Illustration

The Luristan Project - Results from Cut Sword; Part 1

Introduction

Sword No. 5 (2744) had been cut in two parts and will be referred to in what follows as "cut sword".
It could easily provide enough material for a complete Ph.D. thesis. Unfortunately, not only were our project finances and time budgets limited, we also did not have the proper analytical tools (or sufficient experience) at our disposal to do an in-depth investigation. Nevertheless, in what follows you will find a lot of pictures and some comments.

- The huge size of the "specimen" does not allow to use standard equipment like most microscopes, electron microscopes or various spectrometers. One either has to go for specialized equipment (that does exist but is not easily accessible without sufficient funds) or needs to cut the sample to size.
  We did what we could and then donated the cut sword (like the others) to the Royal Museum of History and Art in Brussels, Belgium, where Prof. Bruno Overlaet eventually can instigate a thorough investigation.
- This module (and its successors) uses more and larger pictures than usual, so you might want to enlarge the browser window. An extra module linked to this one shows humongous-size pictures. Why is that-? Simple::

These modules constitute the "official" project report on the cut sword

The normal way to publish project results is to send a paper to a suitable scientific journal. I have done that a few hundred times so I know how it works. Why not here? Simple once more:

1. No self-respecting scientific journal in the field of archaeology would ever except a paper from a bloody amateur like me.
2. No journal whatsoever would publish all those pictures and none could deal with the large sizes needed to see details.

What we [1)] did was:

- Taking some pictures of the "as cut" and "as etched in Bochum" halves. Some examples of that are already shown in the results overview.
- While the "Bochum" half was left untouched, the other ("Kiel half") was polished to a mirror finish. This needed to be done by hand and took a lot of time and effort. Of course that wasn't done by me but by **Ingo Petri** , an archaeologist with an extensive training in metallurgy.
- The polished Kiel half-sword was then etched with Nital. Microscope pictures were taking along defined lines in several areas (see below). Nital etch delineates the basic structure showing grains and in particular cementite inclusions.
- Subsequently the sword was repolished and etched with Oberhoffer etch. Pictures then were taken along the same lines as before.

This was a lot of work. The results (see below) are remarkable but typically raise questions that can only be answered by an in-depth analysis employing more advanced methods.
At this point it is necessary to recall that chemical etching, while a powerful and simple tool, always needs

interpretation by an "expert". But even experts do not always know what they see. An expert does know what a Nital etch reveals in an iron-carbon steel as long as not much else is contained in the iron. With experience, one might be able to interpret what a Nital etch shows in common steels, containing some Mn, Si, etc. besides carbon. What you get if sizeable quantities of the rest of the periodic table are contained in the sample, is not always clear, however. For the Oberhoffer etch these uncertainties are even worse.

- While we do have some experience with etching Fe / steel and interpreting the results, we cannot claim expert status. The interpretations given below thus must be taken with a grain of salt. To make it plain:

