manuballistae* were mainly intended for defensive purposes.

Another useful feature of my reconstruction borrowed from crossbows is a wooden block joined to the bottom of the case's handle (the 'projecting block'), which gives a better grip for the hand and enables the operator to lean the heavy weapon on a crenel or parapet for easier handling (Figs 20–21).[192]

It is readily apparent that I have employed crank-handles to turn the windlass. Marsden believed it 'most unlikely that ancient engineers knew anything about the crank in any shape or form',[193] and he is not the only one. Notwithstanding, a primitive kind of crank was discovered, surely belonging to a bilge chain-pump, in the famous ships of Caligula sunk in Lake Nemi (Italy). The fanciful reconstruction of the pump[194] and the lack of illustration showing the actual find's remains, have somewhat relegated this very interesting find to the misty realms of fantasy, but there is no doubt about its real existence, as the finds inventory entry proves:

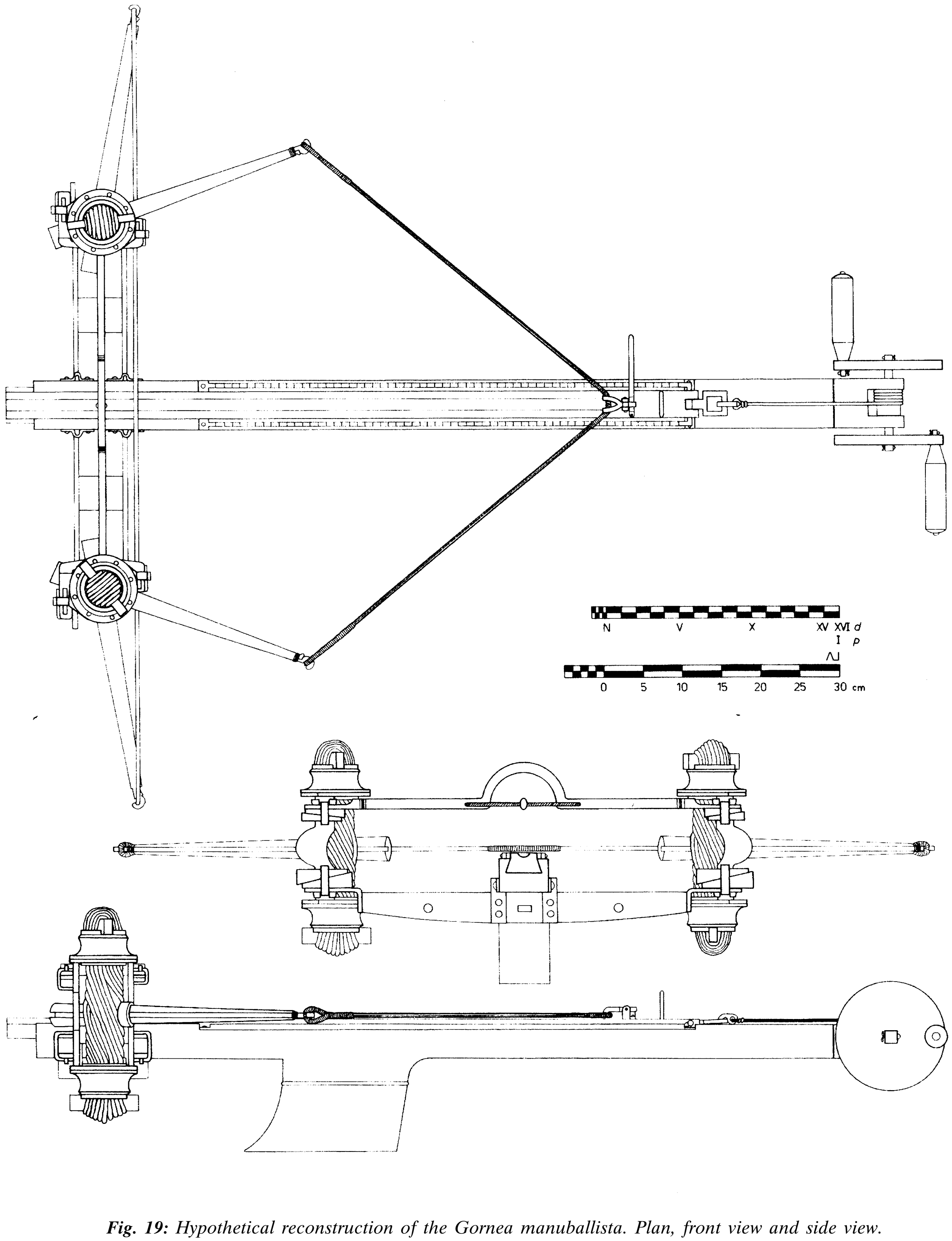
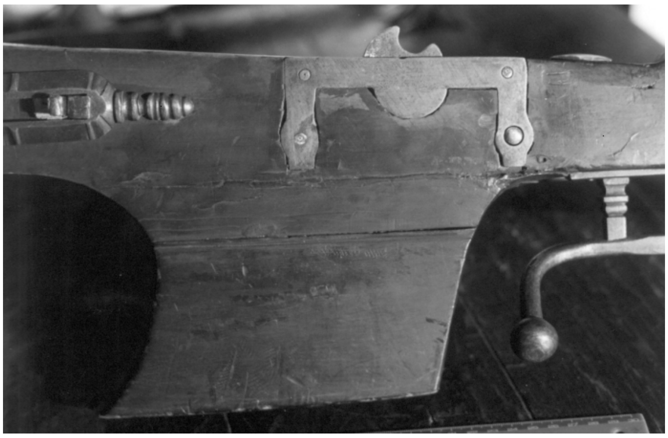


