A METALLURGICAL EXAMINATION OF TWO EARLY IRON SWORDS FROM LURISTAN

VERA BIRD and HENRY HODGES

Abstract—Two iron swords from Luristan were examined by X-rays and using metallographic sections. The first sword was shown to have a hilt made of five pieces of metal joined by four rivets, while the pommel was secured by a dowel on the end of the tang. Hilt and blade were sectioned for metallographic study. This showed that while the core of each part was pearlite, decarburization had taken place at the surfaces to give ferritic structures. The second sword was shown to have been made of seven pieces. The pommel was secured as in the first sword, but all other pieces were joined by fitting into prepared slots, the edges of which were burred. A section was cut from the hilt at a point where a decorative band had been applied. This showed large-grained ferrite at the surface and fine-grained ferrite with cementite at the boundaries in the core. It is argued that work previously carried out by other metallographers was inconsistent due to inadequate sampling, and that swords of this type were essentially of wrought iron, the presence of pearlite being accidental rather than intentional.

The two swords to be described were acquired through dealers and are without precise provenance. However, both are typical of weapons from the Zagros mountains of Luristan currently dated between the twelfth and seventh centuries B.C. Many swords of this type have been found, one author estimating their number as 'hundreds', but none so far have come from any clear archaeological context.* Their precise dating thus remains a matter of considerable conjecture, although most authors would agree that they are amongst the earliest iron weapons to be produced *in quantity* in the general context of the Near East. This type of sword has already evoked a considerable number of radiographic and metallographic studies [1–6]. Seven† such examinations are known to the authors: it might, in fact, seem that the present study is superfluous. Even so, the position of our knowledge, here presented as a summary table, shows certain discrepancies.

	Date	*Owner*	*Analyst*		*Findings*
1	1938	Tehran Museum	—	[2]	Ferrite with slag inclusions (i.e. wrought iron)
2	1957	Hamburg Museum	Naumann	[4]	Wrought steel
3	1961	British Museum	Organ	[3]	Steel
4	1961	Toronto Museum	Ellis	[3]	Steel
5	1961	Brussels Museum	Sneyers	[3]	Heterogeneous carburized iron (i.e. steel)
6	1962	Private	Salin	[1]	Steel
7	1964	Private	Silkiss	[6]	Wrought iron

* The chronology of these weapons, and their archaeological context has been recently reviewed by K. R. MAXWELL-HYSLOP, and H. W. M. HODGES, in *Iraq*, 28 (1966), 164–178.

† Since this paper was prepared for publication C. S. SMITH has published a brief description of work done on Luristan iron objects in: *Application of Science in Examination of Works of Art*, Museum of Fine Arts, Boston 1967, pp. 42–43, particularly an iron axe, in which case only a small sample was taken from the cutting edge.

Thus, five analysts found the weapons they were examining to be of steel, although two circumlocations are worth comment. Naumann [4] uses the phrase 'wrought steel': Sneyers [3] goes even further and speaks of 'heterogeneous carburized iron'. The aim of both writers is, presumably, to ensure that the reader is aware that there is no intention to infer the use in antiquity of the homogeneous type of steel obtained by the indirect process of manufacture, in which the metal is obtained by removing some carbon (decarburizing) from cast iron, a process commonly referred to as fining.*

FIG. 1

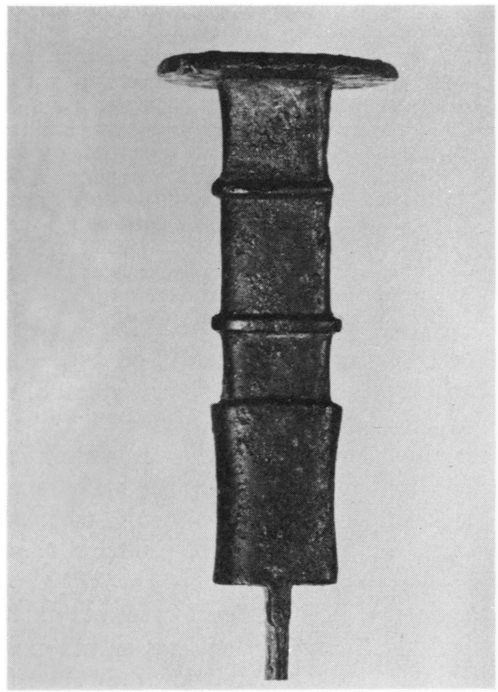

FIG. 2

FIG. 1 Sword no. 2 with section removed for metallographic examination.

