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DAMASCUS STEEL IN LEGEND AND IN REALITY *

by Prof. *Carlo Panseri*, Dr. Ing.

ANYONE who follows the ancient and glorious history of arms, whether as a collector or as a student, has surely in his reading often run across the term *damascened steel* or *Damascus steel*, or simply *damascus*, applied (not always in correct or pertinent fashion) to the constituent materials of edged weapons or of the barrels of firearms.

The reason for a particular type of steel having borne the name of a city in the Near East is something which still evades our inquiries. Yet it may be put on record that at the end of the high Middle Ages the trade in steels and blades of oriental manufactures was concentrated precisely in the ancient city of Damascus, in Syria, the *Dimisk as-Sham* of the Arabs; here, indeed, it appears that important arms manufactories had existed as far back as the era of Diocletian. Yet around 1400 the city of Damascus was conquered by the hordes of *Timur i Leng* (Tamerlane), which enslaved the inhabitants and removed the best artificers, whereupon an effective local center of arms production ceased almost completely to exist.

But in the same city a flourishing textile industry continued to live on, for which reason one cannot exclude the possibility that by reason of the external appearance, the immediate visual impression, which the oriental blades indeed conveyed to the eye of the beholder, the steel of which they were composed may borne a name which commemorates the famous patterned textiles that are still called damask-just as the Italian word *majolica* derives, through late Latin *majorica*, from the Balearic island Mayorca.

The ambiguous meaning of the term and its late attribution to most disparate qualities of steels, however, owe their origin to the indiscriminate use which was made of it in past centuries, and especially in the XVIIIth and XIXth centuries, by European voyagers and commentators; and the justification for this arises from the confused state of metallurgical knowledge, which the refinement of methods of metallurgical research and the progress of the science of metals have only within the last century contrived to place in a certain order, historically and technologically.

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* Translated by H. Bartlett Wells. Washington D. C., December, 1963.
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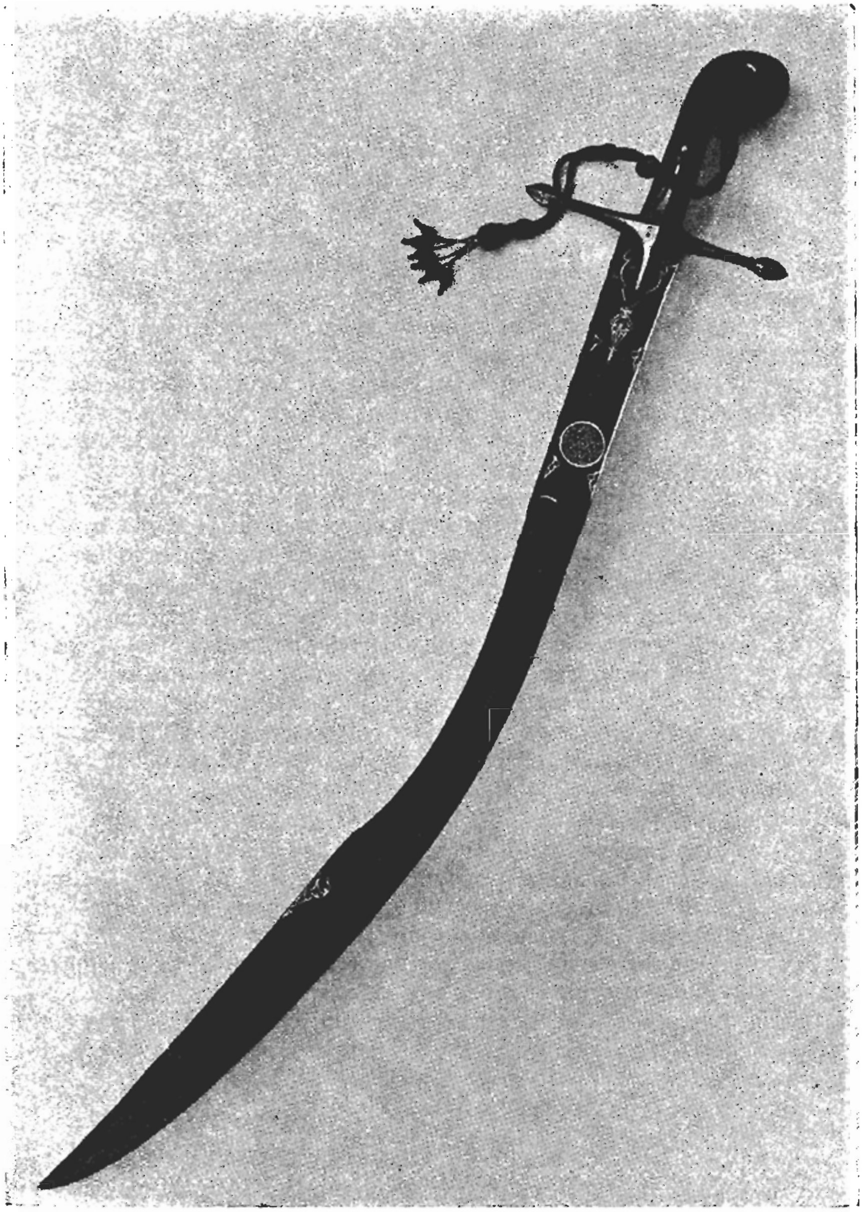

FIG. 1. *A characteristic oriental saber having a handsome Damascus blade styled «Kara Taban» (author's collection).*

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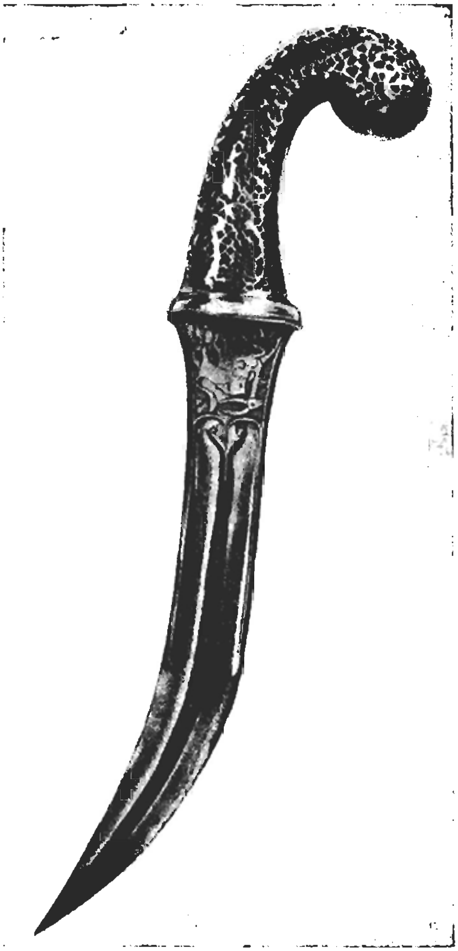

Fig. 2. *Indo-Persian dagger with damascus blade (author's collection).*

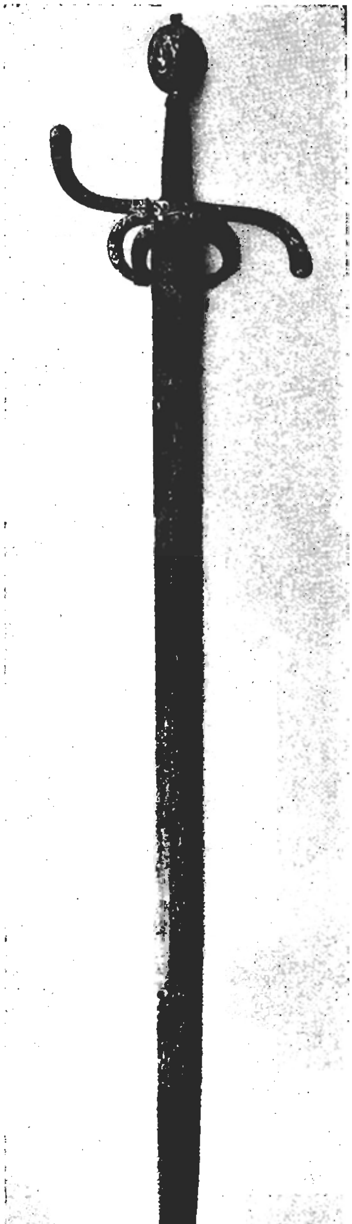

Fig. 3. *Sword of Duke Emanuele Filiberto di Savoia, preserved at the Armeria Reale of Turin. Persian damascus blade with Cufic inscriptions in gold inlay, the mountings being occidental.*

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And still even today students of ancient arms or—as someone has proposed—of *armeology* are rarely possessed of the complex of scientific knowledge which forms the stock in trade of the professional metallographer; still less do they have at hand the complicated range of scientific apparatus, running from metallographic and electron microscopes to the spectrograph, and from micro-hardness testers to electronic probes and to radio-isotopes, that constitute the indispensable tools of the modern researcher.

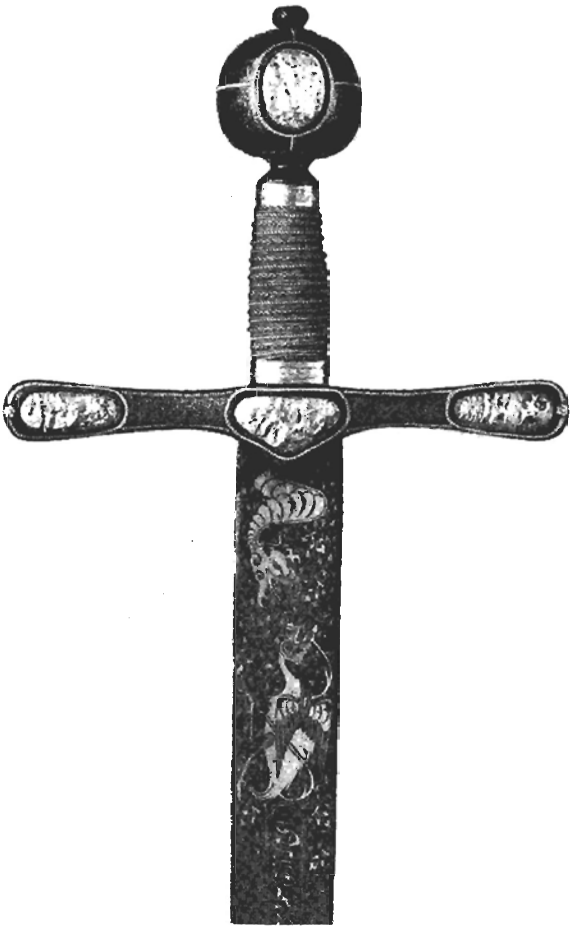

FIG. 4. *Blade of Persian damascus in German mounting of the XVIth century (Schweizerisches Landesmuseum, Zurich).*

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On the other hand, of all the products of ancient metallurgy it is arms of offense and defense that represent in all races, and one may say at all times, the best and the most refined that specific metallurgical knowledge could contrive to bring forth. One may even assert that through structural study of these objects (that is to say, study aimed at determining their intimate structure and, if possible, the resultant technology) it is often possible to deduce the degree of metallurgical skill, intuition, and experience of a people, of a race, or of an entire historical era.

Hence the tendency, ever more evident, to separate from the old trunk of descriptive armeology a new and constantly more promising guideline to investigation, which consists in applying to the study precisely of ancient arms and of associated technologies the most recent concepts and discoveries of the science of metals.

Furthermore, perhaps even better than from the purely formal and external study of the whole pieces, it is possible to derive from structural analyses and reconstruction of operative techniques extremely important deductions of historical character regarding lines of expansion or migration on the part of ancient peoples and regarding zones of influence of the most ancient civilizations.

An example of the results which may be achieved through this new line of armeological research is afforded precisely by the present study, which endeavors to clear up a technical question—that of the production of the steel called Damascus—which for centuries and centuries (the first probable references are to be found in the works of Pliny) has constituted a mystery, with which the greatest technologists and scientists of every country—down to Faraday, who drew from this study the inspiration for his pioneering work on alloyed steels—have busied themselves with varying fortunes.

