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Edited by:

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SHEET METAL WORKING IN THE BRONZE AGE AND IRON AGE IN SOUTHERN CENTRAL EUROPE

J. Fries-Knoblach
Institute of Prehistory, University Erlangen-Nuremberg, Germany

Abstract

The aim of this paper is to demonstrate the diversity of pre- and protohistoric techniques of sheet metal working and to illustrate the high craftsmanship of the metallurgists by means of selected examples. Surviving tools and products with traces of the working process form the only sources of information, because no written evidence exists from the region and period under investigation (13th to 1st cent. B. C.).

Keywords: prehistory, archaeology, sheet metal working, sheet metal decoration

1 Origins of sheet metal working

While sheet metal objects were used in the Near East in the 8th millennium B. C. [1], they did not exist in Central Europe before the transition from the Middle to the Late Neolithic in the 2nd half of the 5th millennium. The first specimens from southern Germany are an ear ring, a finger ring, and a disc of copper sheet metal [2; 3; 4; 5]. With the Bronze Age (2300-1300 B. C.), evidence became more frequent, but only from the Late Bronze Age (13th cent. B. C.) onwards did sheet metal working flourish. New products continued to come forth until the end of the continental Celtic culture (1st cent. B. C.). Different raw materials and semi-products were used in sheet metal working. At first, only the ductile metals copper, bronze and gold were common. The smelting and working of iron were introduced from the East around 1000 B. C. Silver remained rare, because, though easy to work, it was difficult to extract, and became popular only in the Latène period (4th to 1st cent. B. C.) of the Alps. Castings and slugs served as semi-products for sheet metal which was hammered and never rolled [6], because metal rollers were only invented in the 15th cent. A. D. [7]. The product was finished by shaping and decorating the raw sheet metal.

2 Working techniques

The modern methods of sheet metal working (such as forming, cutting, changing of material characteristics, coating, and joining) find only partly their equivalents in the pre- and protohistoric techniques, because the ancient smiths had only a limited repertory of methods and tools at their disposal. The tools (**fig. 1**) included different hammers, tongs, chisels, punches, rasps,