FIG. 2 Sword no. 1 as received.

The use of the word 'steel' by these authors implies that during metallographic examination they found the swords to contain grains of pearlite, that is to say, grains composed of alternating very fine lamellae of iron and iron carbide. The metal is thus an alloy of iron and carbon. Two analysts found only a ferrite structure (i.e. grains of more or less pure iron) with some slag inclusions in the swords being examined, and reported them, therefore, as being of 'wrought iron'.

* The reader who is unfamiliar with the metallurgical terminology used in this article is referred to such textbooks as R. S. Williams and V. O. Homerberg, *Principles of Metallography*, McGraw-Hill Book Company Inc., New York 1948, W. Hume-Rothery and G. V. Raynor, *The Structure of Metals and Alloys*, The Institute of Metals, London 1962, or R. H. Greaves and H. Wrighton, *Practical Microscopic Metallography*, Chapman & Hall, Ltd., London 1960. An introduction to the metallurgy of iron by C. S. Smith is to be found in *Made of Iron*, Catalogue of an exhibition, University of St Thomas Art Department, Houston, Texas, pp. 27–40.

It appeared possible either that swords of identical character were being manufactured in the same area by two different processes; or that, while all the swords were in the first place being made of wrought iron, some were left in this condition, while others were submitted to a process of case-hardening, that is, prolonged heating in the presence of carbon, when the wrought iron would absorb sufficient carbon from the forge to convert the ferrite into pearlite, at least at the surface of the weapon.

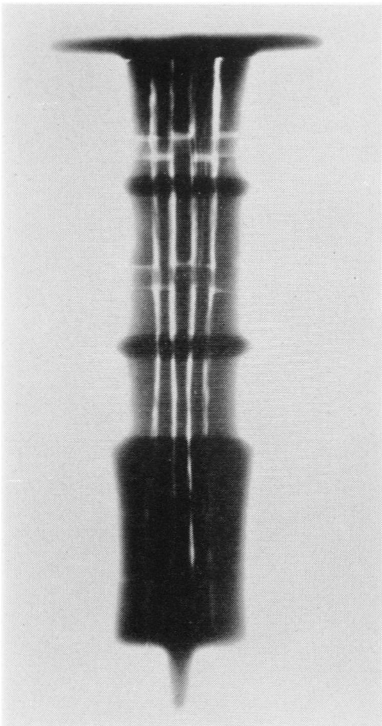

FIG. 3 X-radiograph of sword no. 1.

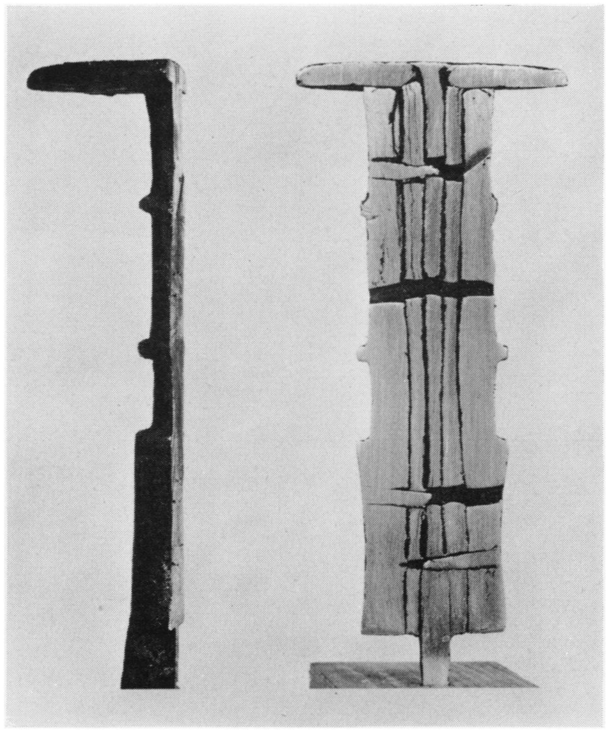

FIG. 4 Sword no. 1 cut for examination.

It is, however, perfectly clear that all the analysts quoted were hampered by the same overriding consideration: a prohibition that did not allow the taking of a sufficiently large sample to determine unequivocally what the true situation was. In some instances it is not even possible to ascertain whence the samples for examination were taken. One analyst (Ellis [3]), however, in a sample taken from the cutting edge of the blade, observed that while the core of his sample contained pearlite, the surface was of more or less pure ferrite.