A representation of the ambiguity and the imprecision which are inherent in the current accepted notion of damascene steel is clearly evident in the item *Damask steel* contained in the most recent edition (1960) of the *Encyclopedia Britannica*, a term which is defined as follows: «A steel with a peculiar watered or streaked appearance, as seen in the blades of fine swords and other weapons of oriental manufacture. One way of producing this appearance is to twist together strips of iron and steel of different quality and then weld them into a solid mass. A similar but inferior result may be obtained by etching with acid the surface of a metal, parts of which are protected by some greasy substance in such a way as to give the watered pattern desired. The art of producing damask steel has been generally practiced in oriental

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FIG. 5. *Two examples of Persian Damascus blades of characteristic appearance (author's collection).*

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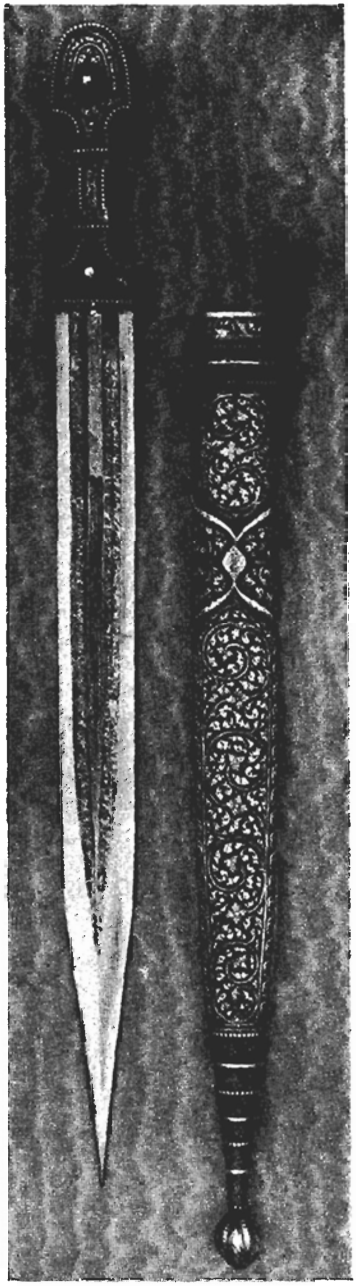

FIG. 6. *Blade of Russian «bulat», with artificial undulations secured through acid attack, in a Cossack «kindjal» (XIXth century) (author's collection).*

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countries from a remote period, the most famous blades having come from Isfahan, Khurasan and Shiraz in Persia.»

In conclusion, under the excessively generic term of *damascus* there are generally understood both that type of steel which we shall from here on call *oriental damascus*, and also the one which we shall prefer to call *welded damascus*, and finally the degenerated *imitation* of the above techniques which is produced through superficial etching via acid attack, via a technique which is not conceptually unlike that currently employed in the graphic arts for the preparation of clichés (see Figure 6).

It is, by the way, evident that the ordinary definition of damascus is based upon criteria which are fundamentally formal and external, without entering into technical merit, which is what really permits one to establish profound technological and structural diversities among the various types described, when one applies to their differentiation the means which are currently afforded by metallographic analysis.

It is nevertheless important to emphasize finally that while both oriental damascus and perhaps welded damascus present appearance characteristics that are especially attractive and decorative, these are not always, or perhaps actually, a determining factor in the intention which moved the first artificers, but that these instead derived from acute observations of functional character, which, for modern eyes, make the spirit of observation, the manual dexterity, and the intuition of the ancient masters so much the more interesting.

As we have had occasion to note in our earlier work (1), the virtues which were attributed to a sword blade were many, and discordant one with another. The edge ought to be hard enough to cut upon impact any reasonable obstruction, but not so brittle as to snap; the blade ought to be rigid enough not to bend upon striking, and elastic and tough enough to bear it without breaking. Hence the conclusion that even today, despite the progress of metallurgy, very few types of steel, however fine and however alloyed, could contrive to draw directly from the homogeneous mass a blade which could compete favorably with one of those which were laboriously put forth from the workshops of the most renowned bladesmiths of past ages.

Hence it was only through chance, and through that divine balance which makes naturally beautiful that which responds perfectly to its purpose, that the ancient artificer, having an intuitive grasp of the solution to the technical and functional problem, here as elsewhere

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(1) C. Panseri: «Ricerche metallografiche sopra una spada da guerra del XII secolo», Milan (1954).

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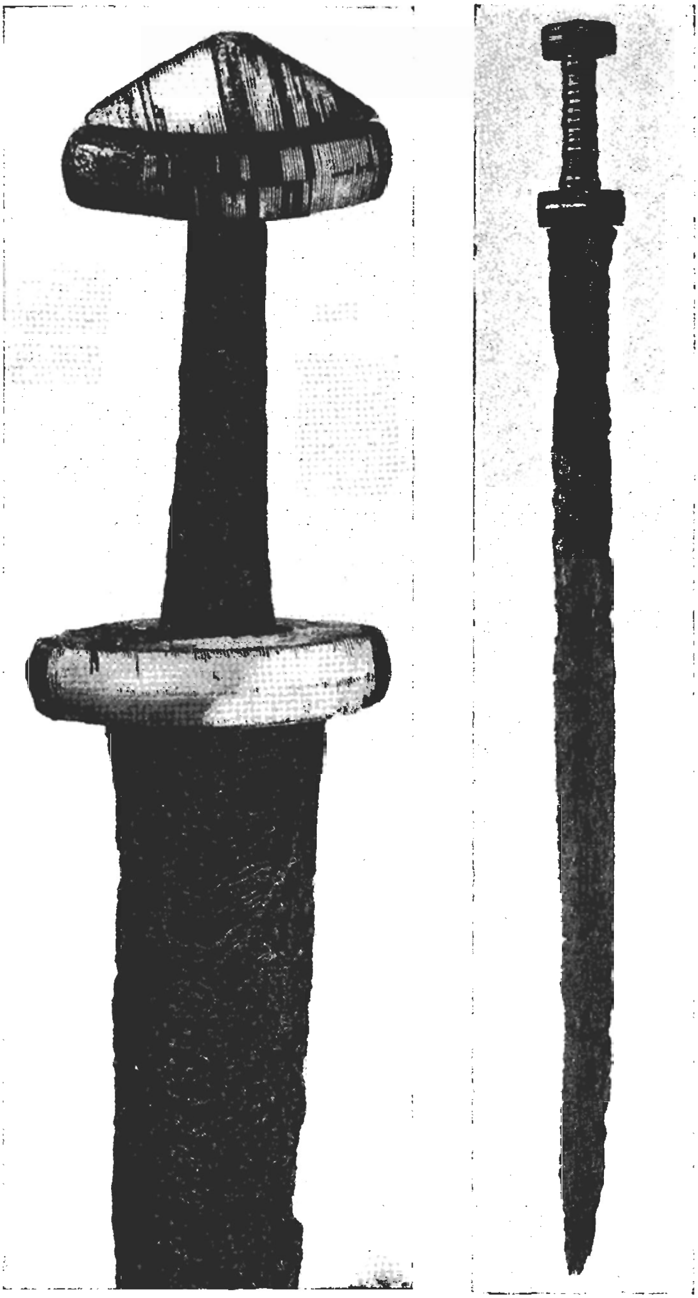

FIG. 7. Left: *Viking blade of welded damascus in a German sword of the IXth century (Schweizerisches Landesmuseum, Zurich).* Right: *Danish sword of the Vth century with welded Damascus blade (National Museum, Copenhagen).*

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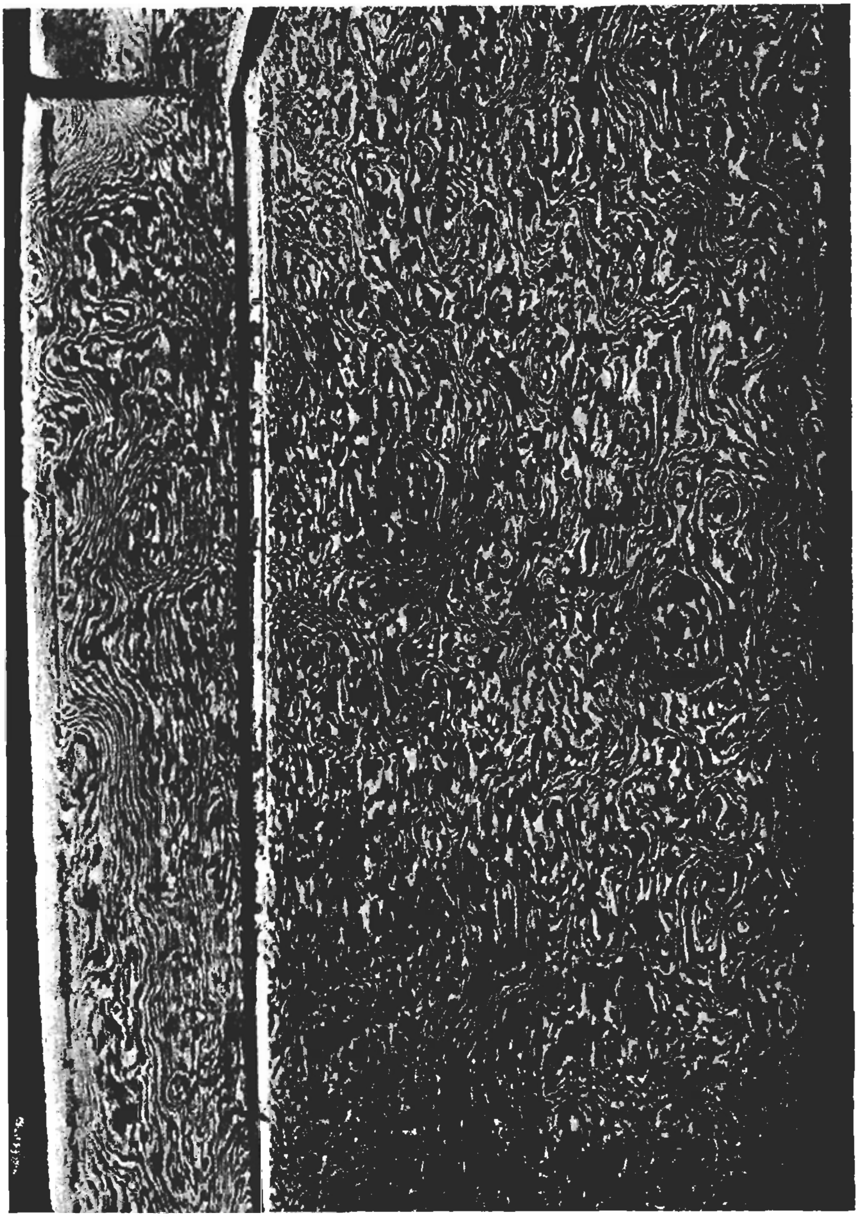

FIG. 8. *Oriental Damascus of «Kara Korassan» type, from blade No. 1 (see Figure 10), enlarged 1.5 times.*

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managed to compose a work full of intrinsic beauty not only to the expert eyes of a profound connoisseur, but also for the technically less well-endowed ones of the ordinary amateur.

The truth is, in fact, that the attractive appearance offered by oriental damascus, with the sinuous and elegant waves of its surface, with the profound tonal difference between its light parts capriciously mingled with its darker ones, did not actually represent the final objective toward which the artificer was striving. One cannot overlook the fact that the manufacture of damascene blades arose in the Near East, in India and in Persia, during a period of continuous and bloody strife, and that it evolved through a number of centuries, during which the blade of an edged weapon constituted the sole, fundamental method of offense and of defense; in an era, that is to say, in which the efficacy of the weapon was fundamental, while the formal appearance was relegated to a subordinate plane—even though the latter did indeed constitute, through long and acute experience, an excellent means, not susceptible of substitution in those times, for the expertise and classification of blades and for the evaluation of their characteristics (2-3).

Yet it is evident that an empirical classification, could hardly have been understood rationally by that congerie of manufacturers and merchants through whom the products of the ancient artificers were distributed in capillary fashion over the vast regions of the Islamic orient, of Russia, and of Europe itself. Hence the quantity of diverse designations which make extremely difficult for the studious man of our day the undertaking of any attempt at serious interpretation, now that even in the Orient the widespread and good practice of the production of edged weapon of prised make has for many years been abandoned, with the consequence that there is no longer any possibility of getting pertinent local information.

