THE DECORATED IRON SWORDS FROM LURISTAN: THEIR MATERIAL AND MANUFACTURE

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INTRODUCTION

The well-known iron swords from early Luristan in Western Iran have aroused much interest from the several viewpoints of style and ornament, place in the cultural history of the Near East, and use or purpose. Their estimated but uncertain date of early 1st millennium B.C. places them early in the development of the use of iron, at roughly the period when iron was beginning to replace bronze in some quantity (Waldbaum 1980). As will be shown, the new metal was found to be very erratic in its mechanical properties, and there was no connection with the well-developed properties of copper and bronze; so the transition in use was awkward and stumbling. Study of the iron of which the Luristan swords were made, and the way in which it was manipulated, can therefore both illuminate the contemporary technical culture and add usefully to the history of the technology and production of iron.

In the category of iron swords from Luristan there are several variants of design, but a particular one is archetypical. This is illustrated in Pl. III, a sword in the Royal Ontario Museum, Toronto (accession No. 931.19.10). It consists of a wide circular pommel with two human heads on opposite edges; a relatively thin grip carrying two transverse raised ribs; a guard carrying two couchant lions on the same opposite sides as the heads on the pommel; and a narrow, two-edged blade which in some cases is slightly curved. The blade is typically about 340 mm. long, and the weight of the sword is well balanced at the guard. The dimensions of various swords vary moderately by about 10 per cent. An unusual feature is that the plane of the blade is consistently set at right angles to the plane of the grip. Only swords of this description will be included in the present review.

There have been a number of reports published of examinations of such swords since they appeared on the antiquities market in the 1920s, which vary in their usefulness. In the 1960s there were several reports that provided more detail, with two of them sacrificing complete swords, but there has been little added since 1971. A limiting factor in the extent of usefulness of reported results has been uncertainty as to dates of manufacture, so it seems worth while to obtain radiocarbon dates on the iron itself. The available published information can then be reviewed and collated, to make a fresh assessment of these unusual swords. As noted above, the variability in composition and strength of early iron was considerable, and study of these early iron objects can contribute to the history of metallurgy and so of the material culture of the time and area. In addition, the properties of the iron can provide a reasonable base for opinion on the possible use and significance of the swords.

NEW INFORMATION

New data acquired by the author consists of radiography of the ROM sword, and radiocarbon dates on both the ROM sword and on the sword examined by Smith at the Massachusetts Institute of Technology.

Radiography

The sword at ROM was seen to have a solid hilt, with thin transverse gaps in the bands around the hilt, similar gaps under the figures, and no evidence of rivets. These show the bands to have been separately made and applied, and the figures to have been made separately and attached without use of rivets. This agrees with several other reports. The voltage of the radiation available was insufficient to show whether the blade was continuous with the hilt or a separate insert.

Radiocarbon Dates

Each radiocarbon date required a minimum of 3 mg. of carbon, and the carbon contents of the two swords were apparently in the order of 0.5 to 0.6 per cent, so iron sample weights of about 600 mg. (a volume of about 27 mm^3) were necessary. The sword at ROM was sampled by core drilling a hole 6 mm. I.D. and 7 mm. deep into one side of the guard; and the small piece of apparently hilt material from the MIT sword was sampled by a slice from one end. The dates were determined by Isotrace Laboratories of the University of Toronto, and were processed consecutively. Since the two swords had been acquired on the antiquities market at times about 25 years apart, they can be considered as a random sample of swords of the type of Pl. III.

The MIT sword yielded a date of 2,880 $\pm$ 60 years

B.P., with a calibrated one sigma date of 1,044 B.C. The ROM sword gave a date of 2,940 ± 60 years B.P., with a calibrated one sigma date of 1,160 B.C. The average is 1,102 B.C., and this date is that of the wood from which the charcoal was made for smelting the iron. The average age of the trees used is estimated as about fifteen years, since small wood is easier to harvest and makes better charcoal than does large wood. With average age of wood in the tree seven to eight years, it seems reasonable to conclude that the iron was smelted in the period 1,094 ± 60 years B.C. This supports the suggestion regarding dates of Maxwell-Hyslop and Hodges (1966).