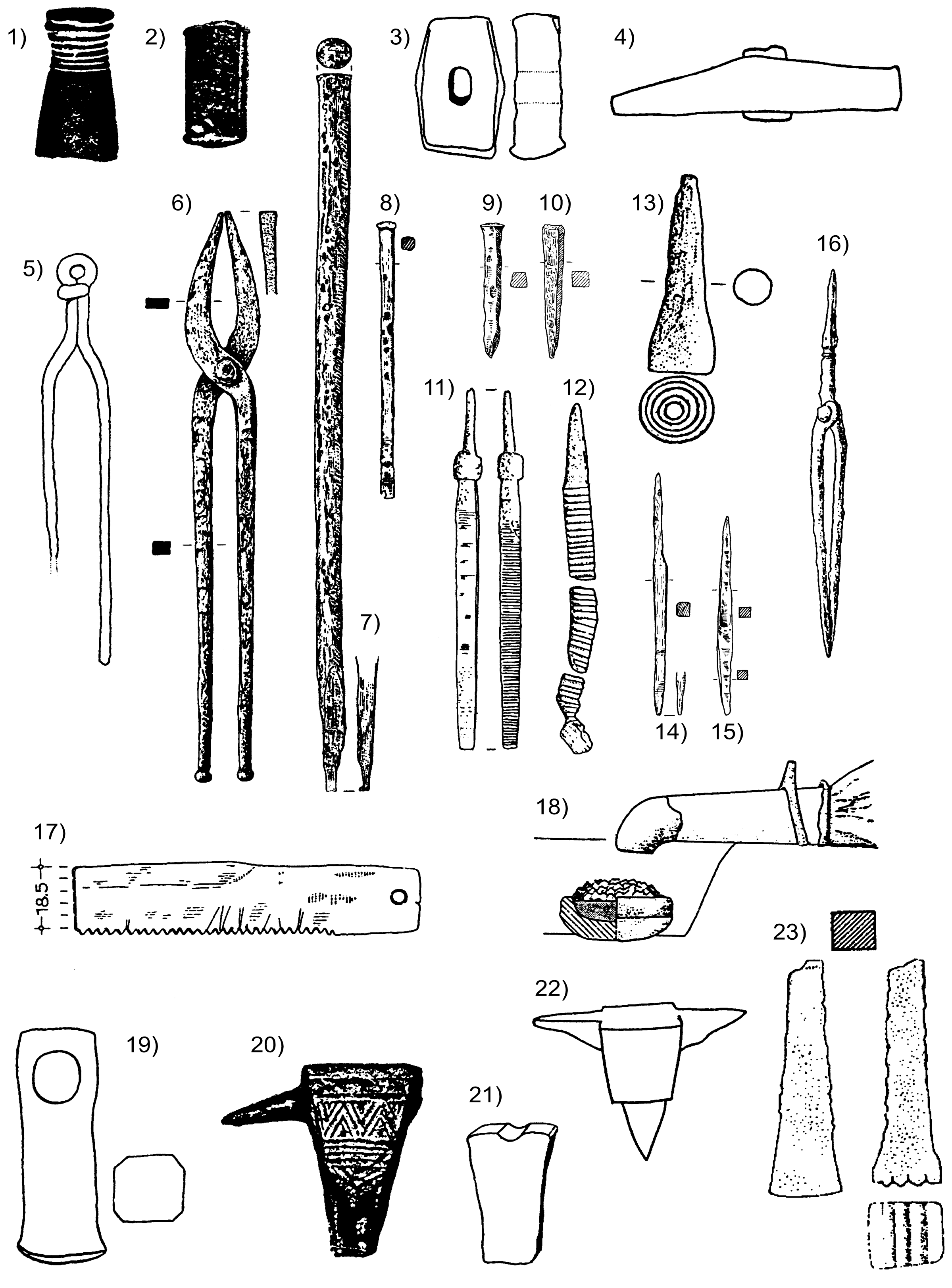

Fig. 1: *Tools for metal working: 1-4 Hammers, 5-6 tongs, 7-8 chisels, 9-10 punches, 11-12 files, 13 stamp, 14-15 engraver´s tools, 16 compasses, 17 saw with calibrations, 18 bellows, 19 small ram, 20-23 anvils with and without dies. 1, 2, 17, 20 Bronze Age, others Iron Age [8; 10; 12-14; 16-18; 20; 43]*

files, stamps, engraver´s tools, compasses, measuring instruments, bellows, and anvils that sometimes contained dies [8; 9; 10; 11; 12; 13; 14; 15; 16; 17; 18; 19; 20]. The character of the work-shops and the high esteem for the smiths and metal workers can be deduced from well preserved excavation evidence and from rich graves [21; 22; 23]. According to Homer, Hephaistos, the Greek god of forging, even stored his tools in a box made of silver (Iliad 18, 410).

2.1 Forming

Of the diverse methods for sheet metal forming, the Bronze Age and Iron Age craftsmen only knew the techniques of compressive forming (free forming, die forming, punching), combined tensile and compressive forming (spinning), bending (free bending) and shear forming (torsion).

Free forming of objects was generally embossing of sheet metal. From surviving hammer marks the working from both inside and outside can be discerned. The most elaborate products are so-called “sheet gold cones“ (**fig. 2**), ceremonial hats of the late 2nd and early 1st millennium B. C. For their fabrication ca. 300 g of gold were hammered down to hollow cones up to 90 cm high and 0.08-0.25 mm thin, by first using the peen and then the convex side of the hammer [24; 25; 26]. Important requirements for this prosperity of sheet metal working were the socketed bronze hammers and anvils created late in the Middle Bronze Age (14th cent. B. C.) [27].

Sheet metal covers for wheel hubs, rims, and spokes of the Hallstatt period (7th to 5th cent. B. C.) were just as elaborately embossed with seamless sheet metal. The spoke covers were ca. 30 cm long and 4.3 cm wide, but only 0.15 mm thin. They are likely to have been produced from a sheet metal ring embossed to form a tube. Finally, the sheet metal sleeve was hammered into the turned ribs of the wooden spoke and perhaps finished by spinning on the lathe [28].