Fig. 19: *Hypothetical reconstruction of the Gornea manuballista. Plan, front view and side view.*



***Figs 20–21:** Handle/rest block in one heavy crossbow (Museo de Armeria, Vitoria-Gasteiz, Spain).*

'Nr. 409: Wooden wheel with crank-handle. 0.490 × 0.050 m. Found: 9-7-31. Second ship, between frames 29 and 30. Inventory nr. 125010 (Museo Nazionale Romano), 055 (excavation)'.[195]

WERE THERE REALLY FIELD-FRAME COVERS?

As far as I know, Schramm was the first who identified the cylinders placed at the sides of the catapults represented in Trajan's Column as 'cases', intended for the protection of the springs.[196]

Marsden was of the same opinion and, furthermore, he assumed that the springs of the *cheiroballistra* should also be equipped with such covers: 'the metal frames seem more durable than those constructed of wood and may be very simply enclosed in thin metal cylinders (not mentioned by Heron, but clearly visible in the machines on Trajan's Column) for protection against rain as well as against enemy missiles'.[197]

Baatz's approach was a little more cautious: 'Both field-frames are visible in the form of cylindrical elements at the sides of the arched strut. The field-frames proper seem to be covered with metal sheeting as a protection against weather and damp'.[198]

Wilkins, finally, has no doubt about the existence of the field-frame covers: 'All the catapults on Trajan's Column have smart, round protective covers for the Field-frames, looking rather like the old style tin biscuit barrels with their lids surmounted by knob handles. A moulding round their base is to be interpreted as the rim of removable bottom caps'.[199]

I shall not deny the inherent advantages of providing some kind of protection for the vulnerable springs but, what kind of solid evidence can be really adduced in support of the actual employ of such covers in Roman catapults? They are unattested archaeologically; unmentioned by ancient writers, Trajan's Column stands as the only available source.

The real value of Trajan's Column as a source of evidence for construction or details in military equipment[200] is a subject that widely surpasses the scope of this paper. Notwithstanding, it is clear enough that field-frame covers can easily belong to the same artistic convention which gave birth to the 'leather' cuirasses, the 'scaly' Sarmatian cataphracts or the narrow cheek-pieces, to mention only some of the more obvious blunders.

I think that the 'cylinders' with their knobbed 'lids' are only stylized representations of field-frames made by artists who did not know either how a catapult worked nor how was it constructed. If we give the lids a closer look (Figs 11–12), we shall discover that their resemblance to conventional washers, surmounted by their levers and the tops of the cord bundles, is enormous (compare Figs 14, 15, 19). The field-frames' rings are also visible, in the form of horizontal mouldings, the same as the conspicuous bulges in the front bars. In my opinion, the cylinders are nothing but the cord bundles which, when twisted, in fact assume a cylindrical form (Fig. 19) and are the most noticeable features in the field frames, much more than the bars.[201] What about the absence of the lower washers? On all accounts, the *ballistae* in Figs 11 and 12 are lacking more vital components, as are the case and the slider. Perhaps the chief sculptor thought that the upside-down washers – such components would, 'no doubt', fall by their own weight – were a mistake in the cartoons and, subsequently, eliminated them. Summing up, I believe that Trajan's Column cannot be taken as a solid evidence for the existence of field-frame covers.

CONCLUSIONS

The *Cheiroballistra* text describes – more or less precisely – the construction of all the main components belonging to a small arrow-shooting catapult. It is true that a retaining device for the slider is obviously missing, but that task can be performed by a simple nail.

The spring diameter is clearly declared in the text as 1⅓ d (25 mm or 26 mm, if one prefers dactyls to digits). Any attempt to increase it will result in malfunctioning by part of the machine or inability to perform its task with only the described components.

The *cheiroballistra* is a metallic-framed palintone weapon. The curved fitting fixed horizontally at the rear end of the stock indicates that it can be cocked in a similar way to Heron's *gastraphetes*. The power output of its springs is no hindrance to this method, even without any kind of auxiliary components which, moreover, are not described in the text.

I think that a weapon with the above mentioned characteristics and the tell-tale name of *cheiroballistra*, can just be a 'hand' – portable – one. In other words, it was a personal weapon, perfectly served by only one man. This circumstance does not preclude the help of a paviser, when employed in open ground, as often happened with the mediaeval heavy crossbows.