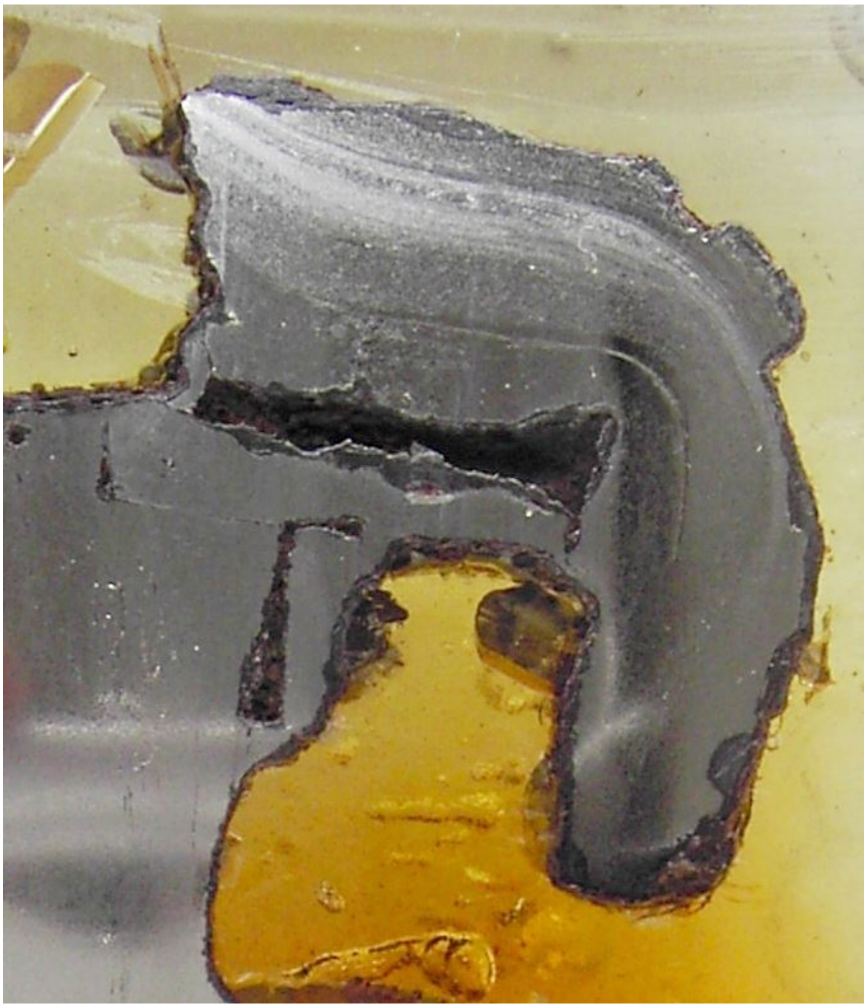
Interpretations here are tentative. They might be wrong.

The "Bochum Striations" and First Conclusions

As pointed out in the results overview, the half-sword etched by the team of **Prof. Ü. Yalcin** in Bochum, Germany, showed well-developed striations on a macroscopic (0.1 mm - 1 mm) scale. Looking at this surface with a microscope does not produce additional information since the roughness of the as-cut surface overwhelms all finer features. It is thus of interest to see if this structure could also be found in the polished and etched half of the sword.

- The answer is: yes - but! While the Oberhoffer etch essentially produced a rather similar striation pattern (see below), the Nital etch only showed it faint striations in particular in the two heads as demonstrated by the pictures below.

	
Bochum half; Nital etched in as-cut condition	Kiel half; polished and Oberhoffer etched. Strongly contrast enhanced. Note mirror symmetry to Bochum half The polished surface also shows (by reflection) the camera and its surroundings.



Part of Kiel half; polished and Nital etched.
Strongly contrast enhanced.