REPORTS REVIEWED

The thirteen published reports of examinations summarised here, vary considerably in the amount of detail they give on the assembly of parts and on the composition and microstructure of the iron involved. In several cases only two or three items of information useful here are given, limited evidently by concern for conservation. The most detailed and informative reports have been made by France-Lanord in 1969 and by Smith in 1971, who were each able to sacrifice a sword completely. Smith in particular published thirteen excellent photomicrographs of etched cross-sections that show clearly both variations in carbon content and microstructure, as well as the methods of making joints between parts of the sword. The total amount of information now available is appreciable, and since it concerns many facets of the swords, discussion could become complicated. This can be simplified a little by recognising that there are several features common to all of the swords examined. These are:

1. The material used throughout is bloomery (wrought) iron of quite variable carbon content.
2. Construction of the swords is by assembly of a minimum eight to as many as fifteen parts including rivets.
3. Fastening together of parts is by mechanical means only, and in no case by welding.
4. The hilts are solid forgings.
5. The rings or ribs on the hilts are embedded in shallow grooves forged into the hilts.

Other features are more variable from one sword to another, and in order to provide a basis for discussion the most important information is assembled in Table 1. All of the investigators here except Organ, Sneyers, and Ternbach, used radiography. In Table 1 it may be noted that:

1. There is a wide range in the carbon content of the iron, within the components of swords and between swords; the reported figures being averages.
2. All of the blades were softer than a work-hardened tin bronze, some of them considerably so.
3. The pommels, in the six cases where determination was made, were attached to the hilts by a tongue on the top of the hilt being inserted into a rectangular, sharp-edged hole through the pommel, then peened over on top.
4. The figures, in the ten out of thirteen cases examined, were fastened to the body of the sword by

TABLE 1

Part Attachment, Carbon Contents, Structure, and Hardness of Luristan Swords

	Attachment			Average Carbon Content, per cent				Blade	
Investigator	Pommel	Figure	Blade	Pommel	Hilt	Figures	Blades	VHN max.	Structure
Damien	tenon	embed	contin.	0.2	—	—	0.5	150	FP
Ellis	tenon	embed	—	0.5	—	0.6	0.8	190	SC
F-Lanord 1	—	rivet	contin.	—	—	—	0.2	207	FP
F-Lanord 2	—	rivet	tenon	—	—	—	0.05	148	FP
F-Lanord 3	tenon	rivet	tenon	<0.1	—	0.1	0.25	254	FP
F-Lanord 4	tenon	embed	contin.	<0.1	0.3	0.1–0.3	0.1–0.8	225	FP
Lefferts	—	embed	tenon	—	—	0.1	0.8	—	SC
Maxwell-H	tenon	embed	contin.	—	<0.1–0.2	—	—	—	—
Naumann	tenon	embed	tenon	—	0.1	0.1	<0.1	—	SC
Organ	—	embed	tenon	0.5	—	—	—	—	—
Smith	tenon	embed	contin.	0.2–0.7	0.2–0.7	0.2–0.7	0.2–0.7	200	SC
Sneyers	—	embed	contin.	0.4	—	—	—	—	—
Ternbach	—	embed	—	—	—	—	0.5	—	SC

FP ferrite-pearlite; SC spheroidised cementite; — not determined; VHN max.—Vickers Hardness Number maximum.

embedding in a shallow dove-tail, which was clearly shown in Smith (1971: Fig. 2.35).