There is enough ambiguity in text and diagrams to allow for several different reconstructions of the *cheiroballistra* and,

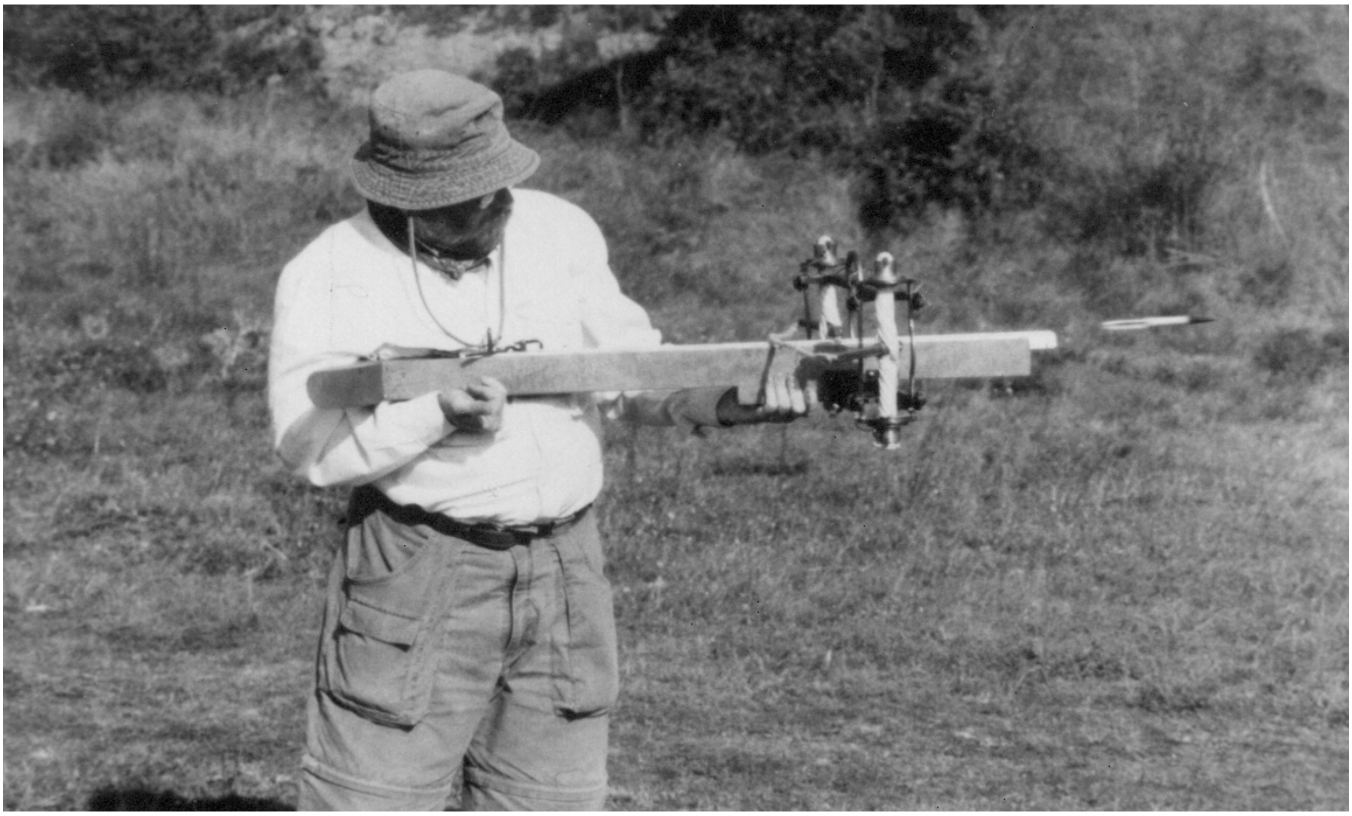


Fig. 22: Shooting a Qasr Ibrim bolt in the preliminary trials.

surely, all of them should be taken as approximately correct[202] unless actual well preserved remains of a true *cheiroballistra* were found, which is improbable. Notwithstanding, I think that Wilkins – following the trail marked by Marsden – has produced a field-gun out of the instructions for constructing a rifle, by the simple expedient of just 'correcting' the unsuitable parts and adding the 'missing' ones.

It is plainly excessive to take for granted that the *cheiroballistra* was a standard weapon. Only after long trials with a reconstructed machine of unaltered spring diameter and, no less important, sinew powered, will the real potential of the *cheiroballistra* as a weapon be established. It should not be a disappointing surprise if the result is that the *cheiroballistra* could only serve as an experimental or practise weapon.

Perhaps to find out the date in which the *Cheiroballistra* was originally written will remain an insoluble problem forever. Nevertheless, though the frame is squat, the springs themselves are slender, and this fact hints at an early period, maybe the very period which saw the initial development of the metallic frames. The only really late feature in the whole text is the title and it could be that, as Schneider suggests, a Byzantine compiler chose it because the catapult described in the untitled fragment was very similar to one of his contemporary *manuballistae/cheiroballistrae*.[203]

NOTES

* Arkeologiarako Arabar Institutua. San Antonio, 41. E-01005, Vitoria-Gasteiz (Spain). Dedicated to John Anstee and Plácido Lasarte.