Bronze Age and Iron Age bronze vessels were mainly produced by embossing from inside and outside, as can be told from a central starting mark and the impacts of the hammer. Recurring patterns of concentric, radial, diagonal or crossed impacts of a rounded or elongated shape allow the reconstruction of a standardized production technique for each type of metal vessel. Variations of thickness at different parts of the vessel allow fur-

Fig. 2: *Bronze Age sheet gold cone [24]*

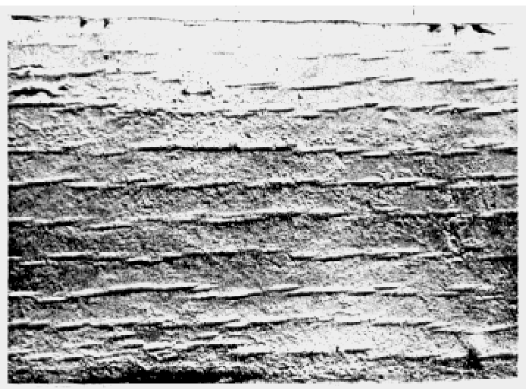

Fig. 3: *Scabbard of the Latène period with hammer impacts [38]*

ther conclusions [29; 30; 31; 32; 33; 34; 35; 36]. Working fissures were mended by clamps and hammering and indicate how easy it was to make a mistake [37]. Usually, however, a very uniform quality was produced as can be seen from sword scabbards of sheet bronze from the Latène period on which hammer impacts some 5 mm in width (**fig. 3**) are smoothly set beside each other [38].

Die forming of sheet metal was a much rarer process. This can be seen from the small number of anvils with dies since the Bronze Age [13; 14; 16; 39]. However, the method was common in particular for the mass production of small items. For example, small bronze bosses were produced in large numbers during the Hallstatt period by hammering a beaded wire flat into sheet bronze and subsequently punching it into a die to raise a small boss [7; 40].

A special kind of die forming was the method applied for the production of corrugations by which large sheet bronze vessels (so-called "ribbed cists" and "canteens") or round bronze shields of nearly one metre in diameter were strengthened. In the case of the canteens, a special device can be reconstructed by which the evenly spaced concentric corrugations were pressed in a lathe-turned wooden die. Ribbed cists were first rivetted to form a hollow cylinder and then hammered into a lathe-turned wooden matrix from the inside [29; 33; 41; 42; 43; 44; 45].

As to the perforation of sheet metal, the methods of piercing, **punching** and hollow-punching can be discerned. While punching and hollow-punching were mainly used for ornamental purposes, piercing with a pointed punch was the most common method for the production of small holes in metal sieves up to 20 cm in diameter of the earlier Urnfield period (13th to 11th cent. B. C.) [36]. Rivet holes were usually made in this way, too.

The working method of **spinning** for the production of axial symmetric hollow bodies requires the lathe, which was taken over from Mediterranean regions during the Hallstatt period. The first products were jewellery such as ear rings and barrel arm rings. These are surrounded by grooves of such precision and parallelism that only spinning with a multi-toothed tool on the lathe can explain their production. To achieve this, the embossed sheet metal cylinder was filled with pitch or a similar substance and fixed to the lathe (**fig. 4**) [41; 46; 47; 48].

The bending of sheet metal was used for forming, particularly for struts. It was usually done as **free bending** by hammering on the anvil. Marked bends in the profiles of bronze vessels, so-called "carinations", were made by widening and shrinking and served as a special form of corrugations. They act as a strut of the vessel rim and lower the risk of battering and crushing of the container during use [36]. When "hemming in" a fragile sheet metal rim, it was