5. The blades, in five out of the nine cases determined, were continuous with their hilts, and the microstructures of hilt and associated blade were then very similar. In the other cases the structures of hilt and blade were quite different. The attachment of blade to hilt at the guard in the other cases as a blind mortice is shown in Pl. 72, Fig. 16 of Maryon's 1961 reproduction of Naumann's excellent radiographs.
6. The comment of France-Lanord (1969: 105), that the figures on the swords examined by him were mostly of low carbon iron that is easier to engrave, does not apply generally.
7. In France-Lanord (1969: 95–104) many of the hardnesses reported are appreciably higher than normal for the associated carbon content and microstructure. The reason is not clear, and it is probably an artifact of the mixed microstructures.

Chemical analyses of parts of swords have been infrequent, the few available being given in Table 2. As will be discussed below, the erratic distribution of carbon in bloomery iron makes representative sampling difficult, and drillings for example perform a local averaging. However, drillings taken 10 cm. away in the same piece may have a carbon content three times as high, as noted by Smith (1971). Estimation of the carbon content of the iron from the proportions of ferrite and pearlite in the microstructure encounters the same problem.

The comment was made by Ternbach (1964: 49) in his report on the visual examination of several swords, that "two human heads were produced by a hammer stroke that raised the thickness of the disc, making it of oval shape and building up material for the heads". However this was apparently opinion only, and no supporting evidence was supplied. Also, Damien (1962) was quite satisfied that the figures were welded on, but later examination of the same sword by France-Lanord (1969) showed this not to be so.

In one of the swords examined by France-Lanord (1969: no. 4), a longitudinal flaw or seam in the iron was found that ran up the centre of the sword, and which was gross enough to probably not escape the notice of the smith doing the forging. A similar but shorter and less obvious seam was noticed in his sword (no. 3), both of these seams being the result of careless work in the consolidation of the raw bloom by forging at the smelter. In the swords of France-Lanord (1969: 95) and of Damien (1962: 23), there were reported sharp changes in the carbon content in the microstructure, which is characteristic of well-made forge welds, and in Maxwell-Hyslop and Hodges (1966: 177) their photomicrograph LII-b shows an excellent weld. In Smith (1971: 48, Fig. 2.46) a weld is shown that has been badly made, in that pieces of oxide scale have been included. It must be emphasised that all of these welds are internal in the metal, and are the typical result of a consolidation of small blooms into larger ones at the smelter. They have nothing to do with the eventual assembly of the swords, but do demonstrate unequivocally that the forge welding of iron was known at the time and also could be well done. These welds have not been commented upon or apparently noticed by any of the investigators, probably because they are internal, but their metallographic evidence is clear.

The comment is made by most investigators, especially Damien (1962), France-Lanord (1969), and Smith (1971), that the slag content of the iron varies considerably from piece to piece. This is a characteristic of random sample of all bloomery iron, and depends on both variation in smelter operation, and on the skill and care of the smelter-smith in forging the raw bloom to a sufficient extent and at high enough temperature to expel most of the entrained slag.

SUMMARY AND DISCUSSION OF EVIDENCE

The information concerning the swords may for convenience be discussed in two categories. One of these is the morphology of the swords, i.e. their design in terms of shape and attachments, and how this was created; and the other is the material of which the swords were made, and how its properties and their inherent variability affected the manufacture and possible use of the swords. The morphology will be discussed first, and the sword material will be discussed after a brief review of the metallurgy and practice of bloomery iron smelting, which was the only method in use in antiquity and which in practice made a product of variable properties.

Morphology

The fairly complicated shape of the hilt and guard of the finished sword is unusual in that it is assembled from many separately manufactured parts, that are held together by mechanical joins that are appropriate to wood-working. These joins are difficult to make in forged iron particularly when much of it is a medium carbon steel that is of poor forgeability compared to a low carbon wrought iron; but they have been made with great skill. In about half of the swords examined, the blade is not a forged continuation of the hilt, but is a separate piece that is set into the guard as a blind mortice and tenon, held in place by a rivet. The fit is not close as can be seen particularly in the radiographs of Naumann (in Maryon 1961: 181), and the join must be very weak mechanically. The ornamental figures are also not strongly attached and would probably not withstand a sharp blow on the guard, which could be disastrous. In fact one was knocked off accidentally during examination by Organ (1961). However, the workmanship is excellent, justifying the comment of Smith (1971: 46) that "altogether these swords are astonishing. I regard (the smiths) as have been extremely adept in complicated shaping."

