Illustration

# The Luristan Project - Results from Cut Sword; Part 4

## Discussion of the "Cut Sword" Findings

### The Findings

Most everything of interest has already been stated in the three preceding modules. For starters I will therefore give a description of how we envision the sword was made. I base this on our findings and on some straight-forward logical deductions. Further down I will discuss how that ties in with what is known from the literature.

### Raw Material

- The raw material used for forging the swords must have been some bloom from an 800 BC or so (and thus relatively early) bloomery. Those blooms might have been compacted and thus purified to some extent right after smelting but they still must have contained a lot of slag and possibly some other inclusions. Their carbon content strongly varied (from ferrite / wrought iron to hypereutectoid steel) even so the bulk of the bloom was probably low in carbon.
- The only raw material that is known to me from the time period in question (ca. 800 BC – 550 BC) are the **Assyrian "double pyramid bars"** found in the palace in **Dur Sharrukin** (present-day **Khorsabad**), the capital of **Sargon II** from 717- 705 BC.
  Khorsabad is close to **Ninve** and thus not all that far from Luristan. In fact, during its largest expansion around 650 BC, the Assyrian empire may have contained parts of Luristan.
  To quote myself: "Sargon II, who ruled the Assyrians from 722 BC – 705 BC, was in possession of a tremendous treasure of iron that was stored in the palace of his capital Dur Sharrukin, present-day Khorsabad. One Victor Place, resuming excavations started by Paul Botta in 1843, found *160 tons of iron* just in storeroom 84. Most of that iron was in the form of bipyramidal bars weighing 4 kg - 20 kg. Metallographic investigations by well-known Radomir Pleiner showed that this iron was rather non-uniform stuff, a mixture of wrought iron, mild steel and hard steel steel, with plenty of slag inclusions.". Fits the Luristan iron like a glove. Just a coincidence?
- If an average bloom weighs in at 10 kg, Sargon's treasure involved 16.000 smelts. Considering that this was just the strategic reserve and that far more iron was most likely out there in the form of weapons and tools, Sargon's Assyrians must have made and forged iron on an industrial base. This implies that plenty of experience and highly skilled smiths were around then and certainly also before Sargon's II reign since this kind of industry does not come into being over night. However, besides the Khorsabad treasure, we have no iron whatsoever from the Assyrians (or Babylonians).
  In contrast, we have the 100 or so Luristan iron swords (plus a few other iron objects) - but nothing whatsoever is known about smelting and working iron in Luristan.

### Starting Material

- From the results we can state with certainty that the ancient smiths did not start to forge a mask sword directly from the bloom. They rather prepared a range of intermediate semi-products as starting material for making the various parts of the sword. It appears from our results that they first forged thin sheets. The elongated slag inclusion always show a large length-to-width ratio, just what you would get if you forge a cube into a sheet that is much longer than the cube and accordingly thinner. Double-pyramid bars by the way, are a good shape for drawing out thin and long strips as evidenced in this picture
  By cutting these single sheets to suitable dimensions followed by stacking them in a way that approaches the desired final shape, fire-welding these layers then allows to produce billets that already assumes the basic shape of the various parts needed. That is particularly attractive for the blade and the hilt; especially if only one piece was used.
  Fire-welding might have been done by forging the stack of pre-shaped sheets or, if the shape attempted was simple, by stretching and folding, i.e. by faggoting.
  Here we propose something new that you will not find in the literature. Mind that we do not claim that this technique was used for all mask swords. Mind also that around 800 BC iron technology made a big step forward

and that composing blades by layering / faggoting was used by the old Celts as demonstrated by the "sword from Singen"

- However - the ancient smiths were not too careful in doing this since the finished stacks, as shown by all our pictures, contains very bad (many large slag inclusions) and very good iron pieces in a seemingly arbitrary manner. Maybe they couldn't do better or - maybe once more - they didn't care since the mask swords were definitely not designed for fighting but only for showing off.
Only the *outside* had to look good, the *inside* quality didn't matter at all- in stark contrast to a fighting sword!. The outside quality mattered for *two* reasons.:

  1. You wanted a blade that looked perfect, without visible flaws on the outside. This necessitated that the top and bottom sheets of the blade / hilt stack was made from "good" iron.
  2. Wherever you wanted to put on the figures on the lower hilt and pommel plate or the rings by **crimping**, you had to make sure that these parts consisted of soft iron, i.e. ferrite or mild steel. I strongly believe that it is simply impossible to chisel off the crimps and bend them over the figures / rings if you encounter the brittle hypereutectoid steel found in several places.
  Indeed, as far as investigated, these parts of the blade / core did consist of relatively good ferrite.

We are thus claiming that the ancient smiths knew that their material came with different hardness values (i.e. carbon concentration) They could forge thin sheets and had a way of sorting the stuff. "Good" iron for the poutside, the "bad" one for the inside.

## Basic Forging

- The artisans making the Luristan mask swords were experts at their trade. They knew not only how to fire-weld but in particular how to make an object with a complex shape out of a (by now layered and possibly pre-shaped) billet) of iron / steel. The next step involved forging the various pieces as closely as possible into their final shapes. This included the rough shaping of the heads and animal figures but also of the pommel plate and the "rings" around the hilt. Doing that would be a challenge to a modern smith today. It was important that the shape after forging was as close as possible to the final shape because that made the tricky and laborious next step easier.
Forging itself did take place at rather high temperatures followed by relatively fast cooling (water quench?) as evidenced by the Widmanstätten structures and other observations outlined in the preceding parts. That seems to be true for pretty much all swords because all investigations made so far agree on this point. High temperature forging requires a hearth of some sophistication and skilled helpers.
There is, however, also evidence for low-temperature forging and even cold forging. Small wonder since the final steps of assembling the sword did need some high temperature but as little as possible. The chisel work for crimping obviously had to be done at room temperature. Then there might have been some short medium temperature annealing after all was done.