The method of construction employed in the making of this type of sword has also given rise to a considerable number of reports [1, 3, 4, 6]. The more common type of weapon, of which our sword no. 2 is a typical example (Fig. 1), with two crouching lions forming the guard and two bearded heads set on the circular flat pommel, was generally made of a number of parts. The blade and grip were commonly a single piece of metal, although one case is recorded in which the blade was forged into a fork cut in the distal end of the grip [3]. The flat, circular pommel was attached to the grip by means of a lug on the end of the grip passing through a hole in the centre of the pommel. The two bands around the grip were set into grooves previously made to take them, while the four decorative motifs were set into rectangular slots made at the end of the grip and in the edge of the pommel. In one instance, rivets were used to secure the crouching lions [5].

There appears to have been no previous examination of the methods of construction used in making the plainer type of sword similar to our sword no. 1 (Fig. 2). Before radiographic examination it was anticipated that it would not differ structurally from those

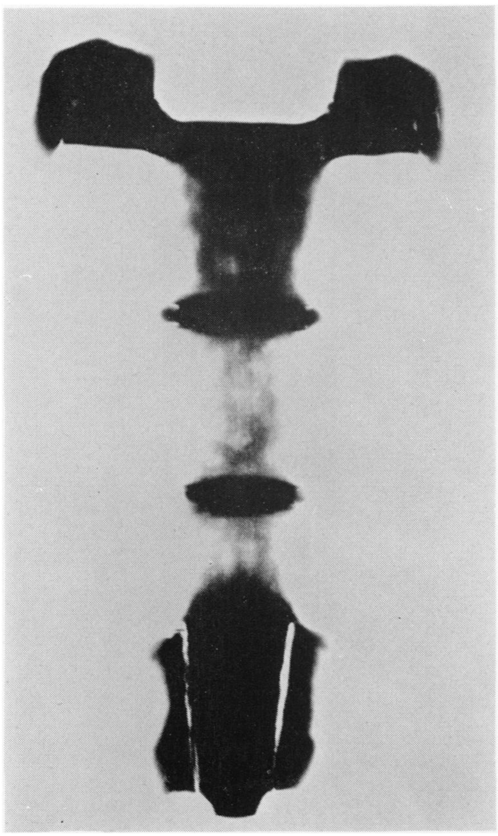

FIG. 5 X-radiograph of sword no. 2.

swords just described, and indeed the X-radiograph was made initially more as a matter of routine than in the hope of learning anything new. In fact, the hilt of sword no. 1 was found to be surprisingly complex and was seen to consist of five sections, held together by four rivets (Fig. 3).

These features observed on the radiograph seemed sufficiently interesting to warrant a more detailed study, and in order to show conclusively the method of fabrication, it was decided to cut the hilt longitudinally (Fig. 4). This showed that the five sections of the hilt had been hammer-welded together and secured in position by four rivets. The centre section was a continuation of the blade (the tang), the end of which had been used as a rivet to hold the pommel in place, a technique common to both types of sword.

The decorative bands were not separate attachments as might have been supposed from the radiograph, but had been fashioned by working the surface of the hilt, in such a manner that the divisions between the separate sections were no longer visible superficially.

The radiograph of sword no. 2 showed that the hilt had been constructed in an identical manner to those just described (Fig. 5). A section was cut from the hilt to show the method by which the bands had been applied to the grip. Unlike the previous sword, these bands were additional attachments, hammer-welded into prepared grooves in the hilt (Fig. 6).

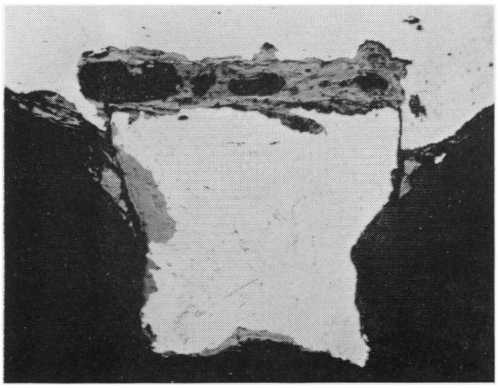

FIG. 6

FIG. 7

FIG. 6 Sword no. 2, decorative band hammered into groove in grip.