The most minutely detailed descriptive sources are those of the various Russian authors who, favored by proximity and by standing

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(2) P. Anossow: «O bulatach» (On Bulat Steels), *Gornyi J.* (Mining Journal), vol. I, p. 162 (1841).

N. T. Belaiew: «Ueber Damas» (On Damascus), *Metallurgie,* VIII, p. 449-497 (1911).

(3) A. Crivelli: «Sull'arte di fabbricare le sciabole di Damasco», Milan (1821)... «The Turks swear to the excellence of the arms they sell, without putting them to any temper; and from the quality of the design they affirm or deny the good success of the tests to which one might wish to subject a blade. In general truly perfect Damascus blades, while they are capable of cutting soft substances with great ease (such as a wet felt folded several times and placed upon a support), will cut with the same blade, and I should say with almost equal ease, both bone and iron, and this without suffering noteworthy damage.»

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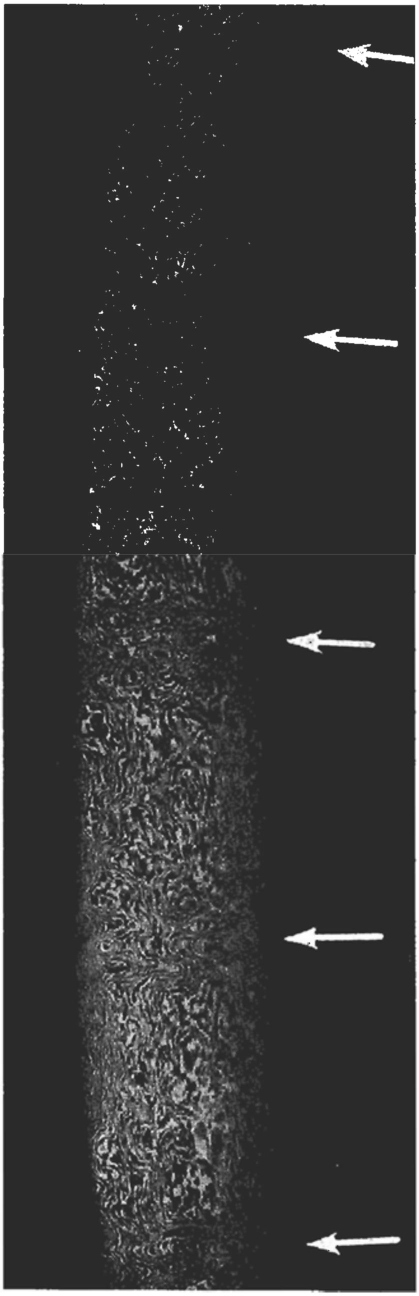

Fig. 9. *«Kirk Narduban» damascus in a Persian blade of the XVIIth century (ISML Collection of archeological and historical steels). The equidistant transverse tracks, called «steps» of the ladder of Mahomet, are perceptible.*

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links with the most famous centers of Persia, from the XVIIth until toward the end of the XIXth century devoted much attention and much study to Damascus steel, which, from the specifically Persian term *poulad jauharder* (literally, waved steel) (4), furnished toward the end of the XVth or the beginning of the XVIth century the name of their *bulat*, just as the Arabs derived from it the name of their *fulad*.

The Russian term *bulat* is in fact documented in Russian texts as far back as the end of the XVth century, and it is known, according to what Lenz reports (5), that round about 1616 the Moscow bladesmith Dimitri Konovalow was producing fine blades of *bulat* steel. Toward the end of the XVIIIth century, however, this art has declined to such a degree that the tsar Alexei Mihailovich resolved to send three of his artisans to Astrakhan «in order that they might learn the art of forging blades of damascus steel» and in his impatience shortly orders the Voivoda of Astrakhan to find and send to Moscow «good masters who know how to forge good saber blades of Circassian damascus steel, and who can teach the art».

But it does not appear that these initiatives left much trace behind them, and it is certain that although among the Russian military class interest in and love for the fine edged weapons imported from neighboring Persia and the Caucasus continued to flourish, the decidedly westernizing trend which came to prevail in Russia through the XVIIIth and the first quarter of the XIXth century imposed upon them decadence and oblivion as fashion changed.

It was in 1828, a few years after Crivelli in Italy, Clouet in France, and above all Faraday and Stodart in England, that there revived in Russia the interest in research into the production of Damascus steel, and that General P. P. Anossow (1797-1851), Director of the Zlatoust Steel Works in the Urals, commenced his studies on the production of *bulat*. He started by sending to Tiflis two Russian artisans and two German ones; these, under the charge of Count Paskevich, were to work in the shop of Karaman Elisarow, the most famous of the Caucasian bladesmiths of that time, and to acquire his techniques. But even this enterprise was destined to fail, because the Caucasian artisans,

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(4) Translator's note on the term *poulad jaurerder*: A. Persianspeaking friend tells me that the best translation is «*bejeweled steel*». The pronunciation, or at least the modern pronunciation, is better indicated as *poulad jauharder*. The true word for «wave» actually appears later on in Professor Panseri's text, as *Koum* or *Kaum*.

(5) E. E. Lenz: «Ueber Damast: Ein Bericht über den Stand der Frage», *Zeitschrift für historische Waffenkunde*, IV, pp. 132-142 (1906-1908). Same: «Bulat», *Sbornik Gos. Ermitage* (State Hermitage Collection), II, pp. 73-82 (1923).

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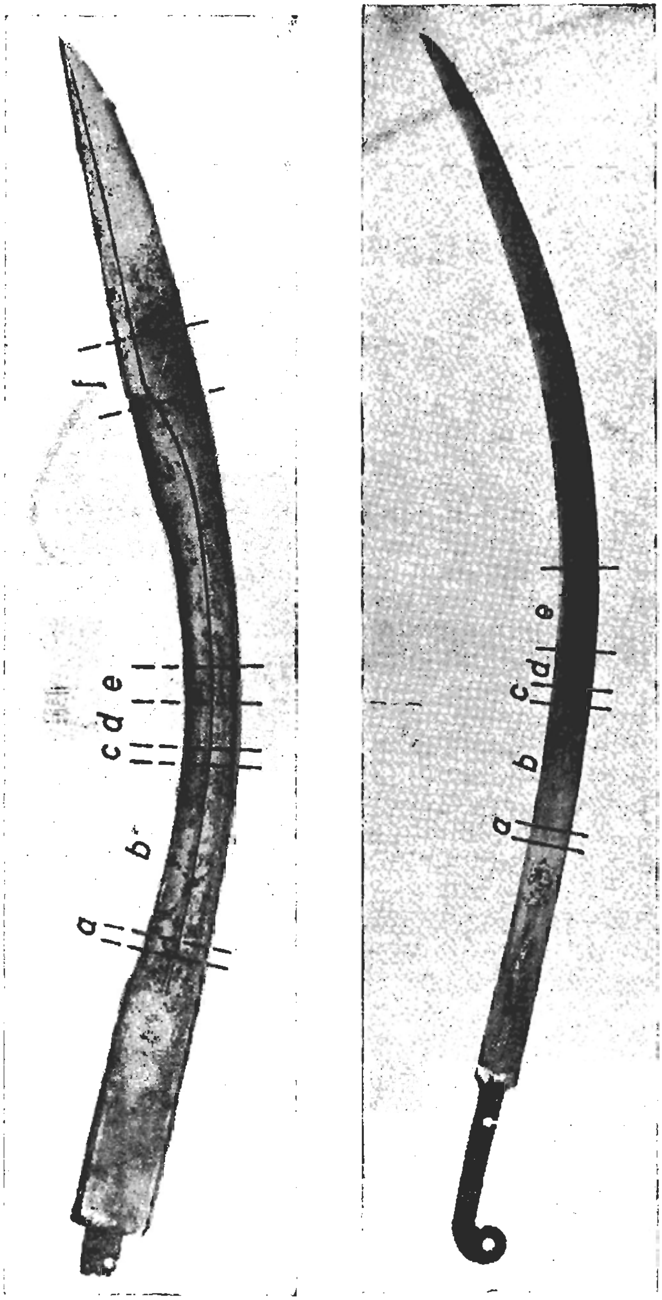

FIG. 10. *Oriental damascus blades (Persian) examined at the ISML.* Left: *Kara Khorassan damascus blade* No. 1. Right: *damascus blade No. 2, signed Asadollah (XVI - XVIIth century) (ISML collection of archeological and historical steels).*

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including Elisarow himself, proved incapable of producing a steel similar to damascus, which they had imported from Persia up till then. Hence the obstinate perseverance of Anossow in the research which he had undertaken, which, it would seem, was crowned with a certain success, although merely a partial one, and which at the same time enabled Anossow to acquire exceptional competence in a field which had up till then frustrated the efforts of the best scientists of the period.

We may add parenthetically that there is further to be credited to Anossow the application of the microscope to the study of steels. This he undertook, it would appear, around 1831 that is to say, earlier than any other European metallurgist.

The work of Anossow was subsequently carried on and completed by D. K. Tchernow, professor at the Mikhail artillery academy at St. Petersburg, and more recently by N. T. Belaiew; while on the other hand, from the more properly historical and scholarly point of view, one must not pass over the name of E. E. Lenz. (See preceding note.)

But one is forced to say that it was not clarity and concision that characterized these authors, nor can one from the reading of their numerous writing derive a sufficient norm for the interpretation of the various qualities of oriental damascus.

Without making any claim to offer an elucidation of the vexed question of the typology and the nomenclature of the Damascus steels, and retaining the firm conviction that in view of the obvious lack of photographic documentation for reference very little light can come from the haphazard description of ancient and of more recent writers, we list immediately below these types, among the ones most frequently referred to, that may with fairly reasonable verisimilitude retain an adequate individuality. These are as follows:

a) *Kara Khorassan* (or *Charà-Corassan* according to Crivelli): almost black backgroud with beautiful broad undulations as of flowing water.

b) *Kara Taban:* analogous to the preceding, with broad waterings of a brilliant black, but with a tone tending more to gray *(Thaban,* according to the spelling adopted by Crivelli).

c) *Kirk Narduban,* or «Mahomet's ladder», characterized by a more minute undulation and by some forty transverse «steps», almost equidistant, running the entire length of the blade (see Figure 9).

According to the terminology of Crivelli, this type is identical

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with *Kakmerduen* (forty steps), and perhaps also with the *chiermani* mentioned by Biringuccio (6).

d) *Sham*, or Syrian Damascus, comprising the less typical and esteemed sorts.

This list, although far from complete (Lenz collects at least 25 diverse designations), probably contains repetitions, and although quoted on the authority of Anossow, with difficulty admits of a precise attribution. This difference between the *Khorassan* and *Taban* types, for example, is so vague and approximate as to render futile the endeavor to classify a specimen. Nor does the *Kirk Narduban* type, which is easier to individualize, seem to be differentiated from the preceding ones as regards intrinsic quality so much as through its more obvious formal characteristics and through a particular method of working.

According to Tchernow, the *Kirk Narduban* is supposed to have been obtained by taking advantage of the natural disposition of the crystalites in the small hemispherical ingot which is characteristic of *wootz* iron. The little ingot is supposed to have been punched at the center, so as to obtain a sort of ring, which was opened up and then straightened out and extended in the longitudinal sense, in order to get the outline of the blade ready to be finished and polished.

Even though it appears that the learned Russian was indeed successful in obtaining some positive result by following this technique, the most widely held opinion at present (7) is a radically different one, in that the «steps» are considered to be obtained instead through cuts made by a file on the surface of the blade, at regular intervals, just before the last forging. The channels or hollowings thus obtained will have exposed the internal strata which are more flattened out, and the last forging, readjusting and leveling the resultant raised portions between hollow and hollow, will finally have managed to preserve, in the apparent structure after chemical attack against the polished surface, the evident trace of the «steps». Yet it seems to us that this interpretation, even though fairly close to the true one, is not entirely correct. Upon examining closely the photograph in Figure 9, which reproduces a Persian *Kirk Narduban* blade in our possession, it is easy to perceive that the individual «steps» show a finer structure than that of the intervening zones and very similar to that which appears con-

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(6) Vannoccio Biringuccio: *Pirotechnia*, Book I, Chapter VII, p. 19 (Concerning the practice of making iron), Venice (1568).

(7) See C. S. Smith: «A History of Metallography», Chicago (1960), pp. 14-29 which also cites bibliographic material concerning oriental and welded damascus.