## Final Shaping of the Parts

- The various parts had to be worked into their final shape and that involved:

  1. Grinding and polishing the "simple" parts like the blade / hilt piece, the pommel plate, and the "wires" for the rings. Sounds not too difficult but try to do that by hand without the benefit of standardized emery paper, all kinds of files, and grinding wheels / power tools.
  2. Carving the figures. As pointed out in the main text, that was the only way you could produce these enigmatic heads and "lions". How do you do this without a range of good steel tools? Well, maybe they had steel tools? We don't know but I think it is quite likely. In any case, they obviously did have some artists (not smiths) who could turn the raw pieces into a finely detailed sculptures.

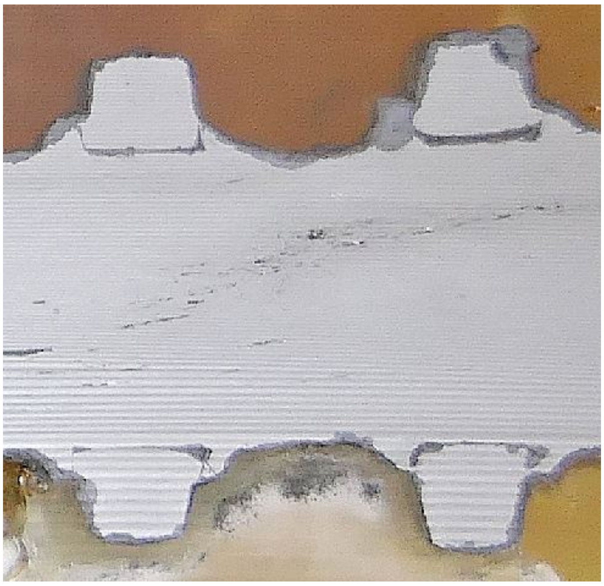
## Assembling the Parts

### *Attaching the Rings*

If you had made the core of the sword (hilt and blade) from one piece of material, I'm rather sure that in a first step the rings were attached. Looking at Luristan iron swords you will find that some rings were just wound tightly around the grip, while others were tightly wound etc. but also crimped into place. The following pictures show this


**Left:** One of the rings on the "cut" sword discussed here. **Right:** The rings on the Luristan sword in the Metropolitan; New York

Source: Left: Project; right: photographed in the Metropolitan Museum Feb. 2020



Cut showing the crimping around the rings

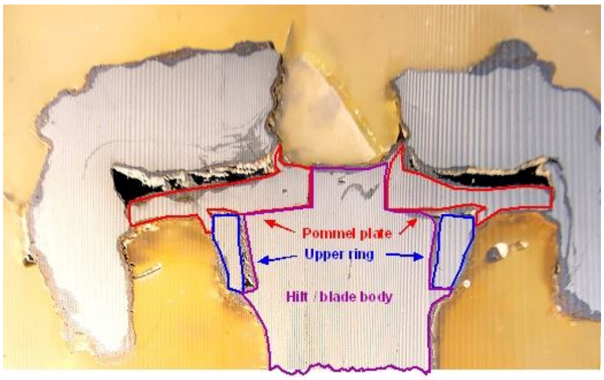

Straight and crimped rings around two of my swords

Source: Photographed by me 2020

- There is no way to bend a partially elastic wire / ring around the hilt at room temperature in such a way that it snugs closely to the hilt at all places. You need to do that at a raised temperature, in particular if he material consists of hard steel as found in the rings. .

*Attaching the pommel plate*

The pommel plate is kind of riveted on, using the thin extension of the hilt that fits through a hole in the pommel plate. A picture says more than thousand words:




Pommel plate and upper ring attachment

- We guess that at this stage the head / animal figures are not yet attached tot the pommel plate. It is interesting in this context that some mask swords do not have an upper ring, while others have complicated constructions right below the pommel. Here are two examples:

Pommel plate attachment on my swords with (upper picture) and without (lower picture)
a "ring" construction
Note that the left-hand figure in the lower picture is not touching the pommel (marked by the arrow) , which is somewhat recessed at this place. Once more sloppy workmanship at places where you won't (normally) see it?

- The upper "ring" in this example (also visible in some of the swords shown in one of the many Luristan modules) is more complex than the regular ones around the hilt, more a kind of decorative band. As the pictures above demonstrate, it takes some tricky crimping to make a fit that looked "wie aus einem Guß" (*like from one casting*) as we say in the true language.

*Attaching the figures*
Early investigators laughed at the "primitive" crimping technique they encountered when they looked at Luristan swords. They assumed that the old smiths had not yet mastered the art of fire welding for putting iron parts together in a solid way. But crimping was the only option for the ancient smiths! As we have seen, at least some of the smiths could fire-weld quite well. However:

**Fire welding would have destroyed the figures**

- Details would have burnt off at fire welding temperature, and banging on the figures with a hammer wouldn't have done them much good either.

Now what? There is no other way but crimping (if we discount modern gluing or soldering) and that, if you think about it, is an exceedingly difficult thing to do.