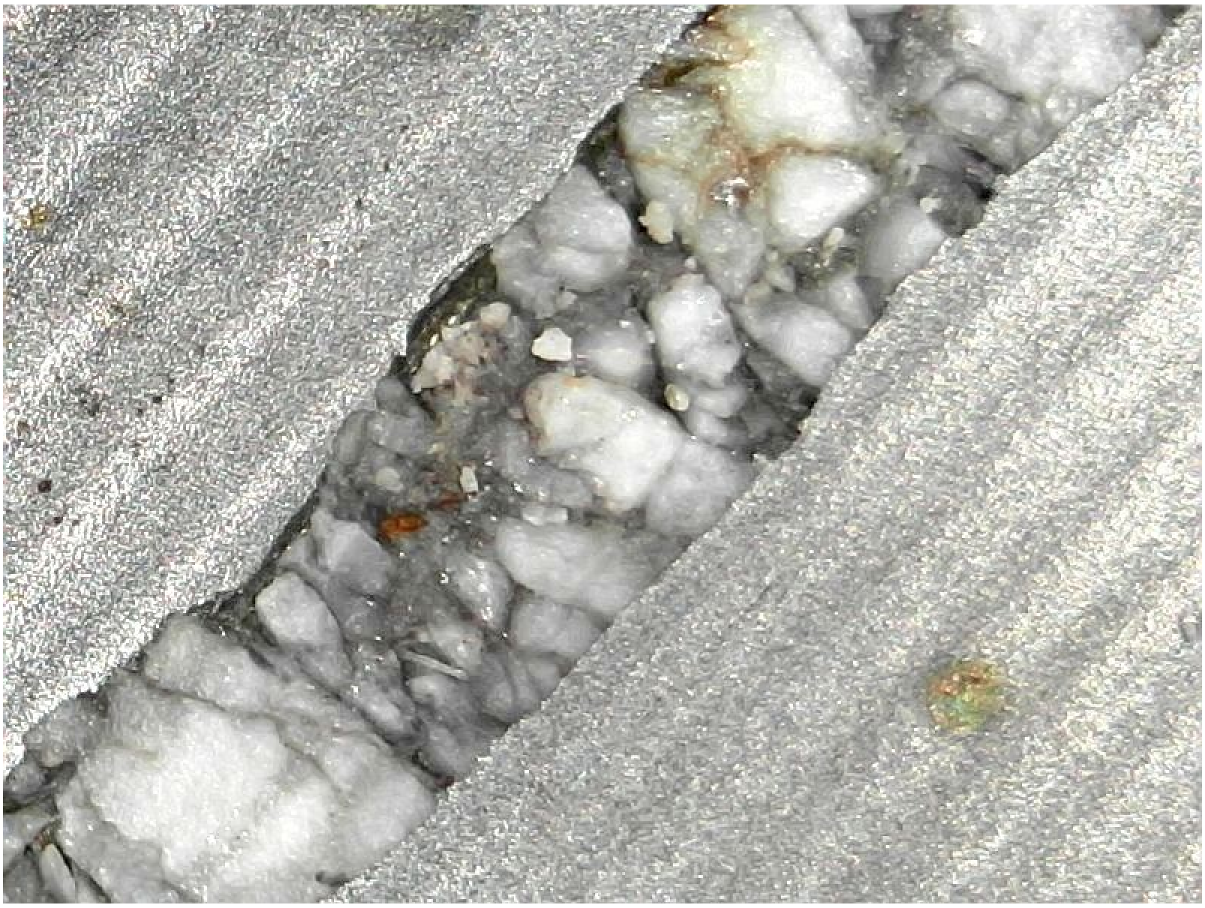
- In producing these pictures a problem is encountered that needs to be mentioned here. Before etching the surface has been polished to a mirror-like appearance. After the etching we still have a mirror-like surface. Now imagine you want to take a picture of the surface of your bathroom mirror. Just pointing a camera and shooting will produce a (mirror-image) picture of you and your camera. Same thing here. Some features in the images are due to reflections and that obscures to some extent the structures we want to see.

Anyway , we may draw some first (tentative) conclusions:

1. The "Bochum striations" are real. They delineate some structural feature of the iron / steel of the sword.
2. These striations must relate to the forging process. Not only the body of the sword but also the "heads" and "animals" originally must have consisted of iron pieces with parallel striations (later bend by forging in the case of the heads). A layered structure is likely and that points strongly to some kind of piling of the *starting material*. If that was done by repeated stretching and folding (i.e. faggoting) or by lamination of individual layers cannot be determined so far.
3. The striations might be due to impurities since they are particularly prominent in the Oberhoffer etch. This etch typically delineated phosphorous (P) but also Arsenic (As) and God knows what else. This implies that the impurities were either introduced during the welding or, if contained in the starting material, that they took on a layered structure during forging by a process known as "banding " that is prominent at the forging of wootz blades.
4. If the "white lines" delineate welded surfaces, we must conclude that the welding process most of the time was rather perfect - but sometimes catastrophically imperfect. The huge "cracks" filled with some extraneous matter (fayalite crystals?)

as shown below and here attest to that.

5. The striations continue from the wide handle part to the narrow blade. They are just "squeezed together" as the material
become thinner in the transition region between handle and blade. That is a strong indication that the smith made the core of
the sword (handle and blade) from one piece of material, "pulling out" the blade part from the (layered) bulk of the starting material.