A smaller but real consideration is that the general shape of the sword is odd, in that the heads on the pommel make the hilt somewhat difficult to grasp quickly, and the blade, set at right angles to the plane of the hilt, does not give a comfortable "feel" to the weapon; although these points are matters of opinion. On the other hand, the weight distribution of the sword has been nicely balanced at the guard.

Assuming that the final shape or design of the sword was specified, and given the demonstrated competence in forging iron, it is surprising that the swords were not made in just two pieces; the pommel with the heads as one piece, and the hilt, guard, lions, and blade as the other piece. The smiths did have the ability to raise ribs on the hilt by forging, as shown by the sword in Maxwell-Hysop and Hodges (1968: Pl. L.1) not considered here, in which the hilt was built up out of plates; and the swaging of the head and lion figures would have been easier as parts of a larger piece, than as single small pieces. The method of manufacture actually used seems like an intentional display of virtuosity.

Bloomery or Solid-State Smelting of Iron

Iron is a metal whose hardness and strength vary widely depending on its carbon content, which in turn depends on the circumstances of its smelting, and millennia of time were evidently required for smiths to obtain some degree of control over what kind of iron was produced. The time period of manufacture of the Luristan iron swords was during the extended transition from when copper and bronze were the only hard, strong, but manipulable metals, to when iron was replacing bronze in some quantity about 1000 B.C. The transition from the smelting, melting, and working of copper and bronze, to the smelting and hot forging of iron, was slow and difficult because of the considerable differences in the chemical and metallurgical properties of copper and its alloys, and of iron with its chameleon range of properties.

The smelting of copper and the manufacture of bronze by alloying with tin are prescriptive processes, in that if the same practices are followed in a given furnace using the same ore and charcoal, reasonably pure copper and bronze can be made that will have usefully consistent properties of ductility, strength, and hardness. The metal is usually produced in the molten state, and can be cast in molds to have close to final desired shapes. Hardening is done by cold working, and softening is by reheating for a short time to a few hundred degrees C. However, pieces of copper or bronze cannot be hot forge welded together in a useful join.

Iron can be smelted in the same furnaces used for smelting copper, by using a moderately increased ratio of charcoal to ore and an increased air supply rate. However, when using the same ore and charcoal in a given furnace, successive smelts do not necessarily produce iron with the same properties. This is because carbon from the charcoal fuel can dissolve in the reduced iron at high temperature to become a powerful hardening alloy. The amount of carbon dissolved depends directly on the weight ratio of charcoal to iron in the furnace burden at a given air supply rate, as was demonstrated experimentally and clearly by Tylcote *et al.* (1971).

In antiquity, while there must have been awareness of a relationship between charcoal, ore, and air supply in order for any metal to be smelted, the importance of weights of materials was not recognised. In addition, the irregularity of air supply from hand-worked bellows added more uncertainty. As in modern primitive practice, ore and charcoal were almost certainly measured by volume such as basketfuls, and since their bulk densities vary with their source, the weight of a basketful could vary. In the case of charcoal for example, the bulk density of charcoal made from hardwood is nearly twice as high as that made from softwood; which is why each smelter-smith would use only charcoal made from certain trees, in order to increase consistency of results.