- First you had to produce the fittings or sockets for the figures (or the rings). You needed to do some precision chiselling, producing the exact outline of the figures to be inserted. You can't do this with the needed 1/10 mm precision if the the work piece is red.hot so you needed to do some heavy room temperatures deformation. That is exactly what we see in one of the crimps
  I claim that you can do this only with soft ferrite / mild steel as a substrate. Hypereutectoid or just eutectoid stuff is hard and brittle and you just can't make those flawless (on the outside) crimping joints we find. Note that you ruin your intended product if the crimp wall you raise with your chisel disattaches, breaks, or gets otherwise disturbed. There is no easy fix if this happens.
  Then you insert the figures and affix them by "**crimping**", i.e. hammering the crimp rim over the figure base. This is not something you do on the side; it must have taken a lot of practice to produce the perfect crimping we still see today.

**Optimizing the production process**
Not caring all that much for the "inside", i.e. slag inclusions etc., saves time and money. The same is true for the fitting between the backside of the figures and the body of the sword. You can't see if there is a lot of empty space between the heads / animals and the pommel plate or the hilt. Perfect fittings would have called for a perfect match of the two surfaces to be joined. We may safely assume that the artisans who made these swords would have had no difficulty to make perfect joints or fits, too - but why go through the labor and trouble?

- I think it is likely that the old smiths also noticed that some of the sheets they made as starting material for stack-welding were of inferior quality, containing large slag inclusions. But so what. Just put them into the inside of a stack and nobody will know. Iron was very expensive, after all.
  Now we have an explanations why theses swords combine breathtaking workmanship with equally amazing sloppiness. The ancient smith had a modern attitude. Making money was more important to them then impressing archaeologists some 3000 years later.

**Final Appearance**
Luristan mask swords today are always more or less corroded and blackish to rusty in color. They are not a particularly pretty or impressive sight. That was certainly not the case when they were new. If polished to a high sheen, they must have been quite striking in appearance.

- But polishing everything would have tended to obscure the fine details of the figures. My guess is that the figures were painted to some extent, outlining, for example, details (like the rims around the eyes) in black or some other dark color. They certainly must have made a (fashion?) statement for the fighting man that was not rivaled by much else available 2800 yeas ago. In Luristan, that had a very specific and very large range of (bronze) weapons and an iconic art style (exemplified, for example, in the "masters of animals"), these swords must have appeared as marvellous implements, but rather exotic in appearance. Not even remotely related to anything else around.
  My guess therefore is:

**Some Luristan mercenaries surviving in the Assyrian army (cavalry?), took an iron mask sword home with them when they finally retired back to the old Homestead.**

I have no proof, of course. But consider:

- Assyria had conquered 20 or more "kingdoms" in the general area, and we do not have any idea of what kind of iron technology these kingdoms commanded. Nor do we know all that much about heir religious believes. Some of those entities might well have promoted an art / religion that produced something similar to the the iconographic heads and "lions" found on the mask swords. The general style of these figures certainly is alien to the well-known Luristan style (or any other style found in the larger area during the time in question). A not so common design made these things particularly attractive for the "tourists" (in the embodiment of soldiers / conquerors).
- Assyria, as reasoned above, must have had a big and thriving iron industry. It also had a stratified society with rich and powerful people who could afford useless but decorative and very expensive trinkets. The Luristanis, as far as we know, didn't have all that.
- If the Luristanis did venture into iron technology at some (later) point in their metal-working history, one would expect that they would have kept the basic design of their bronze stuff as exemplified in thousands of known artifacts. Indeed, the iron Luristan swords of type II are quite similar to the bronze types. The mask swords are

not. .

- A civilization that has turned out thousands of bronze weapons (not to mention comparable numbers of bronze finials, horse cheek pieces, etc.) and put it into the graves of their people, should have produce more than just a 100 iron swords.
- Maybe the iron mask swords were very expensive? Quite likely - but then you would have expected to find them in rich graves of rich people. Nobody knows exactly where they have been found, but the robbed graves were all quite similar, no hint of especially big or otherwise outstanding burials. This means that the owners of the mask swords had the same social status as the many more non-owners. Well, the graves of the pensioned off mercenaries / warriors who by good fortune were able to acquire one of the mask swords (or were given one for outstanding service) would not be much differernt from the graves of their swords-less brethren.

So why didn't we find Luristan mask swords in other places that once belonged to the Assyrian (or Babylonian, if you like that better) empire? The answer is simple and convincing: For the same reasons we found *no iron whatsoever* left over from these empires (besides the Khorsabad hoard) even so we know for sure that a thriving iron industry must have been in place (because of the Khorsabad hoard).
Why did we find far more Roman swords in Denmark (never part of the Roman empire) then in the area the Roman empire (far, far larger than Denmark)? Well, the old Danes liked to go on tours, and like all good tourists, they liked to bring something special back to the old homestead.
I rest my case.