FIG. 7 Sword no. 1, section from centre of blade. Etched in boiling sodium picrate. Note hypereutectoid structure. Magnification *c.* 90×

A metallographic examination now followed to determine the microstructure of the metal. A section was cut from the blade of sword no. 1. This section and that cut from the hilt of sword no. 2 were mounted in a clear methacrylate medium. These, as well as the hilt sections of sword no. 1, were prepared for microscopic examination.

A reasonably flat surface was first obtained by grinding on a motor-driven emery belt. Intermediate and fine grinding were then carried out using wet and dry emery paper of progressively finer grades, and water as lubricant. Final polishing on a rotating cloth impregnated with 1 μ diamond paste gave the desired scratch-free surface. 2% nitric acid in alcohol (nital) was used for general etching, and boiling alkaline sodium picrate for confirmation of the presence of iron carbide.

The composition of the metal in sword no. 1 varies from that of a hypereutectoid steel to a wrought iron, both hilt and blade containing elongated slag stringers. The initial carbon content of the metal used for making the sword was probably higher than the eutectoid composition and extensive decarburization took place during the forming process.

The metal of the central core of the sword has the highest carbon content, as seen in the centre of the blade section (Fig. 7) and in the tang component of the hilt (Figs. 8, 9). The latter consists of pearlite with iron carbide at the grain boundaries. The metal at the centre of the blade has a pearlitic structure. It is approximately of eutectoid composition with a carbon content slightly lower than that of the tang. This is probably due to the extensive hot working while forming the blade, which, together with the resulting thinness of section, caused a higher degree of decarburization to occur.

It is not possible to give the actual carbon content of the metal without chemical analysis. The microstructure will depend upon other factors, such as the rate of cooling and the nature and amount of impurities present.

In both the blade and the sections of the hilt (Fig. 10) of sword no. 1, extensive decarburization has taken place. This is clearly seen in the cross-section of the blade (Fig. 11). The centre has a structure of coarse lamellar pearlite in a ferritic (α–Fe) matrix, the highest

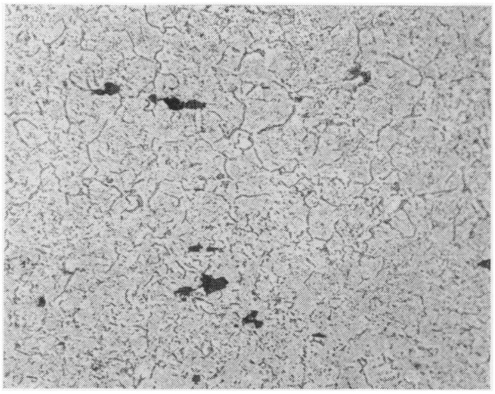

FIG. 8

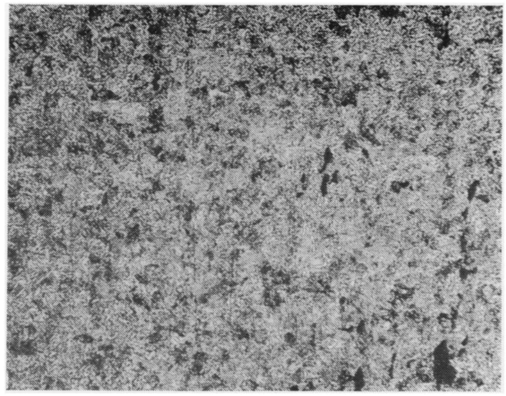

FIG. 9

FIG. 8 Sword no. 1, section from centre of tang. Etched in boiling sodium picrate. Note pearlite grains with partially spheroidized cementite at boundaries. Magnification *c.* 115×
FIG. 9 As fig. 8, but etched in nital.