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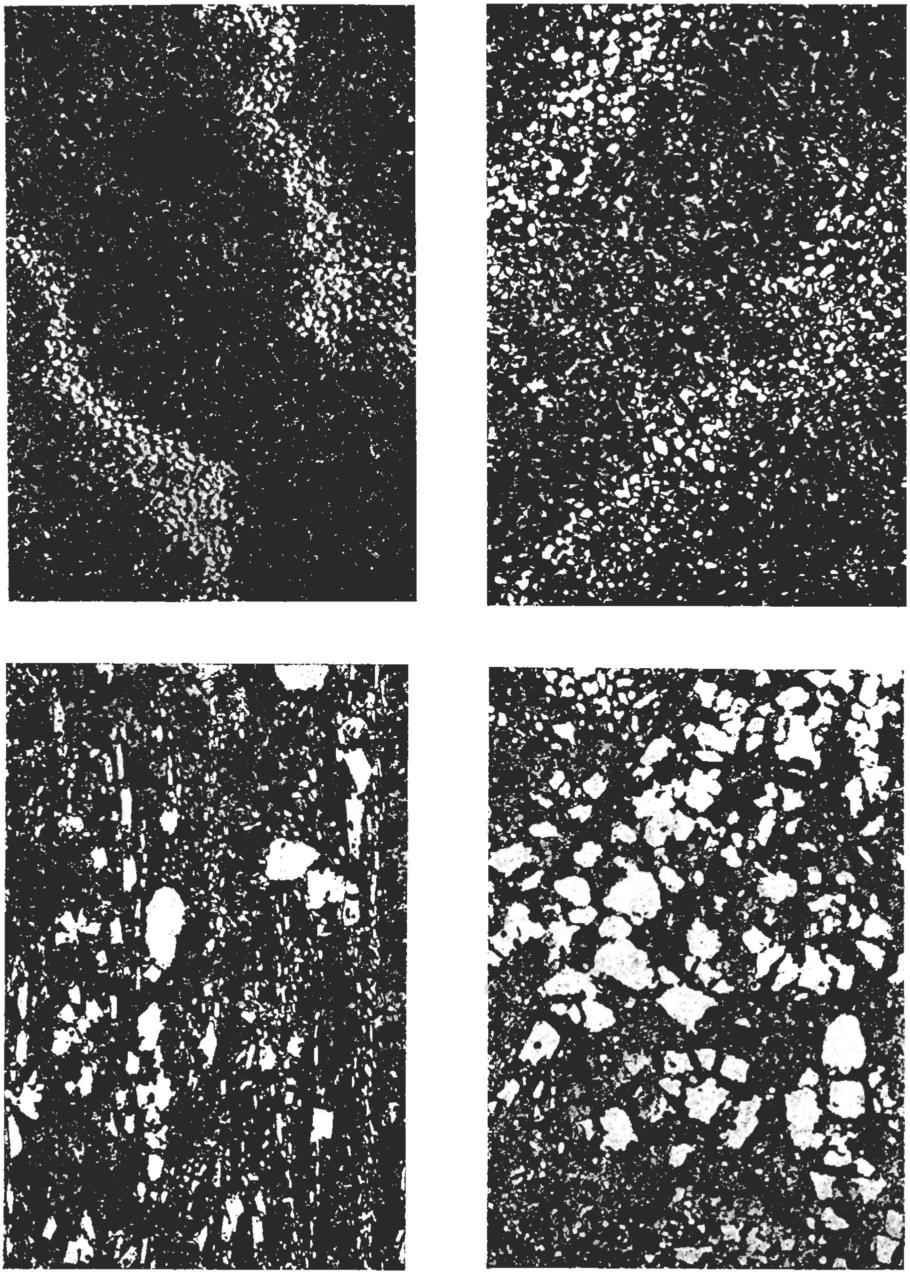

a b c d

FIG. 11. *Micrography of the Damascus steel of blade No. 1. Attack: 4% picral (200 diameters). Under constant optical enlargement the structure of the blade proves to be extremely fine at the cutting edge* (a) *where there are apparent the effects of a partial contact temper. A little away from the cutting edge the structure tends to become coarser* (b) *and at the back (c=transverse; d=longitudinal) the large cementite elements still preserve the alignment traits of the original dendritic crystal.*

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tinuously at the cutting edge, where evidently the action of the hammer during forging is applied at greater length in order to make it thinner. But if the *hollows* had been obtained through the action of cutting with a file, as some authors suppose, it appears to us that the effect should have been manifested in quite the opposite sense, in that precisely in these zones the structure (that is to say,the waves visible after chemical attack) ought to appear broader and more extended, as being less flattened and transformed by the final forging, while in reality exactly the opposite happens.

Thus it appears more probable that the *hollows* corresponding to the steps were produced by hot working, through the local deforming action of a swage having a well-rounded end, bringing out upon the outline a series of constrictions and thus locally reducing the thickness to a point close to the final one. Supposing that the operation was performed on a straight bar and the swage was held at more of an angle toward the desired convexity of the blade, we consider that this technique could furthermore manage to curve the bar itself, along its length, in order to achieve the desired form. Then, removing through the abrasive action of a file or a grinding wheel the resultant parts which have remained raised and which correspond to the distance between step and step, and finally working the surfaces flat, to final completion, the artisan would obtain upon the blade, polished and etched chemically, the natural design proper to this variety of Damascus.

The classifications of Damascus, created by the fervid oriental fantasy, are based now upon geographical origin (for example, *Khorassan, Sham, Hindostani, Kermani, Meshhedi*, etc.), now upon criteria of form (*Koum Hindi* = Indian wave; *Kirk Narduban* = forty steps), now upon color and upon its gradations (*Berd* = full moon; *Sari Hindi* = Indian yellow; *Sobardar* = green; *Taban* = resplendent; *Neiris* = luminous; *Kara Taban* = resplendent black; *Bayaz Khorassan* = Khorassan white).

It is therefore quite probable that a great part of the uncertainties which still exist in the field depend substantially upon our imperfect understanding of early texts and upon the approximative interpretations of European travelers, who often busied themselves with it for mere curiosity and without special technical and linguistic interests and competence, mixing things up through their designations drawn from various indigenous classifications, which were perhaps more rational (as being ordered by appearance, or color, or provenance) than we are now in a position to judge.

In order to give an idea of the confused complication which held away in this field, at a time when the commercial interest of the

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FIG. 12. *Electronic micrograph (6,000 diameters) of the Damascus steel from blade No. 1 (see Figures 8 and 10) in the neighborhood of the back. Islands of primary cementite on a field of little-transformed lamellar pearlite (A C copy, shaded with Cr).*

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FIG. 13. *Electronic micrograph (6,000 diameters) of the Damascus steel from blade No. 1 (see Figures 8 and 10) along the cutting edge (at 0.5 mm from the edge). Islands of primary cementite, partially spheroidized, on ferritic and globulized pearlite field.*

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westerners in Damascus steels were particularly lively, we may recall that J. Barker, British Consul General at Aleppo in the first decades of the last century (8), listed a good ten varieties of them, among these being three types of *Taban* (Khermani-Taban; Dischi-Taban; Erkek-Taban); two types of *Khorassan* (Lahori-Khorassan and Bayaz-Khorassan); *Sari-Hindi; Kaum-Hindi; Lahori-Hindi; Elif-Stamboul;* and finally *Eski-Sham.*

For the purposes of our survey, however, the subtle distinctions of appearance about which so much ink has been spilled, and in the last analysis with such scant result, are not of specific interest. What is important, and what present scientific knowledge achieves with considerable ease, is the definition of Damascus in metallographic terms. According to the scientific criterion adopted at present for the classification of iron and steel products, Damascus steel can in fact be defined as a *hypereutectoid ferrocarbon alloy, with partially and heterogeneously spheroidized cementites*, having a carbon content normally running between 1.2 and 1.8 percent.

A blade of true oriental damascus, whatever its external appearance and provenance, falls within these limits of composition; these exterior characteristics pertaining to it depend solely upon the technological method of working, which varies, within certain limits, from place to place.

As an example, we report immediately below the composition revealed for two specimens examined by us and illustrated in Figure 10, one of which (blade No. 1) we think we can attribute to the *Kara-Khorassan* type (see also Figure 8):

	Blade 1	*Blade 2*
Carbon	1.62	1.42
Silicon	0.027	0.11
Sulphur	0.007	0.038
Phosphorus	0.087	0.035
Manganese	traces	0.13
Nickel	traces	undetected
Chromium	traces	undetected

Thus in both cases we are dealing with hypereutectoid steels, with a high carbon content, of anything but exceptional purity, especially as regards the phosphorus content, which (as is well known) represents a dangerous fragility factor in steels with high carbon content.

(8) J. Barker: «Method of Renewing the *Giohare* or Flowery Grain of Persian Swords Commonly Called Damascus Blades», *Annual Register*, pp. 599-602 (1818).

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At present the non-alloy tool steel with highest carbon content considered by Italian standard norms is type UC 110-UNI 2955, the composition of which we report in Table I, together with some analyses of oriental damascus steels, of welded Solingen damascus, and of bar steels for blades, likewise Solingen.

TABLE I

COMPOSITION OF VARIOUS SAMPLES OF ORIENTAL AND EUROPEAN DAMASCUS STEELS (9)

ORIGIN	PERCENTAGE COMPOSITION (residue Fe)				
	C	Si	Mn	S	P
Oriental damascus:					
Dagger blade...	1.677	0.015	0.056	0.007	0.086
ditto	1.575	0.011	0.030	0.018	0.014
Saber blade ...	1.874	0.049	0.005	0.013	0.127
ditto	1.342	0.062	0.019	0.008	0.108
ditto	1.726	0.062	0.028	0.020	0.172
Solingen type:					
Welded damascus (average)	0.606	0.059	0.069	0.007	0.024
Bar steel for blades	0.499	0.518	0.413	0.038	0.045
UC 110-UNI 2955 steel	1.05-1.20	max 0.30	max 0.30	max 0.03	max 0.03

As can be seen from Table I, the exceptional purity attributed by some authors to oriental damascus steels is thus one of those commonplaces which must be re-examined, inasmuch as it would appear not a matter of course, but in certain respects extraordinary, that the primitive artisans should be able to produce materials, the technology of which is so difficult, with a degree of purity that, although it is in no respect exceptional as compared with what can be done today, must be considered so through the absence among the ancients of any means of checking, save the drastically conclusive one of forging.

The purity of some examples of oriental damascus as regards the figures for sulphur content appears, on the other hand, very high; not

(9) B. Zschokke: «Du Damassé et des lames de Damas», *Revue Métallurgie*, XXI, pp. 635-669 (1924).

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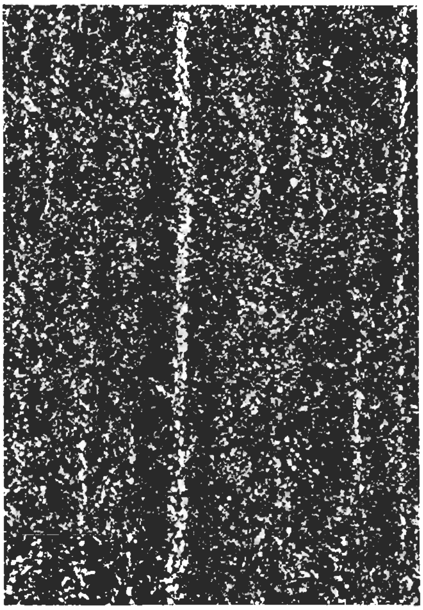

FIG. 14. *Micrographic structure (200 diameters) of Damascus blade No. 1. Transverse section near the cutting edge (200 diameters). Parallel alignment of the cementite crystals profoundly transformed by forging. Attack: 4% «Picral».*

unnaturally, considering that these materials were produced exclusively on a basis of wood charcoal.

Considering that a steel of this type is the more hot-short the greater the phosphorus content is, it is thus very probable that a high percentage of «loaves» (i. e., small billets) of damascus went bad and were discarded during the first hot shaping of the blade, and that only those which stood up through the entire technological processing derived from a steel *fortuitously* endowed with the necessary purity.