## Comparison With the Literature

How do our results from the cut sword compare with what can be found in the literature? The straight answer is:

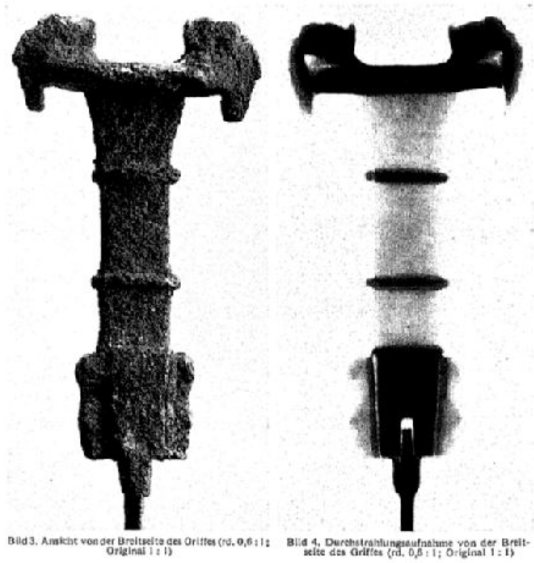
| **A lot of what we found has been known before** |
|---|

However: almost all earlier investigations into the metallography of the mask swords were restricted to very small samples making it hard to impossible to detect fire welding. Moreover, some of the researcher harbored old and by now disproved believes (like the possibility of "carburizing" or "decarburizing" bulk iron) that corrupted their interpretation. Our results shown here therefore do add considerably to our knowledge of the Luristan swords. Moreover, the journals then (as now) printed only a few pictures at small sizes. Worse, print quality was not always very high and prints were only in black and white. Topping all that is the sorry fact that what you see now in (often badly) digitalized copies of copies... is often just a faded ghost of the original picture. That's why we "publish" here with lots of clear and often large pictures.

I shall now progress through the key publications from this list. An earlier "literary guide" is given here.
Let's start with the oldest of these papers:

**1** **1957 F. K. Naumann:** Untersuchung eines eisernen luristanischen Kurzschwertes Archiv für das Eisenhüttenwesen, 28. Jahrgang, Heft 9, (1957) 575 - 581

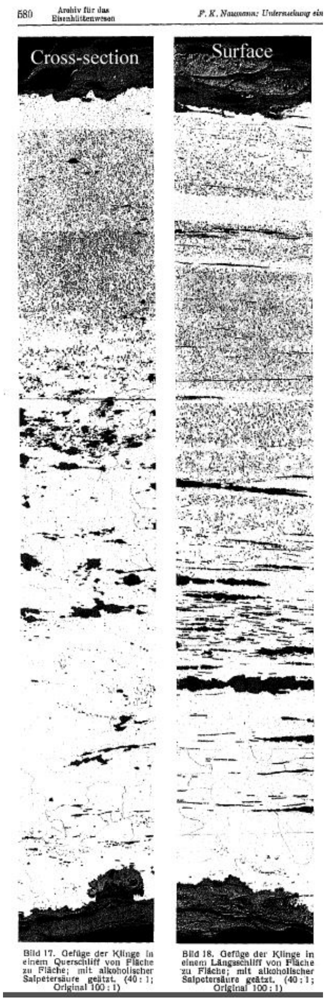
This is one of the earliest but still best papers to the subject. Small wonder, it has been written in the true language by an expert metallurgist. Naumann investigated the "Hamburg" sword and first dispels the believe that some iron casting was involved in the making of the sword. Then he asks all the right questions about the making of the figures, the assembly of the parts, the forging technique (fire welding?), the materials quality and so on. Since the sword had to remain mostly intact, he employed X-ray techniques, or better said, $\gamma$-ray techniques since he used the high energy radiations of the isotope Ir 192. Here is an example of one of the many pictures he took:




The word Naumann investigated together with is X-ray image
Note the bad quality of the picture now.
The originals were much better as we shall see

- The picture is remarkable because it is the first "X-ray" image of a Luristan sword. It (and its brethren) show the individual parts and their partially "sloppy" attachment. We also see that the blade and the hilt were *not* made from one piece of iron (like our cut sword) but were "stitched" together from at least two pieces.

Naumann could investigate only very small parts of the sword metallographically, like an area of about 0.5 $cm^2$ of the blade. The results are shown below:




Naumann's Nital etched sections of the blade

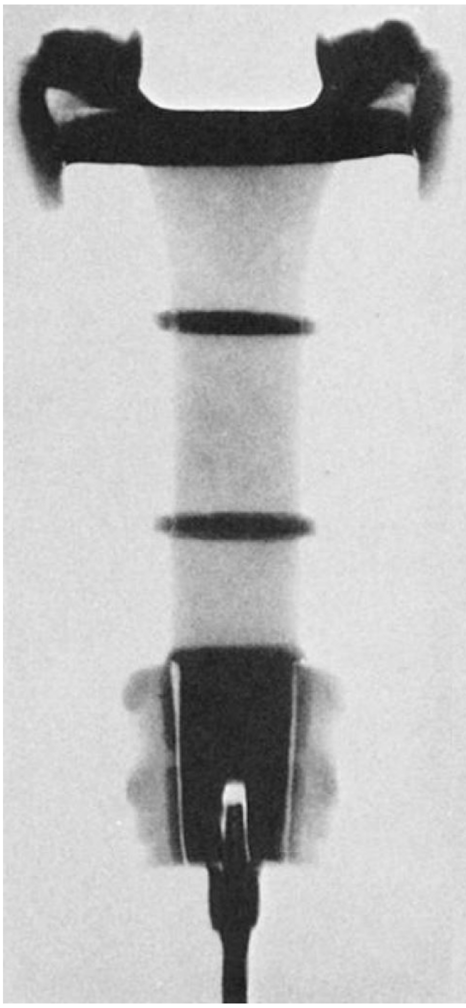
I show this picture to illustrate the point made above: You don't see much anymore in present-day pictures of old publications. You do see , however, that Naumann's finding are quite compatible with ours.