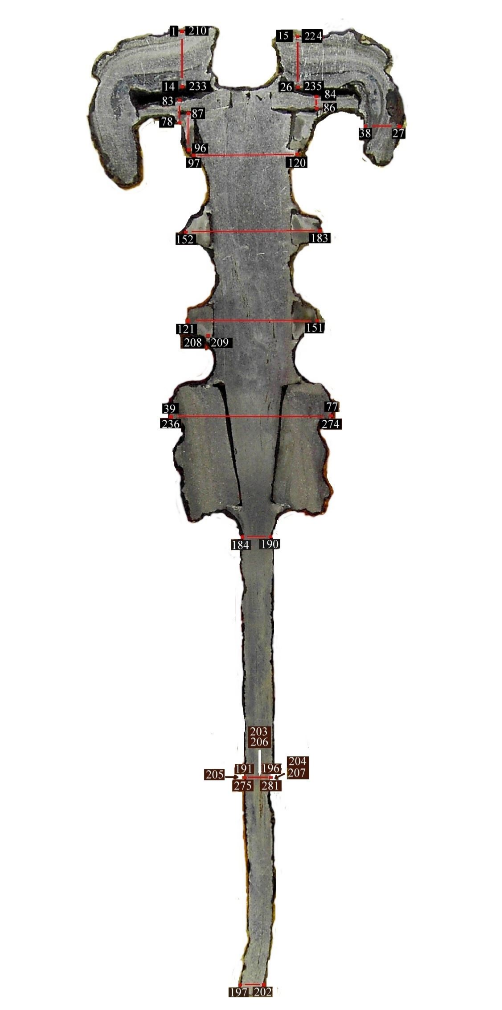


Huge cavity in the blade filled with crystals (fayalite?) seen in the as-cut state.
The parallel white "lines" here are not the striations discussed here but reflect some small waviness from cutting.

- It remains to be seen if the detailed analysis of the etched areas support the above conclusions

Definition of Investigated Areas

The following picture defines the areas investigated in some detail by optical microscopy. Along the red lines a series of pictures were taken and then (electronically) glued together, producing a kind of scan. The numbers denote the first and the last picture ID number for the Nital and the Oberhoffer etch.

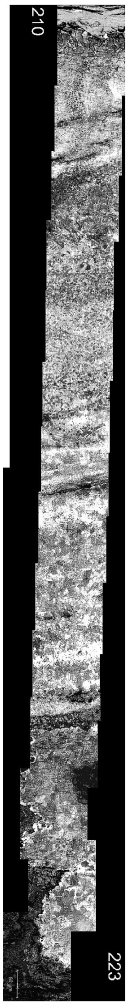


The areas scanned by optical microscopy.

Head Scans

Let's start with the Nital scan through the *left head*; number 1 - 14 for the Nital etch; No. 210 - 233 for the Oberhoffer etch.. Below are small (!) scale pictures of the total scans after Nital and Oberhoffer etching. Some full scale pictures of scans can be accessed via links to the large picture files given in the margins.

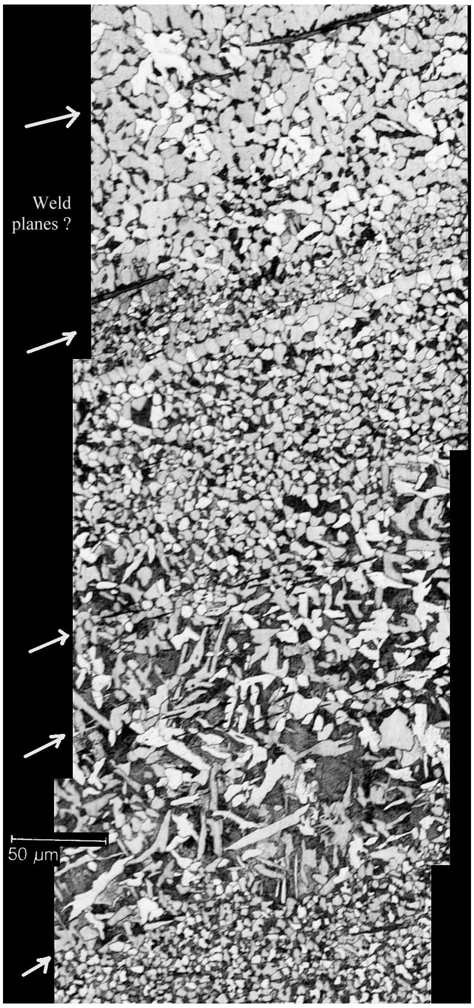
Scan through the animal part of the left head. Nital etch. The full size picture (x 5) can be found din this link.