These considerations were sufficient to justify the very high price of a good damascus blade in the markets of the period and the fact that the «loaves» of *wootz* imported to the West, ones probably not selected from among the best quality, only in exceptional cases proved to be susceptible of hot working, even though entrusted to expert smiths such as those of the famous steel works of Sheffield, who were moreover guided and checked upon by the best metallurgists of the time, like Stodart and Faraday, who spoke at length of this difficulty.

On the other hand, the composition of the oriental damascus steels, characterized as it was by a carbon content generally far above the eutectoid point (0.8 % C) of the Fe-C system, involves a notable degree

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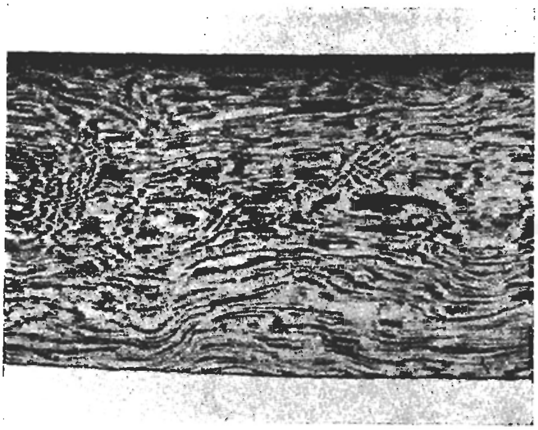

FIG. 15. *Oriental (Persian) damascus of blade No. 2, illustrated in Figure 10 (1.5 diameters).*

of structural instability, due to the fact that the iron carbide Fe_3C (cementite) does not represent the most stable state of equilibrium in the system. Cementite, in fact, tends to decompose, in the course of a long heating in the interval 730-1,000° C (for a steel with 1.5 % C), in accordance with the reaction:

$$Fe_3C \longrightarrow 3Fe + \text{graphitic C},$$

this transformation being favored by antecedent heating to above 730° C, followed by relatively rapid coolings and permanent plastic deformation.

In the case of oriental damascus, the intrinsic difficulty of forging

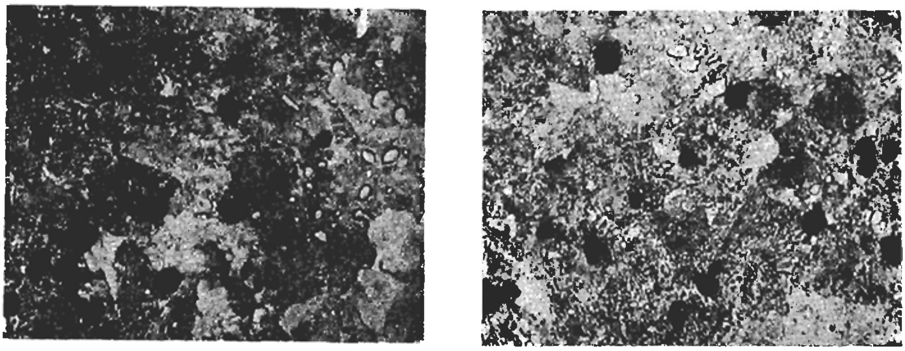

FIG. 16. *Micrographic structure (500 diameters) of blade No. 2. Nodules of decomposition graphite on a field of very fine globular pearlite and of roundish grains of primary cementite.*

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and the limited useful interval of hot plasticity obliged the artificer to carry out numerous reheatings, which were followed, especially in the first phase of shaping, by slight deformations. Hence the material being worked underwent the compounding effects of a rather prolonged holding at temperature between 730 and 1,000° C, with consequent inherent danger of a partial decomposition of the cementite, and of the formation of spheroidal micro-elements of annealing graphite.

And in fact, the *precise* metallographic and chemical analysis of an oriental damascus steel *almost always* brings with it the revelation of more or less elevated quantities of graphite, with consequent fallingoff in the qualities of hardness and tenacity. For example, blade No. 2 examined by us (see Figure 10), subjected to specific analytic check, showed that of 1.42 % total carbon 0.3 % was present in graphite form, a circumstance subsequently confirmed by microscopic examination (see Figure 16), which brings clearly into evidence the presence of typical radiate globules of annealing graphite. It should be noted that this blade is signed by *Asadollah* or *Asadullah*, one of the most famous bladesmiths of the period of Shah Abbas (1588-1629).

The tendency to graphite formation, and the consequent fragility, certainly constituted one of the greatest obstacles in the way of the western efforts to reproduce oriental damascus, at a time when the complex chemical-physical mechanism of the phase transformations of Fe-C alloys was little known, if at all.

Nowadays it is known that some elements, such as chromium (but not titanium, vanadium, and niobium) act in hypereutectoid steels as stabilizers in the transformation of cementite into iron and graphite; and in fact, in modern steels of this type the addition of chromium impedes the formation of graphite, a defect which is instead found, with some frequency, when this element is absent.

The narratives coming from numerous European travelers and students, from Tavernier to Chardin, from Buchanan and Wilkinson to Anossow, and from Tschernow to Belaiew, are almost completely in harmony on the early oriental techniques for the preparation of damascus steel. It turns out that the classical working methods can be regarded substantially as two: the *Indian* method and the *Persian*.

According to the Indian method, the purest iron ore was introduced into a crucible, mixed with teak and bamboo charcoal. The crucible, hermetically sealed, was kept for many hours at the temperature of incipient fusion and was afterwards allowed to cool very slowly indeed. When the crucible was broken there was found in the bottom of it a compact mass of iron, of roughly hemispherical form, which was generally broken in half to reveal possible imperfections and placed

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on the market in this form under the name of wootz (or Indian iron). But this process presupposed the availability of rich and rather pure iron ores, not always to be had and of limited distribution. Thus it is understandable that only a few, privileged localities could devote themselves to this technique, whence the protracted Indian monopoly of *wootz.*

The second method, on the other hand, seems to have been developed and perfected in Persia precisely by reason of the lower local availability of esteemed ores; a centennial experience in forging, acquired on material imported from India, was brought to fruition here. According to the Persian method, the starting material was thus not iron ore, but soft iron, much less costly even though partially imported. To this end there was also used iron scrap, subjected to a treatment of partial corrosion or of wear, which served to eliminate the parts that were less pure and thus were more easily affected by chemical or mechanical action; for this purpose old horseshoes and their attendant nails were particularly esteemed, following a practice also used, as we shall see, by the artisans of early Europe.

This soft iron was then processed in a crucible, probably with the same technique employed in India for *wootz,* through additions of wood charcoal or perhaps also of strongly carburised iron (cast iron), without the temperature of complete fusion ever being reached in this case either, but still by heating the metallic mass for many hours between the limits of coexistence of the liquid and solid phases, which run around 1,400 and 1,250° C approximately, depending on the carbon content.

According to the narratives of western travelers who during the past century attentively observed the indigenous production of oriental damascus (10), the small crucibles containing the carburized iron were kept for 24 hours and more at the required temperature and were then allowed to cool very slowly, in such fashion that the separation of the cementite from the pasty mass might take place in the desired dimensions, in the form of long dendritic needles. The cooled «loaves» were then covered with clay and, according to Malcolmson (9) (Malcohnson in original) (see same note), were kept for 12 or 16 hours at a temperature of 800-1,000° C, and then cooled again. This operation was repeated three of four times, until the metal became sufficiently plastic to be forged with discrimination.

In present-day metallographic terms, we thus have here a spheroidizing annealing of treatment, apt for bringing the structure into a condi-

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(10) SEE W. EGERTON: «An Illustrated Handbook of Indian Arms», London (1880).

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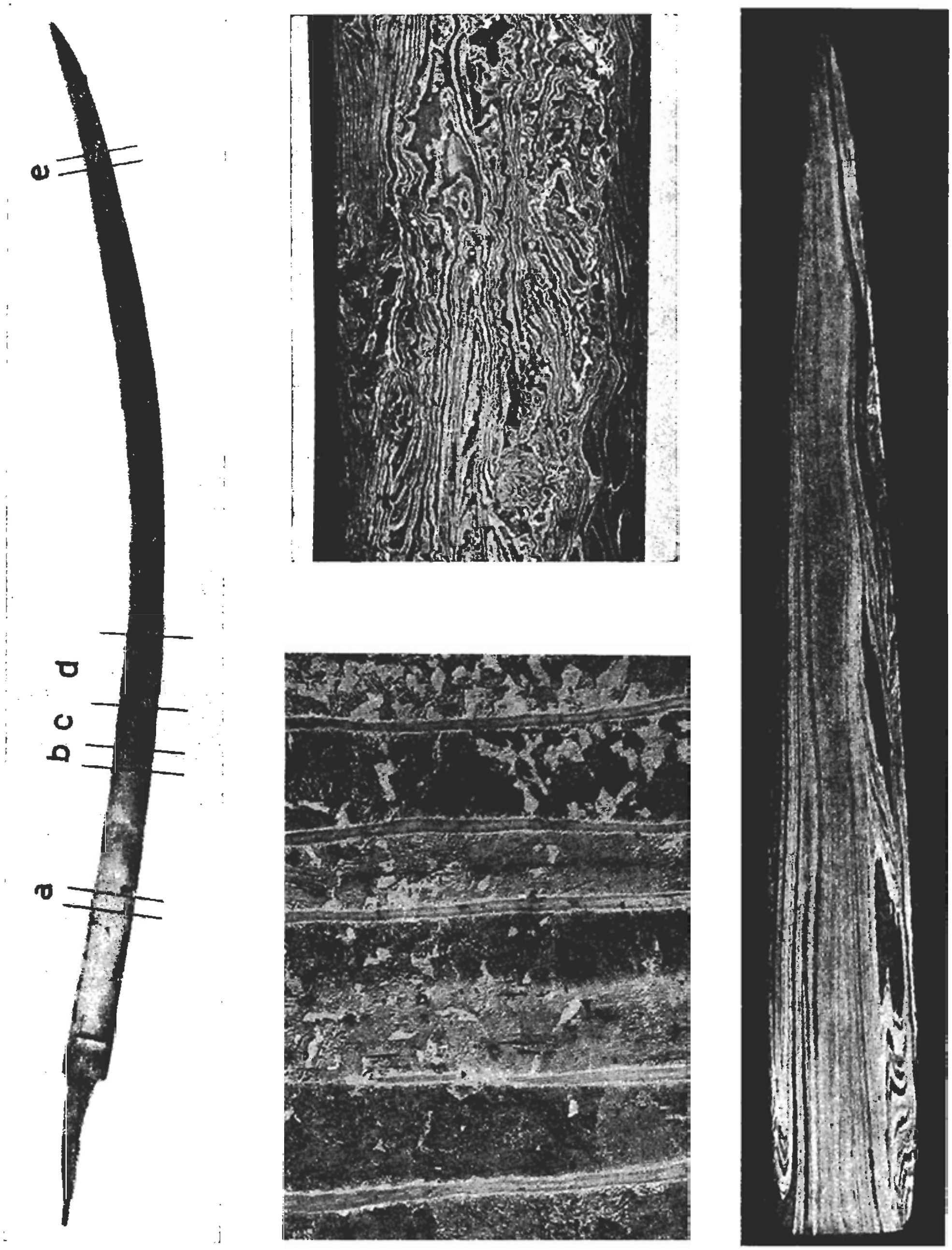

FIG. 17. *Blade of western saber, in figured welded damascus (XIXth century), examined at the ISML.* Left: *Position of the sections examined.* Center (above): *appearance of the Damascus on the flats on the blade.* (Below): *micrographic structure (200 diameters) of the central part of the blade, after annealing at 800° C and 1% Nital attack to bring out the complex stratification.* Right: *Transverse section of the blade at* (b) *(3.5 diameters) after 5% Nital attack.*

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tion of separation of the cementite in a globular form, as has been seen. The slow cooling from the semi-liquid state, however, involved the precedent separation of a certain quantity of cementite in the form of dendritic needles, which the annealing could modify no further than in part. And it is precisely to these dendritic elements, albeit deformed and broken up by the succeeding treatment by forging, that oriental damascus owes its characteristic appearance which is so much admired.