From the little he was allowed to do, Naumann drew many conclusions that are also valid in our case. Here is a list

- No cast iron; the sword consists of many iron parts put together in a not always quite clear manner (for Naumann)
- It's rather unclear how the (in Naumann's case heavily corroded) figures were made.
- One is inclined to assume fire welding but Naumann's results were not yet conclusive for him (even so his blade investigations do suggest this).
- The bulk of the blade consist of wrought iron / mild steel but parts of the (small) area investigate also showed large carbon concentrations.
- Lots of elongated slag inclusion demonstrate some drawing out the material by forging
- Widmanstätten structures plus spheroidized cementite point to high temperature forging in an early state of its making.
- Pearlite structures show medium temperature (700$^{o}$) working at the end.
- Twinning (not observed in our case) hints at local heavy impact deformation at low temperature (e.g. by adjusting parts by heavy hammer blows as required for scrimping)
- Chemical analysis shows relatively clean iron with mostly some C and Si, the latter most likely from the slag inclusions) .
- You need to "destroy" a sword by cutting it apart if you want to answer the many questions still open. Namann is all for doing that.

**2** **1961** Herbert Maryon; with technical reports by R. M. Organ, O. W. Ellis, R. M. Brick, R. Sneyers, E. E. Herzfeldand F. K. Naumann: Early Near Eastern Steel Swords,
American Journal of Archaeology, Vol. 65, No. 2 (Apr., 1961), pp. 173-184

A key paper, reviewing the properties of 11 Luristan mask swords. The Naumann paper from above is prominently featured, including some of its picture in much better quality than what is left from the original. Here is an example:



One of the "X-ray" picture so Naumann's paper, in far better quality
than in the original paper (see above)

- Compare to the picture above and you see the problem with pictures in old publications.
  As far as the metallurgy of Luristan swords is concerned, Maryon reports on Naumann's finding and on metallurgical results from the "Toronto" sword. Only small parts (the "beard region" of one of the figures) was investigated in some detail, and the results are in line with what we found: High-carbon regions, some Widmanstätten structure - an example is shown here,

Maryons paper is interesting because he speculates about the origin of these swords. Here are a few quotes

- No closely comparable material is known, and their place of origin has not been exactly ascertained, though a number of the weapons have been found in tombs in Luristan.
- Although these works are generally recorded as coming from Luristan there is no evidence to show that they were made there.
- The iron daggers are indeed a foreign element among Luristan bronzes, and though only one of the specimens is known to have come from Pontus, that must be the original provenance of them all. In Pontus, iron, easily workable, lies above ground."
  ??? Pontos is the area around the black sea and there are (ancient Greek) claims that iron technology originated there. Maybe, maybe not. Certain is only that no elemental iron was lying around above ground.
- It is evident that at the time when they were being manufactured some very efficient workshops must have been available, and that the separate parts of the weapons were mass produced. The sword may have been worn as a badge of honor, awarded perhaps to some distinguished company of warriors for a notable deed of valor.
  A version of my "trophy brought back from time spent as mercenary".

- Maryon might have been the first one addressing the problem of making the figures:
  "The formation of the lions and of the human heads would have been effected first by forging, then the finer details would be added by means of chasing tools and punches, for there is no indication of the employment of cutting tools upon them."
  He also realized that we are looking at supreme examples of craftsmanship:
  "Just as the earliest books printed with moveable type are in many ways unsurpassed, so here, the sword handles forged in the new metal, steel, by these pioneer smiths of the Near East, exhibit skill of a high order, and no comparable steel sword-hilts have been found in any other land before the time of the Renaissance in sixteenth century Europe."

**3** **1964** Kate C. Lefferts: Technical Notes on Another Luristan Iron Sword
American Journal of Archaeology, Vol. 68, No. 1 (Jan., 1964), pp. 59-62

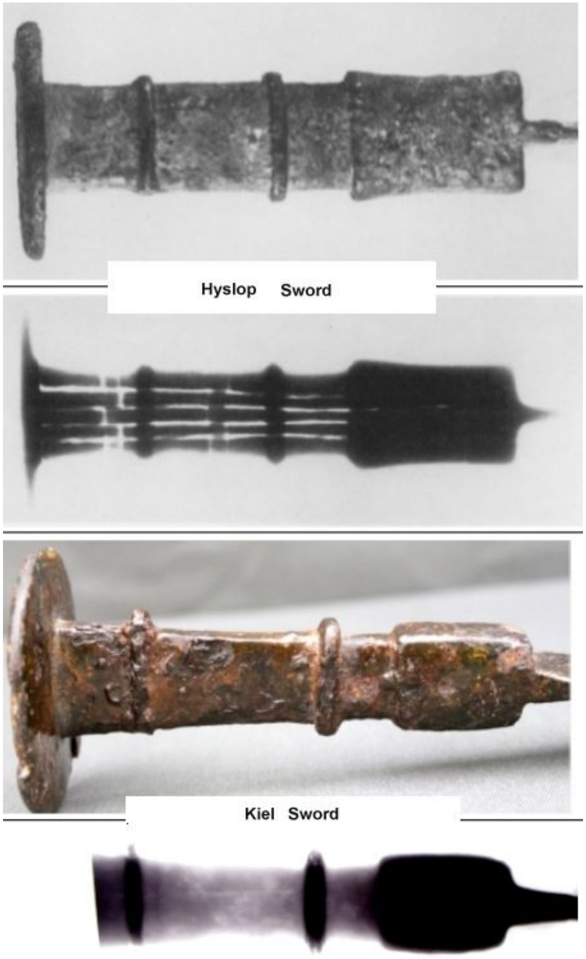
- In this short paper the issue gets confused. Two major if wide-spread errors are introduced in the context of the New York Metropolitan Museum sword.