Scan through the animal part of the left head. Oberhoffer etch.
No large scale picture

A first few obvious observations are:

1. The Nital etch reveals areas with rather different structures (like grain size) that have rather sharp boundaries.
2. The elongated slag (?) inclusions are often close to suspected welding boundaries but not directly on it (see below).
3. Details of grains (see below) make certain that the carbon content varies quite a bit and that (possibly) precipitates of something else are present.
4. The length : width ratio of large elongated slag inclusions is at least 10 : 1. This strongly hints at considerable "drawing out" by forging, producing, e.g., a (100 x 10 x 1) mm^3 sheet from a cube with 10 mm linear dimension
5. The Oberhoffrer etch shows rich structures hinting at the presence of phosphorous (and possibly other impurities) in varying concentrations.
6. The "macroscopic" contrast variation of the Oberhoffer etch picture is compatible with the macroscopic striations.
   A clear interpretation. however, is not possible at present.



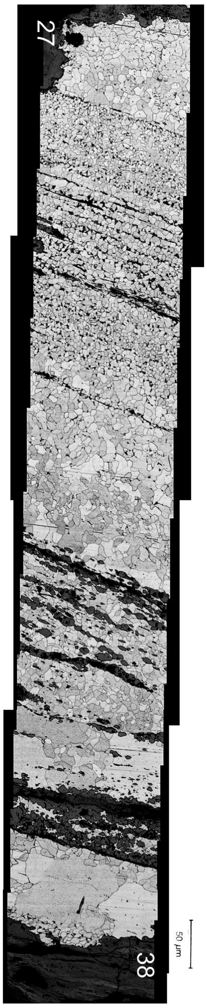
Upper part of the scan through the animal part of the left head. Possible welding planes (more or less perpendicular to the screen) are indicated.
Note the sharp but featureless transitions between regions of different grain size and structure, and the presence of elongated slag inclusions nearby in some cases.

- A first conclusion is possible:

The material of the head consists of a layered structure.
The various layers have different properties / compositions

- In other words: The first tentative conclusions based on the macroscopic appearance of the cut, are fully supported by the microscopic study of one of the "heads". It remains to be seen if the other scans bear out this finding.

- Here are the two "Nital" scans from the second head (right-hand side). I omit the Oberhoffer scan since it does not lent itself to easy interpretation once more.