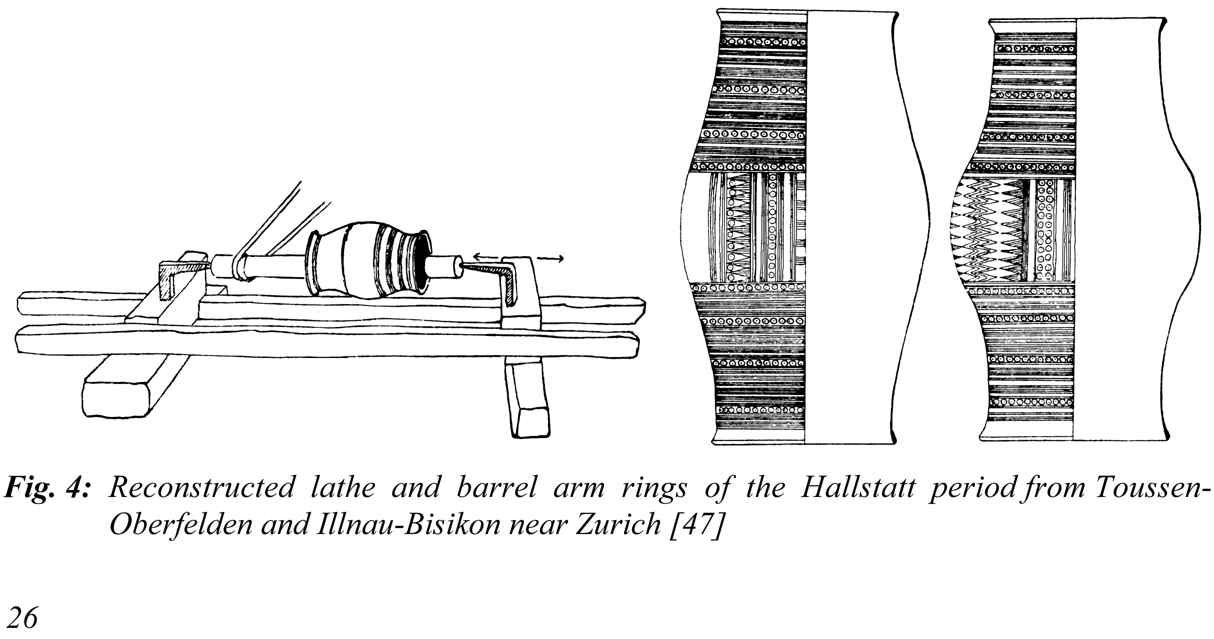

Fig. 4: *Reconstructed lathe and barrel arm rings of the Hallstatt period from Toussen-Oberfelden and Illnau-Bisikon near Zurich [47]*

stabilized by bending in a warm or cold state around an inlay ring of bronze, lead, copper, iron or wood. Examples for this are the edges of sheet gold cones, bronze vessels and round shields [24; 25; 29; 30; 44]. The many different types of metal rivets made of sheet metal and used for the production of larger bronze vessels are models of an almost miniature art of bending [49].

The only method of shear forming was the principle of **torsion**. This was used for jewellery, e. g. twisted rings (“Wendelringe“), for which a thick bronze wire was forged into multi-lobed sheet metal and twisted in only one or section-wise in two directions [50].

2.2 Cutting

For external cuts, apart from tearing or breaking, only the technique of wedge cutting with a knife or chisel was available. With the chisel, cuts, reductions, slits, and ledges were produced [10]. Internal cuts were made with chisel and file or sometimes with drills [9; 28; 51; 52]. Whether the surviving bronze and iron saws were applicable to metal is a matter of debate [e. g. pro: 22; contra: 8]. Shears existed since the Latène period and some sheet metal parts of the time display shear cuts, however, regular plate-shears were not known before the Roman period [53].

2.3 Changing of material characteristics

In prehistory, changing the material characteristics of sheet metal was usually done mechanically or thermally. Bronze and gold were hardened by cold hammering and softened by annealing and quenching in water. For iron, however, both quenching and tempering meant hardening. The latter results in a bluish surface already known to Homer (e. g. Iliad 11, 24 and 35; 18, 564; 23, 850). Iron is also hardened through the enrichment of the surface with phosphate or tempering with carbon to form steel [23; 53]. The only chemical methods in use were browning or blackening of iron by dipping it into warm oxidizing liquids during the Latène period. However, they were applied only to make existing ornaments more conspicuous [54].

2.4 Coating

The coating of items was common in both the Bronze and Iron Age, but only for the purpose of decoration which will be discussed below.