The micrographs accompanying this study (see Figures 12-13) will serve to demonstrate clearly, even to those who are not specially versed in metallographic studies, everything that we have summarily set forth up to this point. Particularly the electron micrographs at 6,000 magnifications obtained by our institute from the Kara-Khorassan blade No. 1 (the first, we believewe, that have been executed through this technique on oriental damascus steel), show clearly that the spheroidisation of the cementite into very minute globular elements was almost completely obtained only in the zones closest to the cutting edge, where the plastic deformation was carried furthest and the original dendritic aggregations of cementite were thus most intensely shattered and finely fragmented.

But in the regions closest to the back, particularly where the thickness is much greater and the work of plastic deformation was consequently carried less far, the globular grains of cementite are manifestly immersed in a pearlitic matrix which is still clearly lamellar, while there are particularly evident here the shattered and haphazardly compacted remains of the original needle-like crystals of cementite.

This demonstrated that the general degree of plastic transformation undergone by the original «loaf» was relatively low, and it likewise confirmed what is reported in the narratives of the western observers, who insisted upon the fact that each «loaf» of *wootz* could serve, as a maximum, for the preparation of two normal saber blades.

The micrographs at lower enlargements (optical) show, with all the clarity one could wish (see Figure 11), the origin of the more and less bright bands of the *jauhar;* these are due to the greater or less local frequency of the original dendritic elements of cementite; a frequency owing its origin to their differing degree of minute fragmentation and condensation upon the field of pearlitic eutectoid.

Naturally a steel of this type would be excessively brittle if it was exposed to a drastic hardening; and in fact none of the examples observed by us showed signs of treatment of this sort. Only in the neighborhood of the cutting edge is there sometimes noted a special structure, probably due to so-called *contact quenching*, brought about

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FIG. 18. *Etruscan lance head of layer-welded damascus, found at Montefiascone (IV-IIIrd century B. C.).*

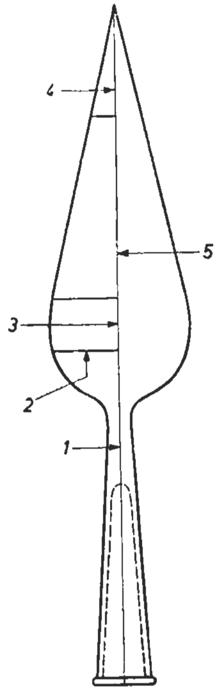

FIG. 19. *Sections of the lance head in Figure 18 examined metallographically and analytically (electronic sonde) at the laboratories of the ISML.*

by local chilling due to the action of the hammer upon a thin section at the lower limit of forgeability, which is found around 800° C.

As regards this question, we believe that anyone who has followed us patiently will spontaneously experience curiosity regarding a concise reply to a question which we may formulate as follows: is oriental Damascus steel indeed the best the metallurgical art of the ancients contrived to produce?

Despite the flowery oriental legends and the enthusiasms aroused by the rather nebulous narratives of some Russian pioneers in metallography, we hold that the reply can but be a doubtful one. Oriental

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damascus is assuredly endowed with esthetic excellences which sharply distinguish it from any other metallurgical product of the sort, but on the practical and functional plane it cannot bear comparison with the products of the technique (refined and perfected through altogether different means) of other diverse metallurgical traditions, the first among which is that of old feudal Japan.

And if, in reality, the composition and the structure of a good oriental Damascus steel represents the ideal for an instrument intended for delicate and repeated cutting operations, such as a razor, the same cannot be said for sword or saber blades, intended to deal localized, violent, and sudden blows. These limits of functionality were, by the way, so well known to the oriental armorers that very few of them and perhaps none have ever seriously thought of using true *poulad jauharder* for the manufacture of gun or pistol barrels; for this purpose Persians, Indians, and Turks have always generally used a composite material, such as is precisely *welded damascus*, better adapted to withstanding the instantaneous pressures of the explosion shock of gunpowder.

Inversely, once the vogue of the *Turkish scimitar* (introduced by the Napoleonic campaign in Egypt) ceased, the interest in oriental damascus steel and the various attempts at imitation carried out by Stodart and Faraday were addressed essentially toward reproducing its excellent capabilities for taking an edge, which made it the best material known at that time for the manufacture of razors, in which the cutlers of Sheffield were precisely most interested.

In contradistinction to oriental damascus, which by virtue of all we have said is *macroscopically* homogeneous, being derived from a single billet (or «loaf»), the substance which, through an expression perhaps not happy yet by now well established in usage, is called *welded damascus* is composed of a combination of various qualities of steels and of soft iron, worked in such fashion that the cutting function falls to the harder material and the toughness function to the softer. From the macroscopic point of view *welded damascus* is accordingly a material that is typically heterogeneous. This composite structure, at one and the same time hard and tough, of welded damascus was anciently, through a happy transposition of concepts, called «*stoffa*» by Italian writers on technical matters, and «*étoffe*» in parallel fashion by the French ones (a «stuff», a material, fabric, or textile).

«The manner of making *stuffs*», Perret (11) wrote about 1770, «is

(11) J. J. Perret: «L'art du coutelier», Paris (1771-72). We consider *pâté* is probably to be translated through the English *faggot* and the Italian *pacchetto (ferro a pacchetto)*.

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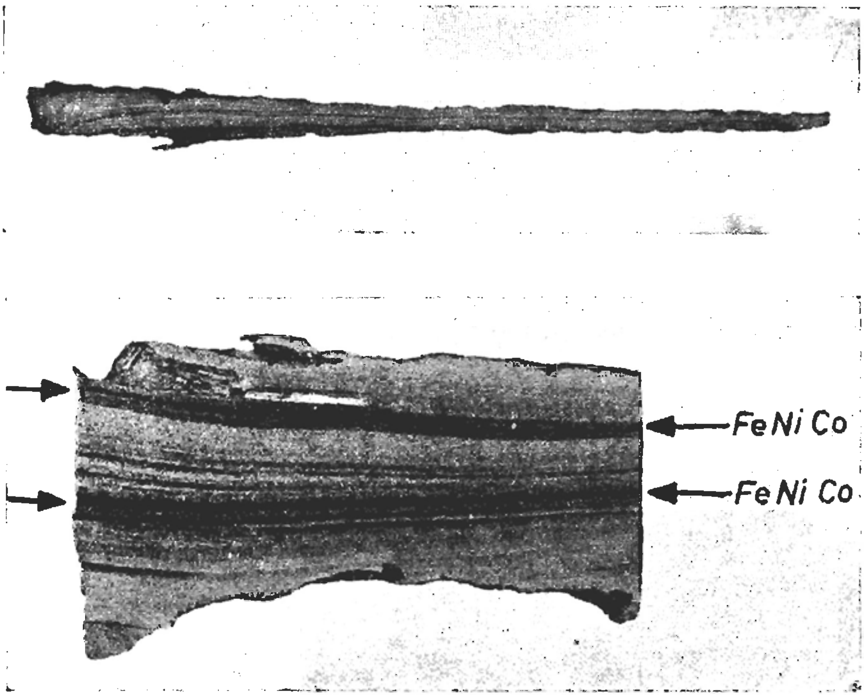

FIG. 20. *Section of the lance point of Figure 18 along plane 5 of Figure 19.* Above: *natural size;* below: *detail (5 diameters) at point 3. There is apparent the typical structure of a layer-welded Damascus and, corresponding to the arrows, the layers of meteoric iron having a high nickel content.*

pretty similar to that of making *pâtés*, that is to say by hammering constantly; with this difference, that the latter is all iron, and that the former is partly iron and partly steel: this is what calls for the most careful attention, both in heating and in forging» (see same note).

The technology of welded damascus is very ancient, surely at least a thousand years older than that of *wootz*, which almost all students are in agreement in holding to have developed in India only round about the first years of the Christian era.

It is in fact known that the most remote antiquity was unacquainted with the art of melting iron and that the product of the primitive hearths in which the ore was reduced with carbon furnished only

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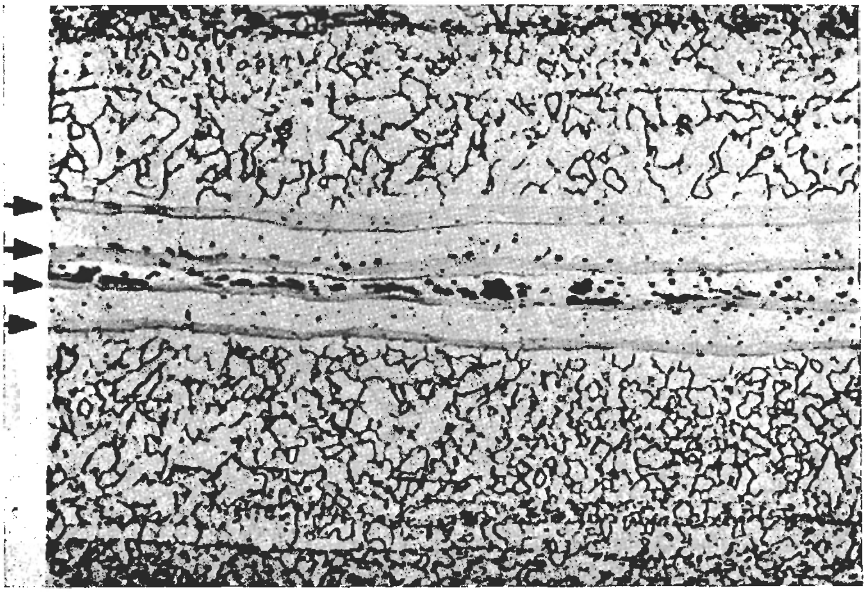

FIG. 21. *Detail (100 diameters) of the layers of meteoric iron from Figure 20. In the central layer the slag which indicates one of the zones of welding is visible.*

spongy masses of metallic iron, ordinarily of modest dimensions, which the smiths quickly learned to work hot, through prolonged hammering calculated to eliminate the slag, through pressure, whereby they obtained what Perret calls a *pâté* and what we could define as a *packed iron (ferro a pacchetto, faggot)*.

The first iron weapons were thus necessarily made up of a whole composed of parts arising from the diverse reduction operations, welded to one another by a long and repeated series of heats and hammerings.

The swords of the Gallic tribes, those of the Hallstatt and La Tène periods, were produced by just this technique (12), and being predominantly composed of iron which was very little carburized, with hard-

(12) Sibrium, III, pp. 129-142 (1956-57); see also, by the same author, the interesting and complete volume «Notes on Prehistoric and Early Iron in the Old World», Oxford (1956).

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ness no higher than 160-200 Vickers, it cannot astonish one that they were the objects of ironical comments on the part of the Latin historians. These tell us how, after a couple of blows, the barbarian warriors had to withdraw from the fray in order to straighten the long blades of their swords by pressing down on them with one foot.

But among other tribes, even much more ancient ones, empirical knowledge of carburized iron (steel) could already manage a considerab-

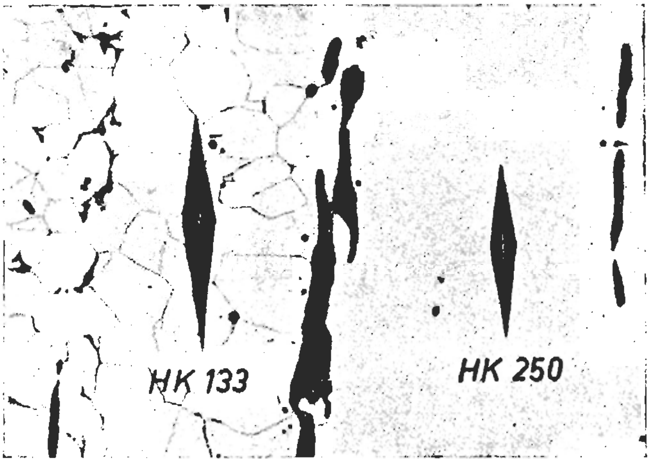

FIG. 22. *The different hardnesses of the carbon steel (HK 133) and the meteoric steel (HK 250) layers brought out by the Knoop prints (300 diameters).*

ly more refined technique for the composed manufacture of sword blades, achieved by carefully alternating the steel strata with the iron ones, as is demonstrated, among other research, by the studies made by the author and by his collaborators on a *kopis* or falchion blade of the Etruscan orientalizing period, found at Vetulonia and surely belonging to the grave furniture of a tomb of the VIIth century B. C. (13).