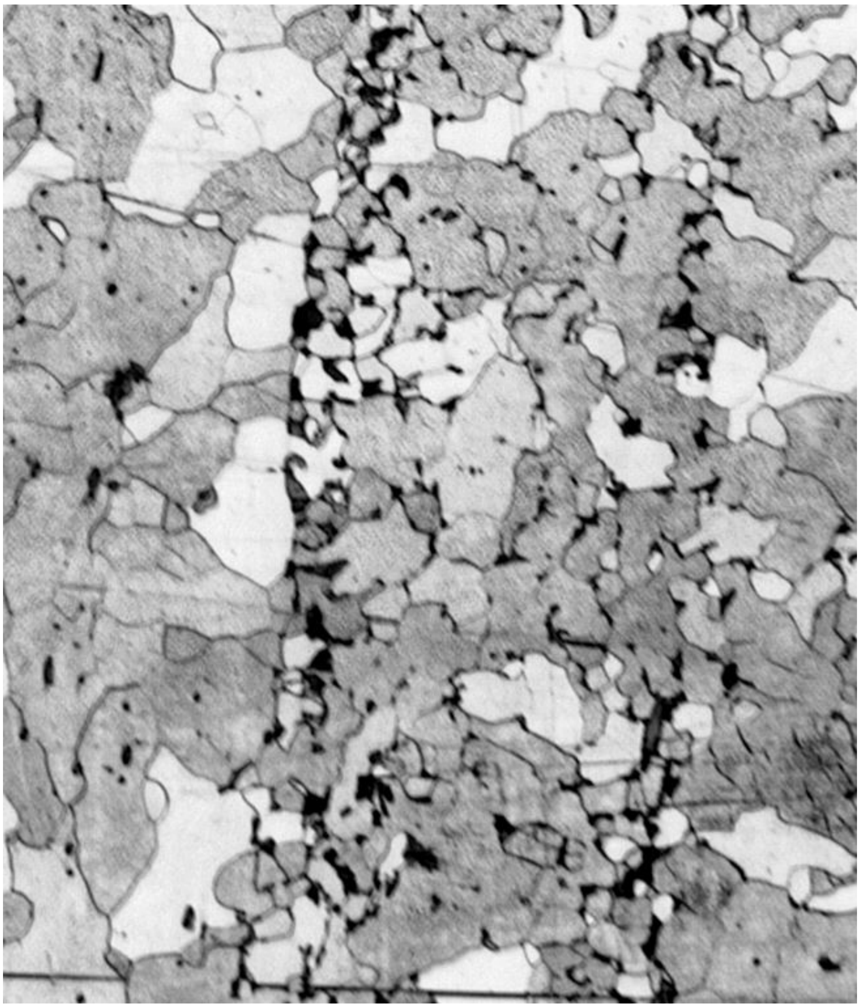
Left: Main scan through right head.
Top: Scan through the "beard" region of right head.
Note the difference in scale.

Everything stated before applies here just as well. The sharp transitions between regions of different grain structures are evident and so are the elongated slag inclusions running parallel to the transition regions. It is also evident that the material consists mostly of iron with a low carbon concentration.
That is, however, not typical for other parts of the sword as we shall see.

Large scan version

It is hard to conceive how these structures could have been produced without fire-welding some layers together.
But shouldn't one expect in this case that the elongated slag inclusion should sit right in the weld boundary?
The answer is two-pronged

- **Yes** - you would expect elongated (slag) inclusion if you stretch your material after fire-welding (e.g while *faggoting* ; shown here).
  Fold over, introducing some (oxide) particles into the welding plane. Stretch and thus elongate the particles, then fold over (introducing new particles), then stretch again (elongating some more), etc. In the finished stacked you find elongated inclusions right in the boundary.
- **No** - you would not expect elongated (slag) inclusions in the weld boundary if you first
  draw out sheets from pieces of the bloom, thereby elongating the slag inclusions contained in the bloom, and then
  fire-weld a stack of those sheets. You would then find elongated lag inclusions somewhere in the welded structure
  and weld seams containing at best small particles that are not elongated. If the smith cleaned the sheets before welding and knew what he was doing, you might find rather perfect welding planes in a material otherwise full of (elongated) large slag inclusions.
  Something like this:



Magnified section of the right head picture from above (turned 90^0).
The black shapes are probably particles introduced during weldning. Some of them might also be pearlite "nests", however.

All things considered, we might safely assume that the old Luristan smiths worked with rather imperfect blooms, containing
quantities of slag and other non-iron objects. They forged thin plates out of the stuff and fire-welded them to the best of their ability.
They may not yet have discovered the art of purifying the bloom parts and thus could not rid the material of the larger slag inclusions.
Alternatively, maybe they didn't care because some "dirty" sheets didn't matter much if you payed attention to what you were doing otherwise. I'll get to that.

In order not to overload this module, I will continue in two separate modules. Here are the links

Part 2 Pommel and hilt
Part 3 Animals and blade
Part 4 Discussion of the results
Large Pictures

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[1] As is customary for scientific papers, the "we" actually refers to the one person (grad student to post-doc) who actually did the real work. Grinding and polishing the specimen by hand for many, many, hours, taking hundreds of pictures with some microscope, editing the pictures, and so on. These students love their work, we assume, basking in the reflected glory of their professors.
Here the unsung hero was Ingo Petri who did the skilled and extensive metallurgical work in this project.