Furnace operating conditions therefore varied considerably without the operator's awareness. Too low ratio of charcoal to ore resulted in little or no iron being made, but too high a ratio produced a molten cast iron. The cast iron solidified to an extremely hard, brittle, unforgeable lump that had to be discarded as useless. However with suitable intermediate ratios of fuel to ore, forgeable solid state blooms of iron were made. This iron could be of low carbon content, 0.02 to 0.20%, and was readily forgeable and very ductile when cold; or of higher carbon content (steels) of 0.30 to 1.50%, which were increasingly less forgeable and harder when cold. This latter iron was eventually found to be quench-hardenable to very high hardness. It must be recognised in passing that the ability to smelt iron ore to a molten cast iron is inherent in even a small charcoal furnace. Its melting point is not much higher than that of copper, and the Chinese recognised in the seventh to sixth centuries B.C. that it could be cast into moulds like bronze (Needham 1958).

The solid-state blooms of iron taken from the furnace contained entrained slag, and had to be reheated to above the melting temperature of bronze and thoroughly forged to expel most of the slag. This also consolidated the iron, welded cavities shut, and shaped it into a bar. The hardness and strength of the final bar increased, and its ductility and forgeability decreased, as its invisible carbon content increased, so use of a bar for a particular purpose could be decided by a few simple, practical tests. These would consist for example of degree of bending without fracture, resistance under the hammer during forging, and the appearance of a fresh fracture surface. Iron has the useful property of welding to itself in a strong join under pressure at high temperature, and it became a common practice at a smelter to weld small blooms or bars together to make larger ones; but if selection was not careful such a composite bar could vary considerably in its properties along its length. In general then, bar iron was a product whose variability depended on the rules of thumb and skill of the smelter.

Because of the physics and chemistry of the bloomery iron smelting process, the carbon within a bloom is distributed unevenly on a microscopic scale and in a characteristic manner. Carbon appears in iron as iron carbide (cementite) distributed in pure iron (ferrite) in proportions that depend on the average carbon content. The geometry of the distribution controls the mechanical properties of iron, and depends on the cooling rate from above a red heat. In iron air cooled from the forge, carbon appears microscopically as grains of pearlite, a finely lammellar structure of cementite and ferrite containing about 0.7 per cent carbon, mixed with grains of ferrite. Pearlite has a hardness about the same as that of a fully work-hardened bronze, and ferrite is softer with a hardness a little higher than that of copper. The proportions that exist in a microstructure thus determine the average hardness, and are also a base for estimation of the carbon content of an iron.

By particular heat treatments the distribution of cementite in ferrite can be changed and the hardness altered accordingly. The softest and most ductile structure possible for a given carbon content is when the cementite is distributed as tiny spheroids, a condition that can be created only be extended holding in a narrow temperature range just below a red heat, or by very slow cooling from a bright red heat. The former would have been impractical in a bellows-driven forge fire, and the latter was probably the way the spheroidised cementite in the Luristan swords was made. It happens that the temperature to which much pottery is fired corresponds to a bright red heat, and so by simply putting a forged sword blade into a pot that is to be fired, it would be heated to the necessary temperature and then slowly cooled by the naturally slow cooling rate of a pottery kiln and its contents.

Solid iron can dissolve carbon through its surface at high temperature, a process called carburisation, which produces a characteristic carbon concentration gradient. Contrary to an assumption widespread in archaeological literature however, this does not occur while heating iron in a forge fire for forging. Actually decarburisation of the surface of the iron occurs, forming a low carbon content skin that thickens with time at temperature. To carburise, iron and a source of carbon must be enclosed while being heated, to exclude products of combustion (Rehder 1989). This is an important point, and in many cases in the archaeological literature dealing with iron, microstructures have been assumed to have been created by carburisation after smelting, when in fact they originated in the heterogeneous structure naturally occurring in the iron bloom.