  - It seems likely then that our sword was hand-forged from wrought iron, and that the parts worked over *became carburized* during the frequent heating process and took on the pattern of mild steel." No, it didn't became carbunized, certainly not to the degree shown in the metallographic picture from a tiny are at the beard of on of the figures. Here are details.
  - "Still unresolved remains the remarkable similarity of the various swords, particularly that of the ornaments. It could be that the main parts of the swords were hand-forged and so have varied proportions, but that the sophisticated ornaments, which are of lower carbon content, were formed by swaging."
    No, swaging was not an option; see here.

- Well, Kate Lefferts obviously is not a metallurgist, as also evidenced by statements like: "This gives us a hardness softer than air-quenched steel and again indicates, as does the absence of pearlite, that the blade was not quenched."
  For you non-metallurgists out there: Hardness increase by quenching *only* works if there is sufficient carbon in the iron (typically in the form of pearlite) and it is the absence of *martensite* that indicates a lack of quenching.

**4** **1966** K. R. Maxwell-Hyslop and H. W. M. Hodges: Three Iron Swords from Luristan
Iraq, Vol. 28, No. 2 (Autumn, 1966), pp. 164-176

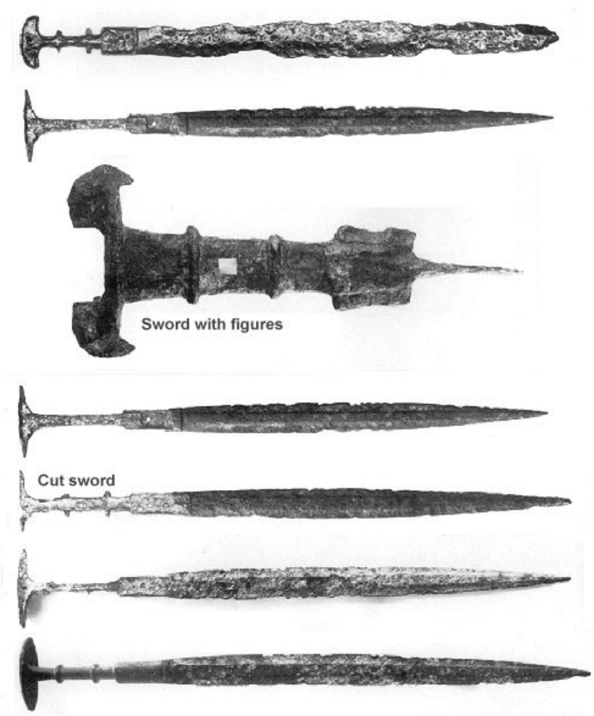
- An important paper describing the first sword cut into two parts like ours. From todays point of view this cut sword was rather atypical in its construction. Since nobody could know this at the time, its unusual construction was assumed to be typical and dominated the structural discussion for a while. Look here and below for some details.
  We investigated a rather similar sword and found that it was much simpler in construction, rather more like our cut sword (just without figures etc.) Here is a comparison:




Maxwell-Hyslop sword plus X-ray and Kiel sword plus X-ray

- Note that the hilt of the Hyslop sword actually consists of a stack of "thin" sheets. Fire weld the stack and you have what we found.

Beside the cut sword several others were investigated, all of them but one without figures and therefore probably earlier than our cut sword. The set of swords investigated is shown below:



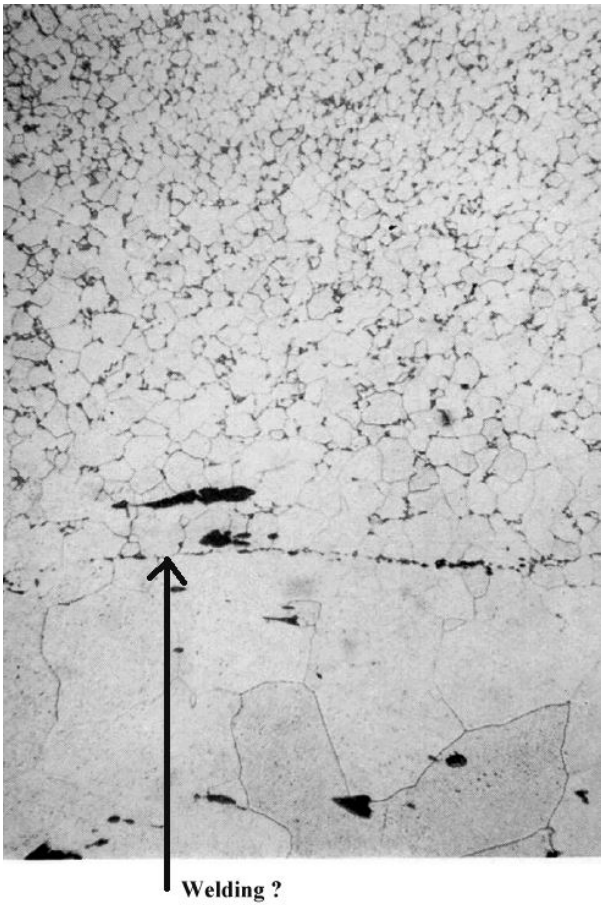
The sword investigated by Maxwell-Hyslop and Hodges. Note that the uppermost one looks rather like a Luristan type II sword

The sword with the figures led to some insights:

- The blade and the grip are a single piece of metal.
- The two seated lions forming the guard, and the pair of bearded human heads facing outwards, with lions' heads facing inwards, that decorate the pommel have been applied by fitting them into recesses formed in the metal. Here again adhesion of the applied parts has not been achieved by heat welding, but by burring over the edges of the recesses, a process already fully discussed elsewhere.
- Close examination under the binocular microscope showed the presence of a number of areas in which copper corrosion products were present. At first it was felt that these were due to contact with corroding bronze objects, but a closer inspection revealed that iron corrosion products from the weapon itself overlay areas of copper corrosion, and one is forced to conclude that areas of this hilt may have been covered with a copper alloy

  The only hint in the literature of some finish of the swords. A bronze coating doesn't make sense, however. Why coat a figure made in a tiresome way from iron with bronze, if it would be far easier to just cast one?