1 MARSDEN 1971, 10.

2 SCHNEIDER 1906, 167–8; BAATZ 1978, 14; BAATZ & FEUGERE 1981, 207, n. 16; WILKINS 1995, 7–8.

3 WILKINS 1995, 6.

4 In the section of the *Cheiroballistra* devoted to the field-frames, washers and levers the unusual fractions ⅓ and ⅔ of dactyl sometimes occur (the usual divisions of one dactyl were ½ or ¼). Hülsen realized that they came from the conversion of Roman inches into digits (1 *uncia* = 1⅓ *digiti*; ½ *uncia* = ⅔ *digiti*). SCHNEIDER 1906, 165, n. 2; MARSDEN 1971, xvii, n. 2 and 200, n. 21; BAATZ 1978, 15, n. 49.

5 See WESCHER 1896, IX–XL and MARSDEN 1971, 9–15, for short descriptions and relationship among these manuscripts.

6 WESCHER 1867, 123–34. It was really not the first edition of the *Cheiroballistra* (PROU 1877, 2, 4–5, 11–14, 18–20), but it is now universally accepted as the standard one.

7 PROU 1877, 116–49. Some redrawn diagrams, of assorted sources, are included. They come mainly from M, but there are some from P and the bizarre P^3, P^5.

8 SCHNEIDER 1906, 146–63. B/W photographs of all the diagrams in M and P are included. There is another German translation of the *Cheiroballistra*, rather technical than philological, and due to Baatz (GUDEA & BAATZ 1974, 69–72). It includes redrawn diagrams from the Wescher edition, basically those of M.

9 MARSDEN 1971, 212–17. No diagrams included. WILKINS 1995, 10–32. It includes redrawn diagrams from M, P and V, but only the M series is complete.