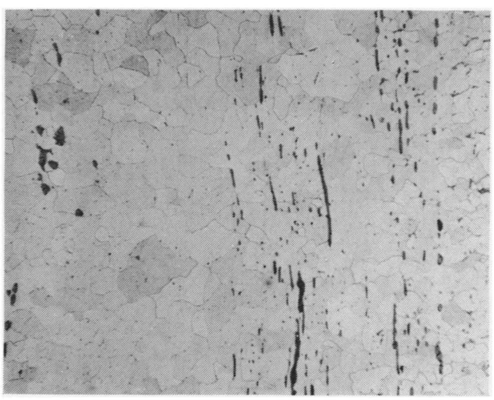

FIG. 10

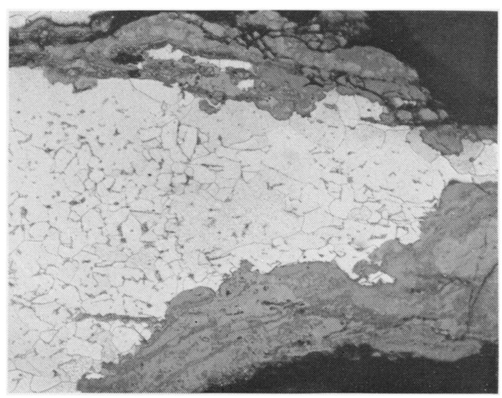

FIG. 12

FIG. 10 Sword no. 1, section from edge of tang. Etched in nital. Note wrought iron structure due to total decarburization. Magnification *c.* 45×.
FIG. 12 Sword no. 1, section of actual cutting edge. Etched in nital. Note almost pure ferrite structure. Magnification *c.* 90×.

carbon content being of approximately eutectoid composition. The surrounding metal has been progressively decarburized, so much that both surfaces and the cutting edge of the blade are almost entirely ferritic (Fig. 12). This is an undesirable structure, since ferrite is soft and ductile compared with pearlite and will not maintain the sharpness necessary for the cutting edge of a sword blade. The deformation and temperature gradients present in the section during fabrication led to grain growth in the ferrite region, resulting in a non-uniform grain size.

The rivets in the hilt of sword no. 1 have a micro-structure typical of wrought iron. They contain elongated slag inclusions and distorted ferrite grains due to hammer-welding (Fig. 13).

A similar metallographic examination of the section cut from the hilt of sword no. 2 showed that the metal was essentially a wrought iron (Fig. 14). The microstructure consisted of large-grained ferrite with a fine-grained core containing globular cementite at the grain boundaries. There were many elongated slag inclusions, especially where the decorative bands were attached to the hilt. These bands had a similar structure to that of the hilt.

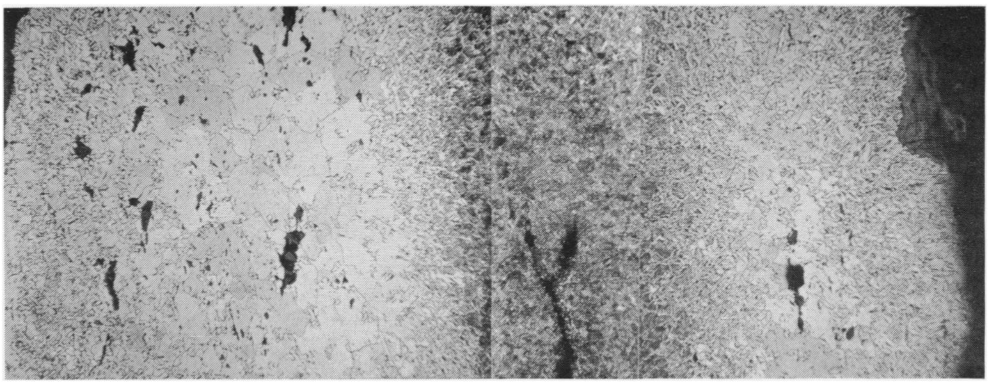

FIG. 11 Sword no. 1, composite photomicrograph through blade from edge to edge. Etched in nital. Note pearlite structure at centre and almost pure ferrite at edges. Magnification *c.* 28 ×.