2.5 Joining

Sheet metal joints were often required in prehistory, because the production by mere manual power from castings of some 60 to 90 cm in diameter and slugs posed narrow limits to the achievable sizes of sheet metal [28; 53]. Different methods were available for this: form-joints by folding or rivetting or material fusions by soldering, compound-casting and welding. The production of Iron Age bronze buckets, the so-called “situlae“, was based on regular section patterns for the sides, bottom and bottom ring [28]. The plates were folded into each other, pierced and fixed with rivets so that containers up to one metre high were produced [29; 36].

With regard to soldering, mainly hard soldering of iron with copper or bronze was important in the Iron Age. It can be found both on objects of the Hallstatt period such as brooches, projectile points with an inserted iron mandrel, sticks with spines, dagger hilts, and of the Latène culture such as fittings for swords with a tuber shaped pommel and horse gear [39;

46; 55; 56]. The hard soldering of sheet gold with a low-melting gold alloy is known of since the Hallstatt period, too [53; 56]. Soft soldering with lead or tin was unknown, perhaps because of its low resistance to stress, although both metals were used in their pure form for the decoration of pottery and metal [57; 58]. As solders they only became common in the Roman period when they were used on table-plate and water fittings [39].

A special type of hard soldering is the technique of compound-casting which was also applied to sheet metal. One of the best examples for this are the Celtic beaked flagons of bronze, of which the piece from grave 112 at the Dürrnberg mountain near Hallein has been investigated in detail (**fig. 5**). The flagon body was embossed of sheet bronze and connected by an infusion of liquid bronze to a beak with cover plate pre-fabricated in "cire-perdu" technique [35; 59; 60].

As to welding, a discrepancy of terminology between the modern definition and the traditional usage exists. In prehistory and in traditional craftsmanship the term "welding" means the joining of white-hot metals. This technique was found in the Iron Age quite naturally when smaller iron slugs were joined to workable size. At latest since the 2nd century B. C. the welding of thin sheet iron laminae was applied as a predecessor of the damascene technique [possibly earlier: 56]. In this process, a hard yet flexible compound-material was created by alternating layers of hard, brittle steel and soft, tough wrought iron. Although the prehistoric damask cannot keep up with Medieval, Oriental or Japanese blades of several hundred or thousand layers, it still possesses the characteristics which determine it for weapon blades [38; 54; 61].

2.6 Subsequent treatments

The final step in prehistoric sheet metal working nearly always was the delicate finishing of the surface by filing, smoothing and polishing which gave a metallic lustre to the object. This becomes quite clear from the Iliad, where chapter 13, 340 tells us: "blinding to the eye shone the bronze lustre of sun-reflecting helmets, newly polished armours and large sparkling shields". Finds attest that these weapons consisted of sheet metal fixed to cores of leather or wood. It is possible to discern a coarse, technically necessary smoothing perhaps with rasps, files or stones and fine, sometimes even ornamental final polishes [37], which were carried out by means of sand, chalk, clay, pumice or agate according to the hardness of the material [53].

3 Decorative techniques

When the forming process was completed, the sheet metal surface could be decorated in widely different techniques [62]. Three main categories must be distinguished, namely techniques bringing about a loss, a displacement or an application of material.

3.1 Decoration by removal of material

The coarsest procedure of this type are patterns created by a chisel and/or file. Nevertheless, even on brittle material such as sheet iron remarkable results were achieved as can be seen from the filed fittings of the wagon from Hochdorf of the Hallstatt period [63]. The techniques of engraving and quavery engraving with an engraver´s tool or quavering iron served the purpose of creating fine linear patterns. Engraving was applied e. g. on bronze mirrors of the Hallstatt