But as for direct and unequivocal proof for the shrewd knowledge of layer-welded damascus on the part of the Etruscans, the writer was recently able to get it from metallographic analysis of a lance point, found at Montefiascone in a tomb referrable to the IVth century B. C., in proximity to the place where tradition places the famous sanctuary

(13) C. PANSERI, C. GARINO, M. LEONI: «Ricerche metallografiche sopra alcune lame etrusche di acciaio» in «La tecnica di fabbricazione delle lame di acciaio presso gli antichi». Associazione Italiana di Metallurgia. Documenti e Contributi per la Storia della Metallurgia. Milan (1957).

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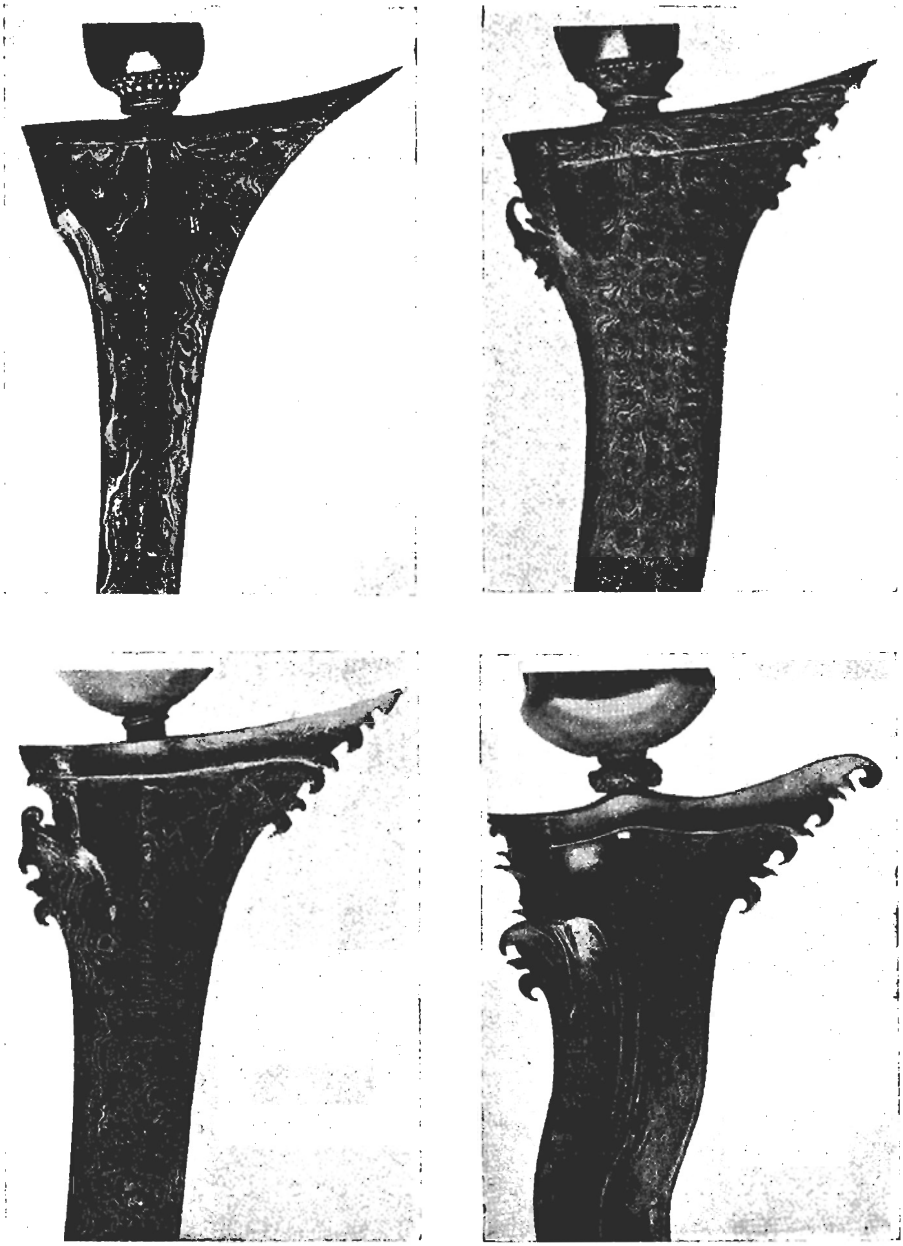

FIG. 23. *Varieties of Indonesian welded damascus in kris blades preserved at the Museo Orientale of Venice.*

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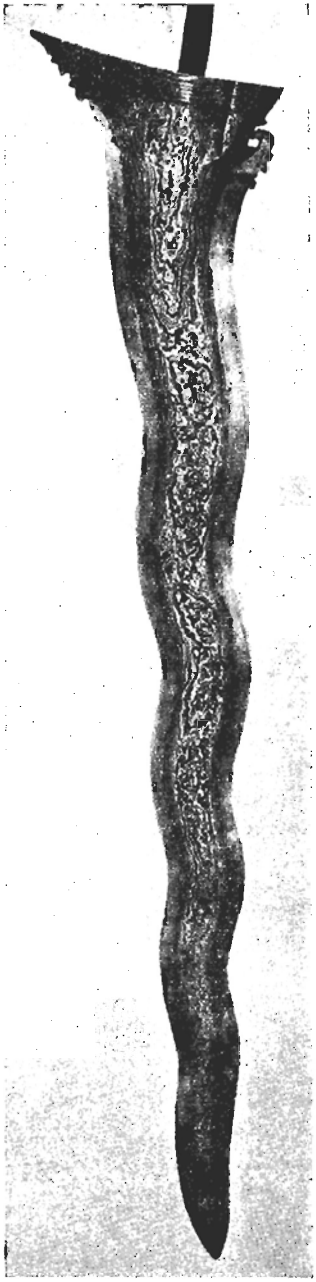

FIG. 24. *Indonesian welded damascus («pamor») in a kris blade (author's collection).*

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of Fanum Voltumnae, at which the greatest representatives of the Etruscan Twelve Cities met annually.

As the material in Figures 18-22 shows, the point was made up of a central layer of hard steel (0.4-0.5 % C), pearlitic, enclosed within two strata of steel having 0.2 % C approximately, these in turn being enclosed within two layers of steel containing 28.8 % of nickel in the one case and 11.0 % nickel in the other (plus 0.1 % of Cobalt), of certainly meteoric origin.

Particularly to be noted is the fact that the artificer was careful to thin and to arrange the two delicate layers of meteoric steel in such fashion as to continue through the entire section of the weapon and to place the central nucleus of hard steel in such a way as to make it form the point and the cutting edge.

The adjacent layers of meteoric steel, laid bare by the refining work, almost certainly constituted a decorative motif, apparent on the two faces of the lancehead as two slender and sinuous bright and shining lines on a darker background.

With this it seems to us that the doubts too lighthy expressed by J. Piaskowski (14) appear entirely devoid of foundation. As it would seem, he would seek to reserve to the populations of the Hallstatt century the knowledge of a technique which we have instead demonstrated to be already perfectly within the acquaintanceship of a people so differently evolved as the Etruscan—one with which, nevertheless, the Celtic and Alpine peoples had frequent commercial contacts.

The meteoric origin of the nickel used by the ancient smith of Fanum Voltumnae, besides being unequivocally revealed by its typical composition (15), is proved by the fact that no iron ore among those which were known and exploited by the Etruscans contains such high percentage of nickel. What is more, the use of meteoric irons (siderites) by the most ancient peoples is well known and documented from the time, and it is moreover certain that the ancients recognized the celestial origin of these (16), so that it is not possible to exclude the hypothesis that the introduction of such slight quantities of this material into the *stuff* of a weapon may have been due to a magic ritual or to individual religious beliefe, as well as to motives of esthetic interest.

The intuition or material knowledge of the extraterrestial origin of

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(14) J. Piaskowski: «An Interesting Example of Early Technology. A Socketed Axe From Wietrzno Bobrka in the Carpathians», Journal of the Iron and Steel Institute, CXCIV, pp. 336-340 (1960).

(15) S. H. Perry: «The Metallography of Meteoric Iron», U. S. Nat. Museum, Bulletin 184. Smithsonian Institution, Washington (1944).

(16) F. G. Zimmer: «The Use of Meteoric Iron by Primitive Man», Journal of the Iron and Steel Institute, XCIV, pp. 306-356 (1916).

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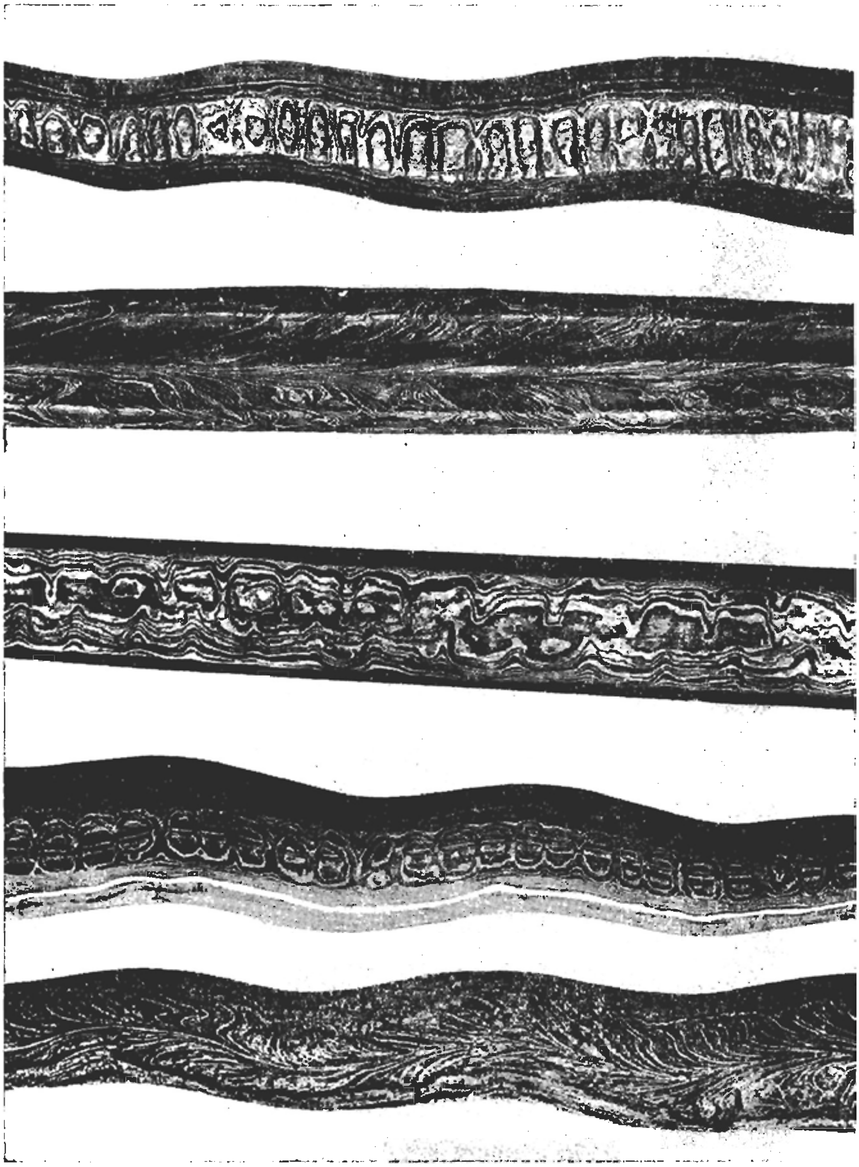

FIG. 25. *Types of Indonesian welded damascus («pamor») in kris blades (courtesy of H. Maryon of the British Museum).*