The microstructure analysis of small areas from the sword with figures are consistent with ours. Slag inclusions, areas with low and high carbon concentrations, and so on. One picture may even show a fire-welding interface:




A possible welding boundary from the sword investigated by K. R. Maxwell-Hyslop and H. W. M. Hodges

However, the authors completely misjudged the sword production process:

- "A competent blacksmith does not rely upon rivets and bands and burred edges to hold his work together; he uses, rather, a hammer weld carried out in the hot."
  No, he wouldn't! That would destroy the carved figures!
- "To be blunt, seen in terms of black- smithing these swords are a mess, and any of them could have been better made by the barbarian smiths of central Europe, certainly by the eighth century B.c. "
- Certainly not. They were also not made for fighting but for showing off.
- "Equally, the fact that, in certain cases, the iron had become carburized does not of itself argue that the makers were intentionally converting some of the iron to steel, but only that the metal was being subject to long, or frequent, periods of heating in carbon."
  Wrong.. There is no substantial carburization ever during forging.
- "It is precisely the incompetence of the smiths that is so interesting: they had so obviously not fully realized the potentialities of the metal they were working. In fact, when one looks critically at the methods of manufacture employed-the use of flanges to hold insets, the punch technique of decoration, and the final planishing-one is reminded as much, if not more, of the bronzesmith than the blacksmith."
  Wrong. Just try to forge an iron mask sword with all the modern tools and methods and you will find it rather difficult.

**5** **1968** Vera Bird and Henry Hodges: A METALLURGICAL EXAMINATION OF TWO EARLY IRON SWORDS FROM LURISTAN
Studies in Conservation, 13 (1968), 215-223 215

- This paper contains in essence the metallographic study to the Hyslop-Maxewell paper above. It contains more micrographs of etched surfaces but does not add much new insights. Two swords were investigated, one was made of "wrought iron", the other of steel (including hypereutectoid steel).
  "There is, however, an amusing inconsistency :On the one hand it could be argued that the second sword was made from deliberately manufactured steel, and that during working the surfaces it becomes *decarburized*". So far, it was the other way around;: The wrought iron, supposedly, became *carburized*. Both processes are impossible anyway as pointed out many times already..

**6** **1971** C. S. Smith: The Techniques of the Luristan Smith
Science and Archaeology (Ed. Rober H. Brill), Cambridge, Massachusetts, 1971

- Smith actually purchased "Luristan" iron swords so he could take them apart for analysis. However, only one of his objects can be classified as an iron Luristan mask sword. At least one of the others is an akinakes, usually associated with the Scythians. Smith knows his metallurgy and the paper is rather interesting. He found and discusses at length spheroidized carbon (actually cementite) and found and discusses nitride precipitates for the first time. Unfortunately, the pictures are by now so bad that one can't see anything anymore.
- A few quotes and comments, always in the context of the Luristan mask sword:
  - "Iranian smiths in the period 800 (±200) 8,C, were highly skilled. although they were unacquainted with some of the basic methods of ironworking. Their forging, which involved the use of special swages, is magnificent"
    This is exactly the opposite of what Maxwell-Hyslop mentioned.
  - "It was mentioned earlier that the steel in the grooves cut to receive the bands on the hilt and pommel of No. 105 had been superficially cold-worked in a manner that suggested working with a chisel. Actually the ferrite in the most heavily cold-worked areas has recrystallized to an extremely small grain size and in similar areas that are pearlitic the carbide has become spheroidized. This indicates that the mechanically finished dagger had been heated for a short time to a temperature perhaps as high as 650 °C."
    Quite likely true.. Some light annealing after all the room temperature crimping would have been beneficial.
  - "There are no records describing the surface appearance of iron objects in the period under discussion, but it seems somewhat unlikely that they would have been bright".
    Well. It is exactly the brightness of polished iron that made it so special in ancient times.
- Smith acknowledges fluctuating carbon concentrations from smelting and the high T - low T forging already mentioned several times.
  He also considers fire welding or faggoting but believes that, if at all, it happened when the bloom was processed. This certainly disagrees with our results

7 **1971** P. R. S. MOOREY: CATALOGUE OF THE ANCIENT PERSIAN BRONZES IN THE ASHMOLEAN MUSEUM

- Interesting, in particular as far as the history of iron and the style of the Luristan swords are concerned, but no new metallurgical information is given.

8 **1973** E. Schumacher: Eisenschwerter mit Maskenzier aus Luristan
Kleemann Festschrift II Teil (= Bonner Hefte zur Vorgeschichte, n. 4), Bonn, 1973, p-97 ff

- Describes the appearance of about 30 mask swords and provides with drawings (including Luristan type II swords). No new metallurgical information is given.