10 WILKINS 1995.

11 SCHNEIDER 1906, 149, n. 1.

12 BAATZ 1974, 70, n. 46.

13 MARSDEN 1971, 218, n. 3.

14 WILKINS 1995, 11–12. He makes also a useful account of the precedent theories.

15 The oldest surviving copy and the only one which preserves the sequence of letters in its diagrams reasonably complete.
16 WILKINS 1995, 12.
17 PROU 1877, 120–21.
18 In fact, I arrived independently to this conclusion before reading Prou's work, which is usually a good sign.
19 WILKINS 1995, 12.
20 PROU 1877, 183 and fig. 43.
21 BAATZ 1974, 70, n. 46; BAATZ 1978 13, fig. 11.
22 MARSDEN 1971, 218, fig. I and diagram 12; WILKINS 1995, 11 and 41–2, fig. 3 and 20.
23 *De Arch.* X, x, 5.
24 WILKINS 1995, 12.
25 WILKINS 1995, 51 and fig. 16. It is a very interesting and sensible solution to avoid the interference of the universal joint's horizontal axis-bolt into the case, but completely unattested by the ancient sources.
26 *Dictionnaire raisonné du mobilier français de l'epoque carolingienne à la Renaissance*, I (1858), entry *arbalète*, fig. 3 and 4.
27 PROU 1877, 122–3.
28 SCHNEIDER 1906, 164 and 168. His ample philological knowledge and his self-exclusion from the artillery field in which concerns to this text makes him sometimes a useful 'neutral third opinion'.
29 MARSDEN 1971, 218, n. 4 and fig. 3; diagram 12; plates 7 and 8.
30 GUDEA & BAATZ 1974, 61; BAATZ 1978, fig. 11.
31 WILKINS 1995, 13.
32 See WILKINS 1995, fig. 3.
33 WILKINS 1995, 13 and 39.
34 MARSDEN 1971, 62. 'A fair proportion of the diagrams in the existing manuscripts of Biton, and of Heron for that matter, suggest very strongly that the originals belonged to that form of drawing which Greek and Roman artificers called *scenographia*...it means, basically, that the architect could include, all in one diagram, the front-elevation and two side-elevations of the proposed edifice...We must remember, however, that to the ancient artificer the front-elevation (*frons*) seemingly meant the view of the catapult from above, which we are now inclined to call the plan of the engine. Therefore, it is most likely that an original diagram of a catapult included the plan, two side-elevations, and, perhaps, front and rear-elevations, all in the same figure'. See also 79, n. 8.
35 This extremely useful updating has been privately edited by Alan Wilkins. He has, with his usual kindness, sent me a copy. His Fig. D is the relevant one for the following lines in the paragraph.
36 A black and white photograph of it can be seen in SCHRAMM 1918, 48, abb. 19.
37 MARSDEN 1971, 209, n. 1.
38 WILKINS 1995, fig. 14 and 24; *Idem*, 13 and fig. 4.
39 SCHRAMM 1918, 32, 33 and 34.
40 PROU 1877, 202, fig. 47.
41 BAATZ 1978, fig. 11.
42 MARSDEN 1971, 218, fig. 2.
43 WILKINS 1995, 11 and fig. 3.
44 What PH surely means is that the slider must fit inside the case to ensure a smooth running.
45 Returning to Heron's *Belopoeica*, in the description of the *gastraphetes*, W 76, MARSDEN 1971, 20–21, the word *ισομηκης* (of the same length) is plainly used to express that concept.
46 WILKINS 1995, 11.
47 MARSDEN 1971, 218, n. 5, fig. 2 and diagram 12(c).
48 WILKINS 1995, 11, fig. 3. Ratchets of any kind are absent from the mss text and diagrams.
49 Which is, incidentally, reaffirmed by Marsden himself when discussing Biton's *helepolis* (1971, 86, n. 27): 'It seems to me that *τράφηξ* and *trabes*, in the strictest technical sense, indicate joists composed of a number of boards all interleaved and glued together; likewise, *κανών* and *tignum* strictly imply solid beams'.
50 This 'about' (*ὡς*) is one of the two that appear in the text related to numerals, apparently with the intention of meaning an approximate measurement. Far from being casual, the use of this word surely indicates that it should be most convenient to adapt the dimension (here, the width of the male and female dovetails) to the given real circumstances.
51 In my opinion, Wilkins' (1995, 56, n. 36) translation of the label *ἀγκών κάτω* in M's diagram as 'beam from below' is not correct. First, *ἀγκών* cannot be translated as 'beam'; it means a 'curve' or the 'curved extremity of an object'. It is easy to understand why it was applied to the curved arms of composite bows and, from there, extended to the arms of catapults (see, for example, Heron, *Bel.* W 81–2). I would, therefore, translate *ἀγκών κάτω* as 'arm (curve) downwards', which is nonsense. Even if it is a palaeographically difficult correction, I am inclined to accept Schneider's (1906, 149, n. 2) proposal of amending the two corrupt labels *θῆλυς ἀγκών* and *ἀγκών κάτω* to *θῆλυς κανών* and *ἄρρην κανών*.
52 M's diagram of the assembled trigger mechanism is, unfortunately, cut at its left and bottom sides but, anyway, an E survives at its right upper corner to demonstrate that it surely had the same lettering as the slider's picture at the first diagram. P's diagram has a Γ at its left upper corner and an E at its right one, but it lacks the Δ at its bottom, which is not surprising, in view of the loss of some other letters.
53 PROU 1877, 186–91 and fig. 22.
54 MARSDEN 1971, 219–22.
55 In his paper about the Gornea and Orsova finds (GUDEA & BAATZ 1974, 258) Baatz seems to be a little misguided, too. I shall only refer here to his slightly later graphic reconstruction (BAATZ 1978, fig. 11) which, unfortunately, he leaves mostly unexplained.
56 WILKINS 1995, 14–17.
57 For accurate reproductions of the diagrams in P and M, see WILKINS 1995, fig. 5.
58 And, to judge from M's diagram, its perimeter line could be open at its lower end, Δ. This feature had been already noticed by Prou (1877, 124, fig. 22) and would simplify enormously the making of the 'handle'. Anyway, in my reconstruction, I have opted for the more complicated, closed form.
59 WILKINS 1995, 16. Notwithstanding, the very name of the component (*χειρολάβη* = handle) suggests strongly that it could be used that way and the evidence furnished by the diagrams is not so conclusive as to allow us to discard categorically this possibility.
60 WILKINS 1995, 17, fig. 6.
61 Additionally, the 'handle' proper is illustrated in the diagrams as always narrower (in a vertical sense) when assembled than when detached. This could imply some intention of rendering in some sort of 'perspective' the 'handle' as placed at right angle with the slider.
62 SCHNEIDER 1906, 164.
63 MARSDEN 1971, 219–20, fig. 4d and 5b; WILKINS 1995, 17, fig. 6.
64 BAATZ 1978, fig. 11.
65 MARSDEN 1971, 220, fig. 5a; WILKINS 1995, 17, fig. 6.
66 MARSDEN 1971, 21, 46 n. 12, 48, fig. 4.
67 I am accepting, like everybody else, Schneider's interpolation of the word '*pitarion*'. Without it, things would go even worse!
68 WILKINS 1995, 16, fig. 6.
69 WILKINS 1995, 15, fig. 5a.
70 The copyist's blunder was not to enlarge the left 'leg', as Wilkins (1995, 16) says, but to place the trigger left end too low from its supposed position at Π. This mistake forced him to enlarge the 'leg' in order to re-establish the relative

positions of all the components of the trigger mechanism on the slider.

71 WILKINS 1995, 16.

72 From the main source manuscripts, only M gives that figure (IC), the other branch – descending from y – P and V (the paragraph is lacking in F), transmits 20 d (εἴκοσι). Wescher, very cleverly, supposed that it was due to an error of interpretation, K for IC in the copy, maybe since y. Marsden, after enlarging the spring diameter of the *cheiroballistra*, realized that a height of 10½ d would result in a very catatonic frame, and so decided to accept the 20 d height (MARSDEN 1971, 222–3 n. 17). Even more catatonic frames did, in fact, exist (Gornea), but with the original diameter given in the text, the springs result more 'old-proportioned', even slightly anatonic, using the 10½ d height.

73 As we shall see later, a figure between ⅓ d (6 mm) and ¼ d (5 mm) can be deduced from the text for the thickness of these bars.

74 Following Schneider's (1906, 157 n. 1) opinion.

75 PROU 1877, 38, 160 and 195; MARSDEN 1969, 189; 1971, 231; WILKINS 1995, 31, 48.

76 MARSDEN 1969, 22–4; Heron, *Bel.* W 103–4.

77 BAATZ 1978, 232–4, fig. 8.

78 BAATZ & FEUGERE 1981, 202–3, fig. 1 and 2. An accurate cross-section for establishing the relative positions of the bars on the rings is not furnished, but the photograph clearly shows that the bars are offset.