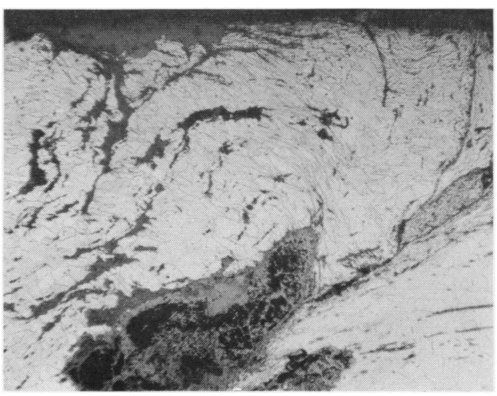

FIG. 13

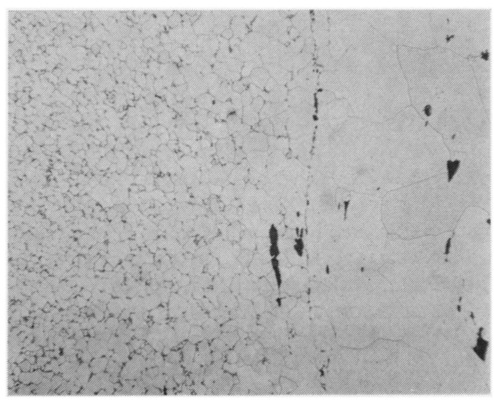

FIG. 14

FIG. 13 Sword no. 1, section through rivet. Etched in nital. Note heavily distorted ferrite grains due to hammering. Magnification *c.* 45 ×.

FIG. 14 Sword no. 2, section through grip. Etched in nital. Note core of fine-grained ferrite with globular carbide at boundaries and large-grained ferrite near surface. Magnification *c.* 45 ×.

When it comes to interpreting the results of these examinations, therefore, the second sword presents no problems: it was made of wrought iron. That it had undergone considerable hot-forging during its final shaping is also clear. It is equally evident that the first sword was not manufactured by the simple process of case-hardening a wrought iron weapon. Indeed, the phenomena observed would seem to allow only two possible interpretations.

On the one hand it could be argued that the second sword was made from a deliberately manufactured steel, and that during working the surfaces had become decarburized. Such a steel could derive either from the fining of pig-iron or from a crucible process akin to that used in the making of wootz. The production of pig-iron at this early date seems highly improbable, but the possibility that the iron bloom was broken up, mixed with charcoal, and reheated in a crucible cannot easily be dismissed, especially as there is an approximately parallel process in copper- and bronze-founding, a craft for which the Luristan smiths are renowned. Blister bronze may well have been broken up, mixed with charcoal, and reheated in a crucible prior to casting, and this process could have suggested a method for the production of crucible steel. This interpretation, although possible, would mean that swords of the same type were being manufactured by two distinct processes, which on purely archaeological grounds seems highly unlikely.

On the other hand these two dissimilar materials may be seen as the result of the lack of controlled conditions in primitive bloomeries. The wrought iron would have resulted from the forging of metal in which the bloom was comparatively free from contamination other than a small quantity of slag. If, however, the initial bloom contained a high proportion of carbon, the reheating required during forging might have resulted in the formation of pearlite. Equally, were reducing conditions maintained for an excessive period after the formation of the bloom during smelting, a pearlite structure might also have been produced, in which case the production of steel may be seen as completely fortuitous.

All the evidence taken together would suggest that the early craftsmen who made these weapons were still far from arriving at any real appreciation of the nature of the raw materials they were using, and the fact that steel was present amongst their products does not mean either that it was formed deliberately or that, having made it, they knew how to use it to advantage.

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VERA BIRD is an Assistant Experimental Officer in the Research Laboratories of the British Museum, where she has worked for the past three and a half years. Before joining the staff of the British Museum she worked for three years at the Central Electricity Research Laboratories. Miss Bird is a Licentiate of the Institute of Metallurgists and devotes all her time to the study of metal antiquities.

Author's address: Research Laboratory, The British Museum, London, W.C.1, Great Britain.

HENRY HODGES is Senior Lecturer in Archaeological Technology at the University of London Institute of Archaeology, where he has worked for the past eleven years. Prior to this he was an Assistant Lecturer at the Queen's University of Belfast. Mr Hodges holds a Postgraduate Diploma in Prehistoric Archaeology and is a Fellow of I.I.C. His published works include *Artifacts* (John Baker, 1963).

Author's address: Institute of Archaeology, University of London, 31–34 Gordon Square, London, W.C.1, Great Britain.

Abstrait—Deux sabres en fer de Luristan ont été examinés aux rayons X et en section métallographique. L'examen a révélé que la poignée du premier sabre se composait de cinq pièces de métal jointes par quatre rivets, tandis que le pommeau était attaché par un goujon au bout de la languette. La poignée et la lame ont été sectionnés pour en permettre l'étude métallographique. Celle-ci a révélé que, si le coeur de chaque partie était en perlite, les surfaces présentaient des structures ferritiques par suite de décarburisation. Le deuxième sabre se composait de sept parties. Le pommeau était attaché de la même façon que celui du premier, mais toutes les autres pièces étaient jointes par raccordement dans des entailles préparées d'avance, dont les bords étaient recourbés. La poignée a fait l'objet d'une section au point où une bande décorative avait été appliquée. Cette section a révélé du ferrite à gros grains à la surface et du ferrite à grains fins avec du cémentite aux alentours du coeur. L'argument a été avancé que le travail exécuté précédemment par d'autres métallographes était inconséquent par suite d'échantillonnages inadéquats et que les sabres de ce type étaient essentiellement en fer forgé, la présence du perlite étant accidentelle plutôt qu'intentionnelle.