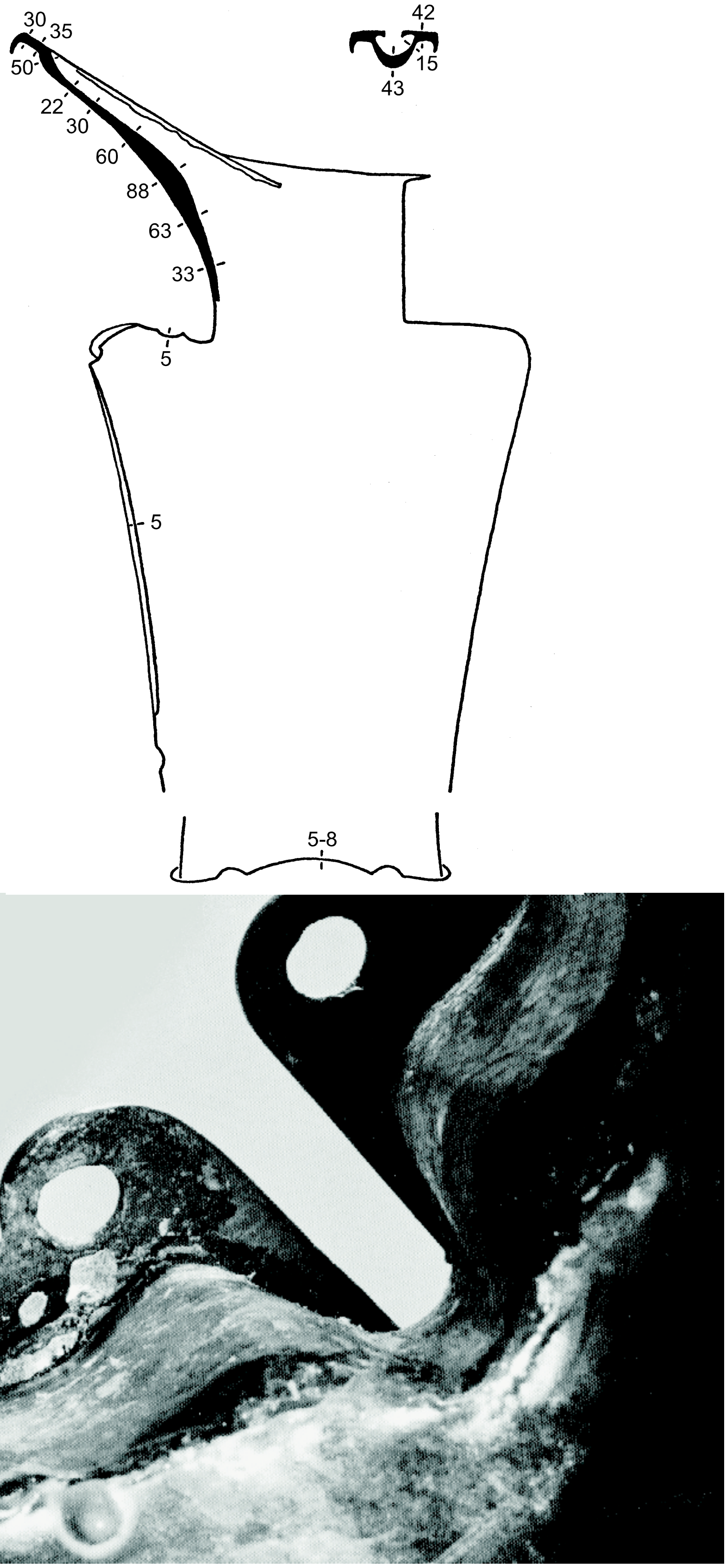

Fig. 5: *The Celtic beaked flagon from Dürrnberg. Thickness in tenths of mm and beak with cover plate fixed by liquid bronze [35, 59]*