79 BOUBE-PICCOT 1988, 213–14, pl. 3, 8–10; BOUBE-PICCOT 1994, 188–91, pl. 49, 96–8.

80 GUDEA & BAATZ 1974, 54–7, Abb. 3–5; BAATZ 1978, 14–15, fig. 12.

81 Some facts cast doubts on the authenticity of the positioning of the bars: all the *kambestria* were recovered in a very rusty and battered condition, and, in the first report, even the Orsova field-frame's bars were given as radially set (GUDEA & BAATZ 1974, 57–8, Abb. 8). The Gornea *kambestria* were chemically derusted (GUDEA & BAATZ 1974, 54–7), which surely loosened the bars' tenons. Further manipulation of the objects during restoration could be implied by the fact that *kambestrion* nr 3 has its straight bar upside down (GUDEA & BAATZ 1974, 57, 67 n. 35, Abb. 3–4).

82 WILKINS 1995, 21, 31.

83 WILKINS 1995, 19.

84 In Baatz's graphical reconstruction of the *cheiroballistra* (1978, 13, fig. 11) – as widely diffused as largely unsupported by his own paper – the field-frames bars are offset.

85 PROU 1877, 154–64; SCHNEIDER 1906, 165.

86 MARSDEN 1971, 223 n. 19.

87 Among the archaeological field-frames, only the Sala one exhibits more than four holes on each of its 'rings'. However, it is easy to discover that we are confronted with two different groups of four holes, the smaller ones being the originals, and the bigger ones a later repair. (BOUBE-PICCOT 1988, 220, pl. 3)

88 WILKINS 1995, 36.

89 BOUBE-PICCOT 1988, 214, n. 33.

90 GUDEA & BAATZ 1974, 67; BAATZ 1978, 12.

91 BAATZ 1994, 276–9. For the Volubilis washers, see BOUBE-PICCOT 1988, 215–17, pl. 7, 11–12; BOUBE-PICCOT 1994, 195–7, pl. 50, 99–100.

92 ½ d (MARSDEN 1971, 223 n. 18); 9 or 10 mm (WILKINS 1995, 21)

93 MARSDEN 1971, 223 n. 19; GUDEA & BAATZ 1974, 63; WILKINS 1995, 21.

94 MARSDEN 1971, 224 n. 20; GUDEA & BAATZ 1974, 64; WILKINS 1995, 24.

95 MARSDEN 1971, 222 fig. 7a; GUDEA & BAATZ 1974, 64. However, in his famous graphic reconstruction (1978, 13, fig. 11), the levers' tips distinctly protrude from the washers. WILKINS 1995, 24.

96 Ephyra: BAATZ 1982, 222. Elginhaugh, Miss Lindsay Allason-Jones (*pers. comm.*).

97 MARSDEN 1971, 13-14.

98 MARSDEN 1969, 4.

99 MARSDEN 1971, 224 n. 20.

100 GUDEA & BAATZ 1974, 58, Abb. 9, 10a and 10b. BAATZ 1978, 11, fig. 9.

101 BAATZ 1978, 13, fig. 11.

102 WILKINS 1995, 25 fig. 11.

103 WILKINS 1995, 34.

104 MARSDEN 1971, 208 and n. 1. This is the second and last occurrence of the word 'about' (ὡς) in the text, related to numerals. As I have mentioned earlier (see my n. 50), I do not think that it is casual or PH's pet word.

105 PROU 1877, 142 n. j.

106 WILKINS 1995, 31.

107 WILKINS 1995, 34.

108 WILKINS 1995, 31.

109 MARSDEN 1971, 225 fig. 10, a, b; BAATZ 1978, 13, fig. 11; WILKINS 1995, 29, fig. 13.

110 MARSDEN 1971, 225 fig. 10, c, d; 226 n. 26; BAATZ 1978, 13, fig. 11; WILKINS 1995, 30–1, fig. 16 and 24.

111 In bigger catapults, if this peculiar construction of the arms was also employed in them, there would be room enough in the bars to accommodate a pair of rivets to attach the ring to the bar, but in the *cheiroballistra*, welding seems to be the only possible means of doing it.

112 MARSDEN 1971, 226 fig. 11; 227 n. 27; GUDEA & BAATZ 1974, 64; BAATZ 1978, 13, fig. 11; WILKINS 1995, 32–4, fig. 15. Wilkins uses the following arguement to support his chosen length: 'I made a pair of telescopic arms, gradually lengthening both them until they reached the point which allowed the Slider to be fully retracted and the arms to lie almost parallel with the stock. When measured the arms were found to be 17½ dactyls long.' It sounds perfect, but is only a fallacy: as the precise point of attachment of the *klimakion* (and, thus, of the whole frame) to the case does not appear in the mss text, Wilkins has been able to place it where he has wished and, consequently, to lengthen or shorten the arms at will.

113 'It is most unfortunate that the manuscripts provide an unsatisfactory figure (1⅓ d) for the internal diameter of the washers...' (MARSDEN 1971, 228).

114 'We are a little doubtful about Heron's measurements for the arms, which seem rather thin and fragile and, thus, slightly out of proportion' (MARSDEN 1971, 233). 'Like him (Marsden) we had misgivings about their ability to withstand the forces of pull-back' (WILKINS 1995, 32).