The Iron Used in the Swords

The results of the metallurgical examinations that are summarised in Tables 1 and 2 show that the iron of which the Luristan swords were made was very variable in its carbon content, which produced corresponding variations in the strength, hardness and forgeability of the iron. The internal distribution of carbon in the iron was also erratic in the way that is characteristic of bloomery iron, and there is no evidence of carburisation after smelting. The quantity of slag remaining in the iron as microscopic stringers was similarly variable depending considerably, as it does, on the skill used in forging the raw bloom to a bar. The manganese and sulphur contents were unusually l.w, and the phosphorus content was low, all indicating the use of high purity ores.

The microstructures of the iron in the swords, except those of the sword blades, were almost entirely the mixtures of pearlite and ferrite that are typical of iron that has been air cooled from at or above a bright red heat. The hardness decreases with pearlite and therefore carbon content as described above, and the lower carbon irons such as those in the Naumann sword would have hardnesses of less than 100 VHN (Vickers Hardness Number), though not measured. The blades are unusual, in that not only is their maximum hardness only a little over 200 VHN, much less than the 280 to 300 VHN of a fully work-hardened bronze; but a considerable proportion have been given the heat treatment described above that provides the softest structure possible for a given carbon content, a spheroidised cementite. An oddity is that the Naumann blade, which would have been soft as air cooled from the forge because of its low carbon content, was also given a speroidising anneal. This indicates that all blades that were forged separately were so annealed as standard practice. The mixture of procedures is puzzling, but it must be remembered that in view of the number of swords made, there were probably several smiths making similar swords to have specific characteristics, and personal opinion or skill varied the means. It does seem clear however that a blade as soft and ductile as possible was required.

TABLE 2

Chemical Analyses of Parts of Swords

Investigator	Part	C	Cu	Ni	Other
Damien	Blade	0.45	0.050	0.035	Cr 0.005
Damien	Pommel	0.20	>0.1	0.085	Cr 0.005
Salin	Blade	—	0.046	0.024	Cr <0.015
Lefferts	Blade	—	0.00X	nil	Cr nil
Lefferts	Beard	—	0.0X	tr.	Cr 0.0X
Naumann	Blade	0.067	—	—	—
Smith	Blade	0.63	<0.01	0.01	Co 0.01

Maximum manganese content of 4 reported was 0.02 per cent; phosphorus of 2 reported 0.04 per cent; and sulphur of one at 0.002 per cent. The analyses reported by Salin *et al.* (1962–3: 209–17) were done on the sword examined by R. Damien.

Origin of the Iron Used

The iron was of course not necessarily smelted where the swords were manufactured since trading was active, but it is almost certain that it was smelted close to easily workable deposits of iron ore. Recoveries of iron from ore during smelting were low, typically more than 10 kg. of ore (depending on its grade), being necessary for each kg. of iron bar made. It was thus easier to do the smelting near the ore deposit and send 1 kg. of bar out in trade, than to carry 10 or more kg. of ore from a distant deposit. For this reason it is also unlikely that ores from different sources would be used at a given smelter.

Most iron ores contain small quantities of oxides of other metals such as manganese, nickel, chromium, and copper, and all of these if present in an ore can be reduced to some extent in a charcoal furnace smelting iron ore. The amounts, both absolute and relative, of these trace elements in an iron bar can act as useful indicators of the ore from which the iron was made. In Table 2 above the few analyses made of trace elements have been shown, and it appears that at least two different sources of ore have been used to make the iron bars from which the present sample of swords has been made. Since as noted above two different ore sources were unlikely to have been used at a given smelter, it appears that iron bars from at least two different smelters were used in making the Luristan iron swords.

This in turn makes it unlikely that the iron was smelted at or near where the swords were made, and the resulting lack of observation of practices used in smelting gives reasonable explanations of both the apparent lack of knowledge of forge-welding by the swordsmiths, and of why these skilled bronze founders did not use cast iron as did the later Chinese. It is also evidence of the parochial quality of early technology, inhibiting innovation.