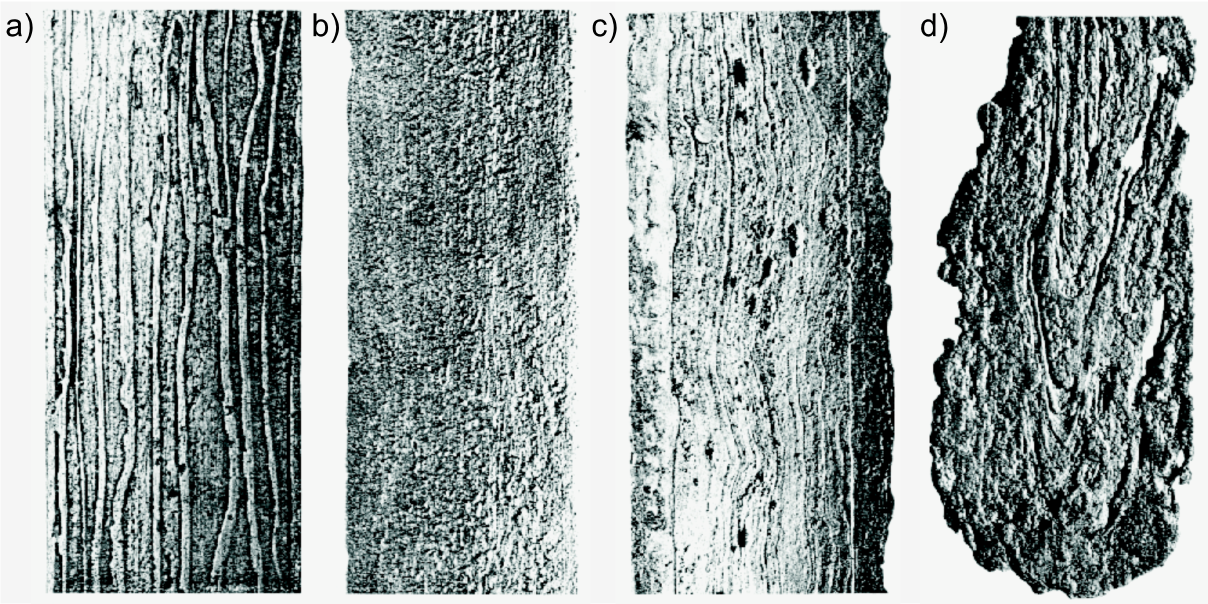

Fig. 6: *Etched Latène sword blades: a-b linear and beaded patterns, c-d damask blades [38]*

period [64]. Quavery engraving is a process in which a narrow engraver´s tool is pressed into the metal alternately with the left and right edge and at the same time turned forward. It was used for example to create the wavy patterns of belt plates of the Hallstatt period [40].

The technique of etching with fruit acids and acetic acid perhaps with additional salt was capable of creating extensive patterns. For this purpose some areas were covered with wax, pitch or fat and thus protected from the corrosive force. On the one hand linear and beaded patterns on sword scabbards of the Latène period were created [54]. On the other hand the components of angular, zig-zag or wavy damask blades (**fig. 6**) were made visible by their different colours on the surface and served as a quality mark at the same time [38].

Sheet metal perforation work, the so-called *opus interasile*, had been current on wagon fittings, horse gear, dagger and belt plates since the Hallstatt period [40]. At the beginning, linear geometric patterns on sheet bronze prevailed, because they were well adapted to the fabrication with a chisel. In the Latène period they were superseded by elaborately swung patterns on belt plates, sword scabbards and wagon fittings of sheet metal that were made by chisel and file of sheet bronze, but also of brittle sheet iron [65; 66].

3.2 Decoration by displacement of material

The technique of punching occurs as plain punching and hollow-punching with punches. These stamp-like tools with differently shaped and hardened points existed as chisel-shaped punches, beaded punches and punches with figural motives. They could be used to produce single, linear or extensive ornaments [40; 43; 62; 67]. If chisel-shaped and beaded punches are applied in a linear way the technique is called chased work, while an extensive use of a beaded punch is called “dotting“. The bronze tools of the Bronze Age were quickly worn out during work, as can be seen from surviving vessels with deteriorating marks, while in the later Urnfield period (10^{th} to 9^{th} cent. B. C.) no wearing can be observed even after many hundred impacts. This makes it likely that punches of steel were available at this time [67; 68]. The application was made by a stroke with an hammer either from the front or from the reverse side (repoussé technique). The

Fig. 7: *Early Latène sword scabbard with iron filigree and red coral inlays from Manching-Steinbichel, grave 26 [70]*

sheet gold cones mentioned before were made by negative punches from the outside as can be seen from significant intersections of punch marks. Elaborate sketches and divisions were necessary on the piece to ensure an even spacing of the punch marks all around the cone [25]. On the bronze situlae decorated with figures, on the contrary, the noses, cheeks, chins and mouths of people as well as the hooves and joints of animals were added to the embossed bodies by means of positive punches from the inside [64]. The same is true for the production of stamped sheet gold covers for brooches of the Latène period, which were embossed in moulds from the reverse side („Preßblechtechnik“) [69].