115 The energy stored in one torsion spring is proportional to the cube of the spring's diameter. SOEDEL & FOLEY 1979, 127.

116 WILKINS 1995, 33.

117 WILKINS 1995, 33.

118 BAATZ 1978, 16, n. 55.

119 BAATZ 1994, 281–2.

120 An exhaustive review of the sources in MARSDEN 1971, 234–48.

121 BAATZ 1978, 3–9.

122 Even if in Baatz's reconstructed side-view (1978, 8 fig. 7) an ill-positioned back-stanchion almost completely hinders the travelling of the *ballista*'s arm (unless he is meaning inward swinging arms!).

123 The full functionality of this position is confirmed later, in the section 'The arc travelled by the arms'. It is encouraging to see that John Anstee (ANSTEE 1998, 131) has independently reached the same conclusion. Curiously, Victor Prou (PROU 1877, 69 fig. 9) disposed identically the two *hemitonia* in his

highly unorthodox reconstruction of the *palintonon*, long before any component of a catapult was archaeologically attested.

124 Wilkins seems implicitly to state (1995, 54–5) that the Orsova *kambestrion* and *kamarion* belong to two different catapults, which must be undoubtedly ruled out, as Gudea (GUDEA & BAATZ 1974, 58) clearly says that they were found together.

125 GUDEA & BAATZ 1974, 68.

126 They had been already noticed by Schramm, who thought, rightly, that they were protections for the arms. SCHRAMM 1918, 32, 34.

127 WILKINS 1995, 34–6.

128 WILKINS 1995, 36–8.

129 Perhaps it is not proper to mention in this theoretical paper information resulting from my actual working *cheiroballistra*, but I have to say that the doubts about the solidity of a tenon-*pitarion* joint expressed by Wilkins are absolutely unsound, because such joints work perfectly in my machine and its frame is perfectly solid and undeformable.

130 The Sala field-frame is noticeably clumsy in all aspects, but I must admit that in case it were positioned like an 'old' palintone half-frame, then it would allow the arm freedom to travel a really wide arc. This would imply, of course, that the tenons of the frame struts were not passed through this field-frame's *pitaria*...

131 Of course, it has been tempting to choose the 2 d separation. It would have, undoubtedly, widened the arc travelled by the arms and, therefore, the amount of energy developed by the springs, but, at the same time, complicated undesirably the already troublesome design of the 'ladder'.

132 In this design, as in the rest depicting views of catapult springs, the twisting of the cord bundles is represented incorrectly, since I have fallen into one of the usual novice's blunders. I am grateful to John Anstee for pointing this out.

133 PROU 1877, 69, fig. 9; 79–88; 111–13.

134 ANSTEE 1998, 131–2.

135 PROU 1877, 113.

136 See COULSTON 1989.

137 *Quæst. Nat.* II, 16.

138 *Res Gestæ* XIX, 5, 6; XIX, 6, 10; XXIV, 4, 11 & 16.

139 *Res Gestæ* XIX, 7, 6.

140 WILKINS 1995, 9, 34–8.

141 GUDEA & BAATZ 1974, 64.

142 MARSDEN 1971, diagram 12; WILKINS 1995, fig. 14, 20, 24.

143 MARSDEN 1971, 233, pl. 7.

144 PROU 1877, 187, fig. 43; BAATZ 1978, fig. 11.

145 WILKINS 1995, 36–8.

146 WILKINS 1995, 12.

147 Unfortunately, there is still a lot of work to be done with the springs before my catapult will be in real working condition. It will be the subject of a future paper: 'Pseudo-Heron's *cheiroballistra*, a(nother) reconstruction. II.– Practise'.

148 WILKINS 1995, 39.

149 *Epit. Rei Milit.* IV, 22.

150 MARSDEN 1969, 79 n. 1.

151 PROU 1877, 6–10, 111–13.

152 *Res Gestæ* XIX, 4, 4.

153 For Vegetius, see the introduction of N. P. Milner to his English translation of the *Epitoma*. For Ammianus, see A. Wallace-Hadrill's introduction to W. Hamilton's English translation of the *Res Gestae* (The Later Roman Empire, in Penguin Classics) or the introduction of J.C. Rolfe to his translation in the Loeb edition.

154 *Epit. Rei Milit.* II, 15; III, 14 (the *carroballistae*, certainly, were not light weapons, but their high mobility made up for it); IV, 21.

155 *Epit. Rei Milit.* IV, 22.

156 MARSDEN 1971, 231.

157 *Bell. Goth.* I, XXI, 14–18 and MARSDEN 1971, 248, n. 9.

158 WILKINS 1995, 45; WILKINS 1995 updated, iv–v, fig. C.

159 It was found during the excavations of the Egypt Exploration Society, the shaft (British Museum EA 71818) in 1978 and two detached iron heads (EA 71842 and 71914), in 1972. JAMES & TAYLOR 1994, 93–5. Carol Van Driel-Murray kindly measured this quarrel for me while investigating the leather items.