INFERENCES AND CONCLUSIONS

The skill demonstrated in the manufacture of the decorated iron swords from iron of variable hardness and forgeability has been amply commented upon, and it has been accentuated by the piece-meal method of manufacture. The final impression the present author receives is one of display, and it is difficult to escape the conclusion that the swords were made only for ritual, display, or prestige purposes.

This is supported by the mechanical weakness of the methods of making joins in assembling the parts, and the intentional softening of some blades to less than one-third the hardness possible with a work-hardened bronze. The softened blades were then fastened to their hilts by a difficult-to-make blind mortise and tenon join in the guard, which would be very much weaker than a blade forged continuously with the hilt. When soft, ductile blades were apparently desired, and the simple procedure for annealing iron was evidently known, the easiest method of manufacture given the demonstrated skill, would be to forge hilt, guard, and blade as one piece and then anneal the whole. The hilt and guard would be amply strong in such condition and the blade connection equally so. The absence of such or similar procedure suggests again that display was an objective and that the strength of the hilt-blade join was not important.

The differences in methods of attachment of blades and of ornamental figures, as dove-tails, mortises, rivets, or all three, are probably the result of the work of several smiths with different opinions; but similarity of over-all design and of softness of blades again argue a display purpose. The swords are in fact poor weapons and are not even comfortable to handle.

As noted above, the iron of which the Luristan swords were made was typically bloomery iron, likely made in blooms weighing not more than a few kilograms, and varying in carbon content and mechanical properties from one bloom to another. The resulting variation in hardness, forgeability, and weldability would have created difficulty for forge-smiths, and would have resulted in continual pressure on smelter-smiths to increase the uniformity of their product. The Luristan forge-smiths not only coped with this variability very well, but used a slow-cool heat treatment to produce maximum softness and ductility in the iron no matter what its original condition was. Welding was not used for any attachments or joins, nor is there any evidence of the use of quench-hardening, to which much of the iron used was very well suited.

The metallurgical evidence as a whole provided by these swords shows that as early as 1100—1000 B.C. there existed in the Near East a considerable ability in the smelting and forging of iron, which must have taken many centuries to develop. The examples of iron reviewed above could easily be mistaken for Roman iron made more than a thousand years later, which incidentally gives a measure of the glacial slowness of the development of control over the product of an iron-smelting furnace. Iron was also being made in some quantity at the end of the second millennium B.C., since in the known Luristan iron swords alone there may be a total of more than 400 kg. of finished iron. Total iron production in the Near East at the time must have been considerably larger, and in the making of such quantities of iron occasional production of molten cast iron would have been likely. This increases the probability of its use somewhere in the area, in a foundry mould intended for bronze, and this gives increased significance to the translations assembled by Košak (1986), of Hittite references to iron objects of considerable size and weight, that would have been impractical to make as forgings.

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It was at the suggestion of Dr. P. R. S. Moorey, Keeper of Antiquities at the Ashmolean Museum in Oxford, that the question of the material of which the Luristan decorated iron swords were made, was reviewed in some detail. The starting point was the sword in the collection of the Royal Ontario Museum in Toronto, and the cooperation and interest of Dr. T. Cuyler Young Jr., former Director of the Museum, extended to the point of the Museum generously funding the cost of the radiocarbon determinations. Dr. Edward Keall, Curator in the West Asian Division of the Museum, arranged for radiographs to be taken by C. Toogood of the Museum staff and for a sample to be taken from their sword, and provided a photograph and useful discussion. Dr. U. M. Franklin, Professor Emeritus of Metallurgy at the University of Toronto, not only gave valuable guidance and background, but arranged for Professor Heather Lechtman of the Massachusetts Institute of Technology to find and kindly provide a sample from the sword that had been examined and published by Professor Cyril Smith; this provided the statistically important second independent sample for radiocarbon dating. Dr. Moorey, Dr. Young, and Professor Franklin have all read drafts of the manuscript and made useful comments, but the opinions expressed in the paper are those of the author, for which they are not responsible.

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