A special type of punching is the technique of chagrinage (French “chagrin“ = grained leather). It was used for sword scabbards of the Latène period on which extensive patterns of impacts by chisel-shaped, beaded or figural punches were applied from the front [38; 54].

3.3 Decoration by application of material

As to the ornamental application of material, two major types can be recognized, namely plastic decoration such as granulation or filigree and colour ornaments such as linear and extensive metal inlays, gilding, enamel and application of non-metals.

Granulation means the adding of tiny gold spheres, the so-called “granaliae“, by means of soldering, a technique introduced from Etruria into the Celtic world. The granaliae were either glued to the sheet metal by rubber, resin or glue containing a flux (e. g. potash) and a solder and then heated or soldered by reaction soldering with copper salts like malachite or verdigris, a technique which was easier to dose and to control [23]. Filigree work in which wire is fixed to sheet metal can be found e. g. on sword scabbards. A master piece comes from a grave of the early Latène period at Manching (**fig. 7**). Here, a plastic network of thin iron wire was rivetted to the scabbard plate by tiny iron pins and additionally decorated with inlays of red coral [70].

A frequent colour ornament were metal inlays of a different colour in pre-fabricated hollows in the metal plate. Bronze Age examples consist of gold in sheet copper [23; 71]. In the Hallstatt period, bronze in sheet iron was the most frequent combination. The application was only rarely done by hammering or glueing of bronze into a notch engraved and undercut with the engraver´s tool [72]. Normally, it was achieved thermally by melting the metal down into an engraved or filed hollow. For this purpose, the object was totally coated with liquid bronze which was then rubbed off with emery or sand so that the bronze was preserved only in the decorative notches and at inaccessible parts. The emerging strokes, fish-bone, circle, dog´s tooth, wicker-work and complex ornaments embellished e. g. scabbard plates, hilt tubes of daggers, belt plates and wagon fittings [56; 72]. Presently, research on tin coating of the Hallstatt period on a grand scale is going on in Tübingen. A special type of metal inlay is the application of plastic diagonal sheet iron threads on iron sword blades of the Latène period [38].

Since the technique of hot-gilding with quicksilver was not universally known, larger applications or complete coatings of precious metals were usually made by glueing onto or inlays into sheet bronze or iron. These could be further elaborated with regard to colours by rivetted inlays or applications of amber, coral or glass [23; 62; 69; 73]. Glass was familiar to the Celts from their own glass production and working and was used for enamel from the 4th cent. B. C. onwards. Usually the enamel melted around 900° C and had a bright red colour which is the reason for its being called "blood enamel" by archaeologists. This imitated the expensive red coral popular since the Hallstatt period. Blue and yellow enamel existed, too, but were very rare. The common technique was that of champlevé (i. e. enamel melted into a hollow in the metal plate), while the cloisonné technique (i. e. enamel melted into metal compartments on top of the metal plate) was only invented in late Antiquity [62; 74; 75].

4 Summary

This overview was intended to demonstrate that sheet metal working boomed in southern central Europe in the 1st millennium B. C. Many of the methods still current today were first applied and accomplished then. Their use in the forming and decorating of items touched upon most aspects of everyday life, such as apparel, jewellery, toiletries, dishes, horse and wagon gear, weapons, and probably religion. Often, extremely delicate and tedious work was carried out, which indicates that, in prehistory, working hours were not an important factor in the production process. It is for a good reason that some of the techniques such as quavery engraving, granulation or damascening are almost extinct today and are only mastered by very few specialists. Also, it becomes clear that craftsmanship in prehistory was nearly always synonymous with arts and crafts. The aesthetic value of an object was given as much esteem as its practical functioning. Accordingly, the status of the artistic craftsman was as high as the value of and the respect for his products which were often repaired to the very decay. On the one hand, the art of metal working was exemplary for other crafts, e. g. when precious metal vessels were imitated in wood or pottery and metal jewellery in stone or glass. On the other hand, the technique of metal working received inspirations from fields such as leather working, e. g. for the methods of chagrinage and *opus interasile*, or pottery for punching, inlays, polishing, etc. Therefore, metal working has always been in the focus of a long tradition of intensive exchange with other fields of daily life and manufacturing. This is a characteristic that has been retained to the present day.

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