160 JAMES & TAYLOR 1994, 95.

161 Plácido Lasarte forged three heads and Agustin Kamiruaga made the shafts and final assembly.

162 SIMONETT 1942, 16.

163 JAMES & TAYLOR 1994, 96 n. 31.

164 SIMONETT 1942, 16, Abb. 11–12.

165 DAHM 1903, 63; SCHRAMM 1905, 121.

166 DAHM 1903, 64, taf. XIII, right.

167 SCHRAMM 1905, 121 and figure on p. 123.

168 DAHM 1903, 64. This weight seems – even without the tang – too small anyway. Given the volume of the complete head, 25 or 30 gm should be the minimum estimate.

169 SCHRAMM 1905, 123–4.

170 JAMES & TAYLOR 1994, 97–8.

171 SCHRAMM 1905, 123–4; notwithstanding, he presents the three vanes as the best suited disposition for a tenon. JAMES & TAYLOR 1994, 97.

172 See specially section Aii in JAMES & TAYLOR 1994, 98 fig. 5.

173 JAMES & TAYLOR 1994, 95, 98, fig. 5.

174 *Pers. comm.*

175 The Qasr Ibrim shaft has, in fact, a peripheric rabbet, but it is too slight – less than one mm deep – to fulfil that purpose. In JAMES & TAYLOR 1994, fig. 3 and 4, this feature is exaggerated by never representing the vanes parallel to the view.

176 SCHRAMM 1905, 122.

177 Uncritically repeated in JAMES & TAYLOR 1994, 95, 97: 'It is far too short to be a complete shaft, as it would be quite unstable in flight, and would tumble.'

178 FOLEY, PALMER & SOEDEL 1985, 84–5.

179 During the XII[th] ROMEC public demonstrations at the fort of Arbeia, Alan Wilkins kindly agreed to shoot one of the reconstructed Qasr Ibrim bolts with his powerful *cheiroballistra*. The bolt, once more, behaved remarkably well.

180 SCHRAMM 1905, 122; JAMES & TAYLOR 1994, 97; reference to Baatz's experiments in n. 35.

181 Incidentally, my reconstructed Qasr Ibrim bolts tend to develop, after three or four 'uses', exactly the same kind of damages present in the original shaft (JAMES & TAYLOR 1994, 95). Fortunately, these missiles are not very expensive if iron heads can be salvaged but, for the Roman Army, thinking of recovering such tiny bolts for a second use after an engagement would be over-optimistic, to say the less.

182 WILKINS 1995 updated, ix.

183 GUDEA & BAATZ 1974, 67 n. 37. Later, he changed his mind and catalogued them as the foreshafts of composite-built bolts, see JAMES & TAYLOR 1994, 97 n. 35, 37.

184 BAATZ 1988, 64.

185 With their bars in an offset position (see 'The arc travelled by the arms'). Estimated spring diameter: 54 mm.

186 BOUBE-PICCOT 1988, 215, pl. 7, 11–12; BOUBE-PICCOT 1994, 195–7, pl. 50, 99–100. Their external diameters at their bases are, respectively, 49 and 51 mm. They could perfectly have belonged to the same *manuballista*, which had a spring diameter (41–4 mm) slightly inferior to that of the Gornea ones.

187 See MARSDEN 1971, 160–1 n. 22.

188 WILKINS 1995, 26.

189 WILKINS 1995 updated, vii–x.

190 MARSDEN 1969, 14.

191 GUDEA & BAATZ 1974, 54–7.

192 The crossbow here illustrated belongs to the collections of the Museo de Armería (Vitoria-Gasteiz, Spain), to whose Director

and staff I give thanks for the facilities given during my examination of the weapon.

193 MARSDEN 1971, vii.

194 UCELLI 1950, 184, fig. 199.

195 UCELLI 1950, 428.

196 SCHRAMM 1918, 31–4, 60.

197 MARSDEN 1971, 229. His working reconstruction was, in fact, provided with copper cylinders and caps. MARSDEN 1971, 233, pl. 6–8.

198 BAATZ 1978, 12.

199 WILKINS 1995, 46.

200 I think that COULSTON 1989 is an interesting read in regard to this matter.

201 Maybe the twisted cords were depicted only in paint, like the rings in the mail shirts.

202 This does not mean that I agree with the other working reconstructions of whose existence I have notice. Leaving aside Prou's machine (perhaps only a scale model, if we believe Schneider, and a clear example of what kind of results wishful thinking can produce), I have already discussed Marsden's and Wilkins' catapults (both with enlarged springs, winched and possessing stands), but only mentioned Digby Stevenson's one: it is cocked, like mine, as a stomach-bow, but the (sinew-cord!) springs are 2⅔ d thick and this has conduced to the use of straight side ratchets and to a final weight of 12.24 kg, which makes the machine rather unwieldy as a portable weapon. Finally, in the group of 1⅓ d thick springs, Jeremy Barker's *cheiroballistra* (*pers. comm.*) seems very similar to my own proposed reconstruction, but in many details is basically an enhanced version of Baatz's popular graphic proposal (but it has a wooden 'ladder', a weight-saving option also favoured by Digby Stevenson); I only know of Michael Lewis' reconstruction (an inswinger) and that of Bernard Jacobs through Digby Stevenson.

203 SCHNEIDER 1906, 167–8.

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