9 **1987** Claude Forrieres, Étude par microscopie électronique de structures de trempe d'une lame d'épée du Luristan, Étude par microscopie électronique de structures de trempe d'une lame d'épée du Luristan ArchéoSciences, revue d'Archéométrie Année 1987 11 pp. 17-29

- It's in French! Probably interesting but meant only only for Frenchmen. In addition, the (many) pictures are of bad quality.
  We do see Widmannstätten structures, spheroidized cementite, and things with some similarity to what I've called "really weird" for our sword

10 **1988** O. Muscarella: "Bronze and Iron", (Book)
New York 1988 (pp 184 . 189)

- The "Pope" speaketh. O. Muscarella certainly knows about Luristan things and has written about it at length. He is, however, not a materials scientist or metallographer. In the book referred to here, he gives - among much other stuff - a detailed description of the special mask sword in the Metropolitan Museum in New York. It is special because

  - It's figures have 64 carnelian inlays, never seen (so far) on any other mask sword.
  - The blade is not set at a right angle to the axis running from head to head on the pommel like all others (see below).
  - It's hilt is rather primitive in comparison to our "cut" sword or to the Louvre sword and its brethren

Carnelian insets of the Metropolitan sword

Source: Photographed at the Metropolitan in Feb, 2020

- Muscarella makes a point for the origin of these swords in Luristan (which I'm not so sure about) and mentions that he is aware of 88 of those swords.

**11** **1991** J. E. Rehder, The Decorated Iron Swords From Luristan: There Material And Manufacture; Journal of Persian Studies, Iran, Vol. 29 (1991) pp. 13 - 19

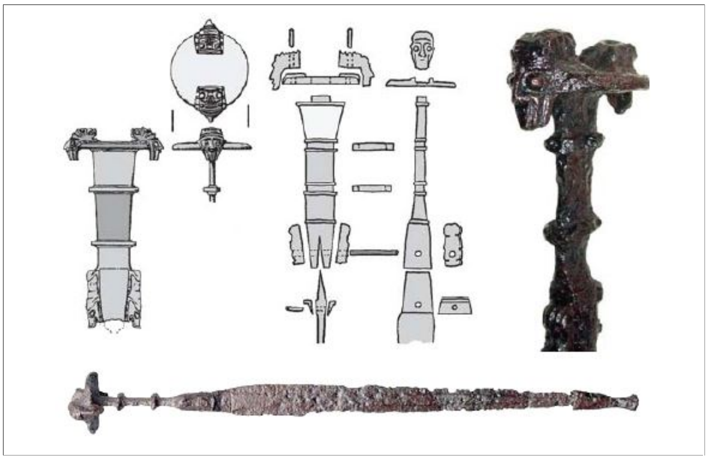
- This is a review without pictures. Rehder discusses the "Toronto" sword and others, including the radiocarbon dating of the Toronto and MIT sword.
  He reviews the available information and mentions spheroidized cementite. He also points out erroneous or misguided stuff in older publications.
  Rehder marvels at the workmanship and concludes that the swords were not good as weapons and probably for representation.
  He discuses smelting techniques and iron / carbon systematics in detail and relates that to the making of the swords..

**12** 2003 Bruno Overlaet, The Early Iron Age in the Pusht-i Kuh; Luristan;
Acta Iranica, Vol. XXVI, 2003; selected parts of the huge volume
Bruno Overlaet, The Chronology of the Iron Age in the Pusht-i Kuh Luristan,
Iranica Antiqua, Vol XL (2005), pp. 1 - 33

- The ultimate about Luristan graves. Excerpts from the detailed excavation report and so on - but no details abour mask swords.

**13** A. Hasanpur et al.; The Baba Jilan Graveyard Near Nurabad, Pisht-i Kuh, Luristan - A Preliminary Report, Iranica Antiqua, Vol. L (2015), pp 171 -212

- Some details about the only mask sword (now in Brussels) ever found during an excavation by archaeologists (if only in the detritus left by the grave robbers). No metallurgocla details, however.



The "excavated" sword and its internal composition
The figures are shown as "riveted" to the body of the sword, which is doubtful.

## Conclusion

There is a general agreement in the old literature about the following points:

1. The iron used was rather inhomogeneous. Mostly ferrite / mild steel but with high carbon concentrations in some part. It also an contained many large slag inclusions. The concentration of P, S and some other elements was rather low, however.
2. The figures must have been made by forging the rough outline and then finishing somehow with tools (i.e. "carving" in a general sense).
3. Forging took place at high temperatures (Widmannsätten structures) followed by finalizing at lower temperatures (spheroidized cementite) and possibly a final mild anneal. Some cold working is also evident on occasion.
4. The craftsmanship is superb; the way of assembling the pieces by "crimping" unique. The finished sword is most certainly not a weapon but a honor or show-off item.
5. No clear evidence of fire welding has been found.
6. No clear evidence of using low / high carbon materials conscientiously by the smith has been found.
7. There is no standard composition of mask swords. We have blade / hilt in one part or composed of many parts. Simple rings around the hilt or more involved structures. Long / short blades. But the figures are always quite similar and the general appearance is unmistakable.

Our findings generally agree with that but we claim the following points as new:

1. We have definite occurrence of fire welding - in contrast to point 5 above. Note, however, that in most cases above the samples were too small to find definite prove of fire welding, and that some of the old picture may well contain welds.
2. We raise strong points about a conscientious choice of material for certain parts of the sword by the old smiths. We can't prove it beyond doubt, however.
3. We suggest that the old smith used "bad" material on purpose (for the invisible inside) and "cut corners" in the construction whenever the result couldn't be seen. They had no intention of making a useful weapon but rather a piece of art (an money).

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**Part 1** Heads
**Part 2** Pommel and hilt
**Part 3** Animals and blade
**Large Pictures**