Abstrakt—Zwei eiserne Schwerter aus Luristan wurden metallographisch und mit Hilfe von Röntgenstrahlen untersucht. Das erste Schwert hat einen Griff, der aus fünf, durch vier Nieten verbundene, Metallteilen gefertigt ist. Der Knauf ist mit einem Dübel am Ende des Heftzapfens gesichert. Für die metallographische Untersuchung wurden vom Griff und der Klinge Anschliffe hergestellt. Diese zeigen, daβ der Kern beider Teile aus Perlit besteht, während an der Oberfläche durch Entkohlung ein ferritisches Gefüge entstanden ist. Das zweite Schwert ist aus sieben Teilen zusammengesetzt. Der Knauf ist wie beim ersten Schwert gesichert, hingegen sind alle anderen Teile durch Einpassen in vorgefertigte Nuten verbunden. Von einer Stelle, an der ein Zierstreifen angebracht ist, wurde ein Anschliff angefertigt. Dieser zeigt an der Oberfläche grobkörnigen Ferrit und im Kern feinkörnigen Ferrit mit Zementit an den Korngrenzen. Der Verfasser führt Widersprüche zu vorhergegangenen Arbeiten anderer Metallographen auf ungeeignete Probeentnahmen zurück und darauf, daβ Schwerter von diesem Typ im Wesentlichen aus Schmiedeeisen bestehen, in welchem Perlit eher zufällig als beabsichtigt auftritt.

Estratto—Due spade di ferro del Luristano sono state esaminate mediante i raggi X come pure dalla sezione metallografica. La prima spada rivelava un'elsa costituita da cinque pezzi di metallo uniti da quattro chiodi, mentre il pomo era fissato da una cariglia all'estremità del codolo. L'elsa e la lama sono state sezionate per lo studio metallografico. Ciò ha dimostrato che mentre l'interno di ciascuna parte era di perlite, alla superficie invece ha avuto luogo una decarburazione per dare delle strutture ferritiche. La seconda spada rivelava essere costituita da sette pezzi. Il pomo era fissato come nella prima spada, ma tutti gli altri pezzi erano uniti mediante alloggiamento in incanalature preparate i cui tagli presentavano delle bavature. Una sezione era tagliata dall'elsa alla punta dove era stato applicato un nastro decorativo. Questo mostrava della ferrite a grana grossa alla superficie e della ferrite a grana fine con cementite alle estremità interne. Si sostiene che il lavoro eseguito in precedenza da altri metallografi era incoerente a causa di campionatura inadeguata, e le spade di questo tipo erano essenzialmente fatte di ferro saldato, essendo la presenza di perlite piuttosto accidentale che intenzionale.

Extracto—Se examinaron dos espadas de hierro provenientes de Luristan por medio de rayos X y de sección metalográfica. Se demostró que la primera espada tenía un puño hecho de cinco piezas de metal, juntadas por cuatro remaches y que el pomo estaba asegurado por un botón en el extremo de la espiga. Se seccionaron el puño y el pábilo para estudio metalográfico. Esto demostró que, el núcleo de cada parte siendo de perlite, se había realizado decarburisación en las superficies para dar estructuras ferríticas. Se demostró que la segunda espada había sido hecha de siete piezas. El puño estaba asegurado igual como en la primera espada, pero todas las demás piezas estaban juntadas a base de encajar en ranuras preparadas, los filos de las cuales mostraron barbas. Se cortó una sección de puño en un lugar donde había sido aplicada una cinta decorativa. Esta parte enseño ferrite grande granulado en la superficie y ferrite fino granulado con cementite en los términos en el núcleo. Se argumenta que el trabajo hecho previamente por otros metalógrafos era inconsistente debido al sacar muestras de una forma inadecuada, y que espadas de este tipo eran esencialmente de hierro forjado, siendo la presencia de perlite accidental más bien que intencional.