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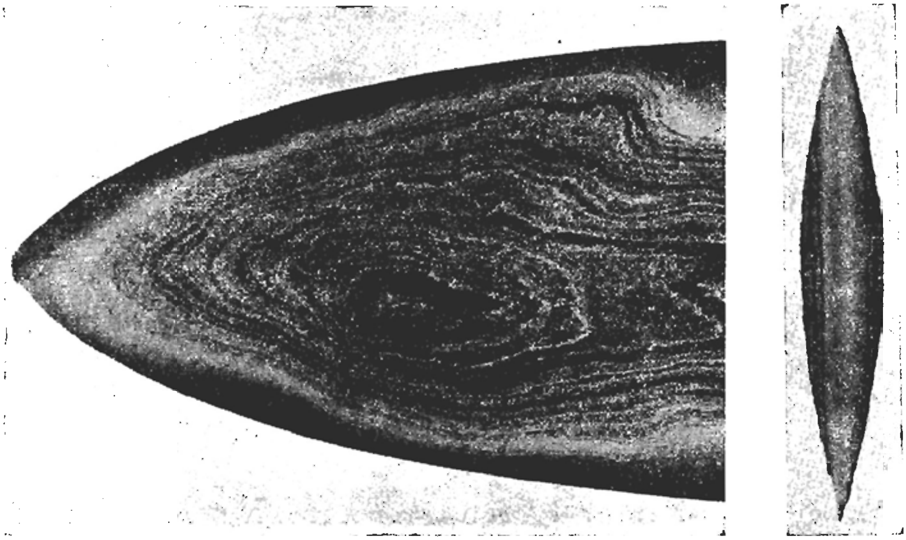
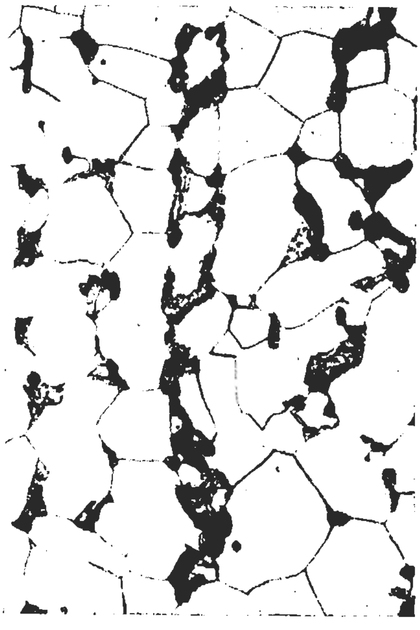
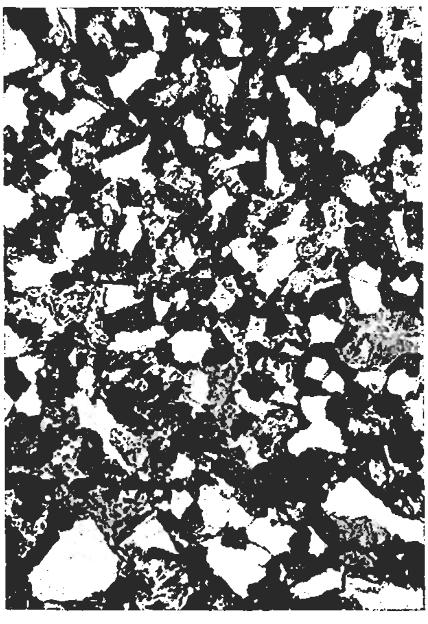


FIG. 26. *Macrographic appearance of the point of a Malay kris.* Left: *(6 diameters) after attack with 5% Nital.* Right: *Crosswise section (10 diameters). The typical superficial stratification of soft iron is visible (see 500-diameter micrograph below, left), and the central part of hard iron (see 500-diameter micrograph below, right). This latter exhibits grains of ferrite and of martensite together with nodes of troostite, indicators of a rapidhardening thermic treatment.*





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meteoric iron among the ancients is documented not only by the numerous legends of the classical world relative to the Cyclops and to the forge of Vulcan from which the thunderbolts of Jove emerged, but also by the fact that in many of the most ancient languages iron is called «metal of (or from) the heavens», as in the Egyptian *ba-en-pet*, the Assyrian *parzillu*, and the Hebrew *barzel*.

According to Zimmer, Greek *sideros* (iron), too, offers a meaning related to the Latin *sidus* (star, planet).

The availability of sideritic masses, of more or less considerable weight, was surely in a relative sense not very exceptional in the first dawnings of human civilization, and, however complex in their utilization, these materials were certainly employed with some frequency by the primitive smiths.

As is well known, meteoric iron is characterized by constant presence of nickel (5 to 26 % Ni) and of cobalt (more than 1 % Co); it further contains more or less discernable traces of carbon, silicon, phosphorus, and perhaps also of copper. In their individual weights masses of meteoric iron may vary from a few kilograms to a number of tons. In general meteoric iron is malleable upon being heated and, through the absence of included slag, it can be worked even better than primitive materials derived from iron ore (17).

But the thing that may truly astonish the metallographer is the perfection of the welding (or fusion) carried out by the ancient artificer of Fanum Voltumnae between the layers of carbon steel and those of meteoric nickel iron; a perfection which only a long and refined antecedent experience can explain, and which at the same time demonstrates how the working of *layered welded damascus* had already for some time become part of the normal practice of Etruscan armorer smiths of the IVth century B. C.

The variety of possible techniques for the production of welded damascus is by the way enormous, the fantasy of the artificer, and various considerations of functional character, contriving to vary in infinite ways the alternation of the diversely carburized zones. Thus we may sometimes see the harder steel enveloping the softer central core; at other times the reverse arrangement is carried out, yet in such fashion that the edge always corresponds, after partial removal of the surface layers of soft iron, to the harder material and to that which is thence more suited to the function of cutting with a blow.

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(17) For further information on the use of meteoric iron in antiquity see also the very recent work of R. F. Tylecote «Metallurgy in Archaeology», London (1962), and that of C. S. Smith «A History of Metallography», Chicago (1960).

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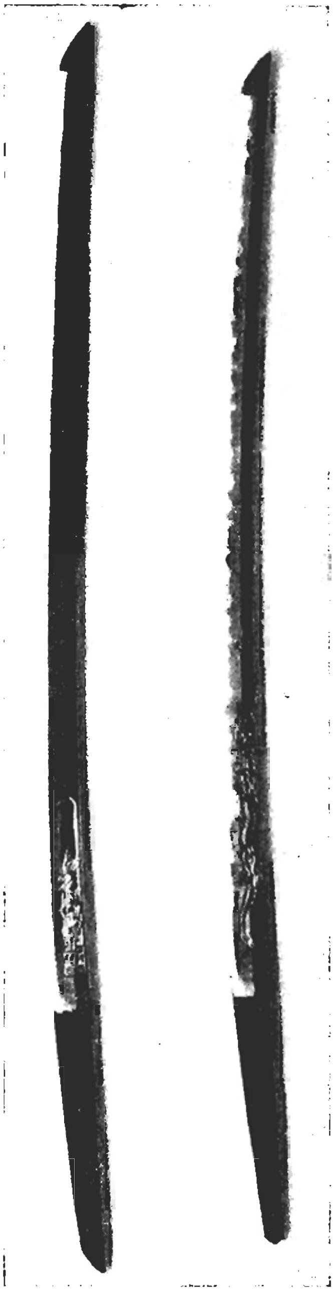

FIG. 27. *Two magnificent examples of Japanese blades of the Shinto period, signed Hankei Noda (1646) and Miōju Umetada (1632), at the Victoria and Albert Museum, London (C. S. Smith; see note 20).*

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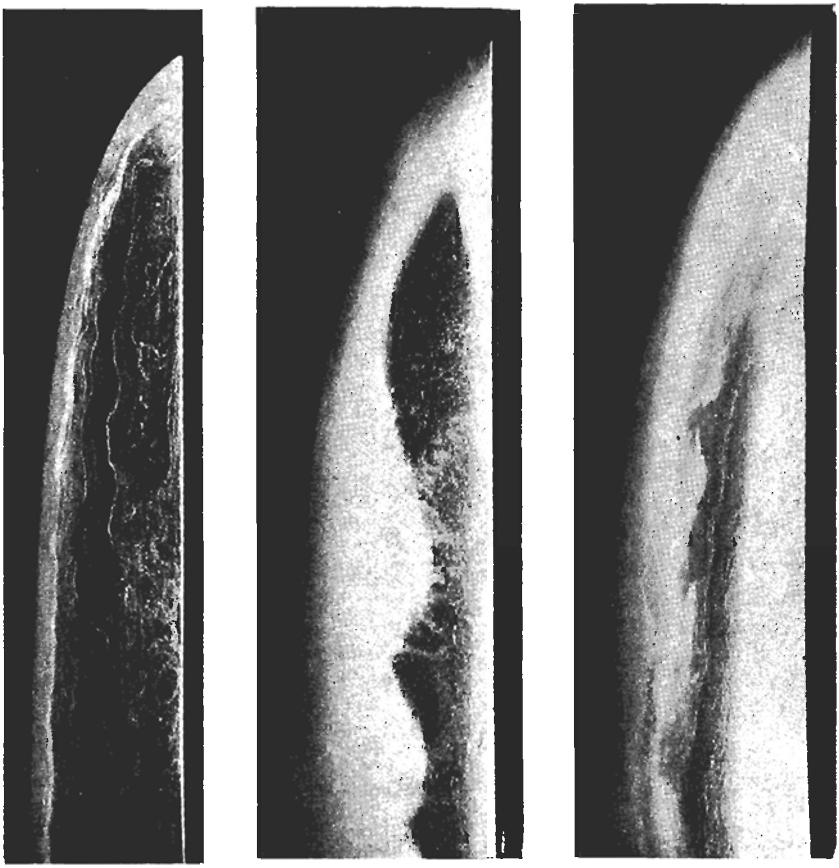

FIG. 28. *Japanese «wakizashi» points of good school, with evident damascus effect (see C. S. Smith; note 20).*

In each case there was ensured, through long and laborious forging, the elimination of the slag which in fagotted iron and in welded damascus always constituted the greatest danger and the point of least resistance to stress.

The transition from simple *layer-welded damascus* to *pattern-welded damascus* is not easy to locate in time; or at least the elements, subjected to a sufficient number of observation, which would necessary in order to establish this point are lacking.

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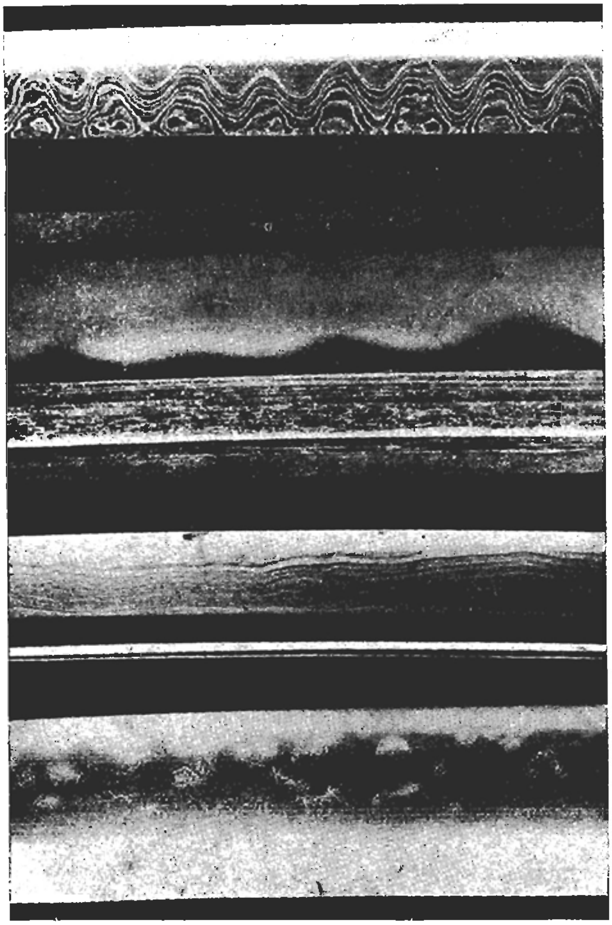

FIG. 29. *Characteristic appearance of outstanding Japanese sword blades, with evident damascus effect on the hardened cutting edge (C. S. Smith; note 20).*

It has nevertheless been determined that pattern-welded damascus with external designs commences to be soundly documented toward the IIIrd century A. C.

In the VIIth and VIIIth centuries this technique (18) is at its height

(18) M. FRANCE LANORD: «Les épées damassées du V à X siècle», Bulletin archéologique, Paris, pp. 193-202 (1950).

Id., «La technique du Damas dans les épées mérovingiennes et carolingiennes», Revue Historique de Lorraine, LXXXVI, pp. 25-32 (1949).

H. R. ELLIS DAVIDSON: «The Sword in Anglo-Saxon England: It's Archaeology and Literature», Oxford (1962).

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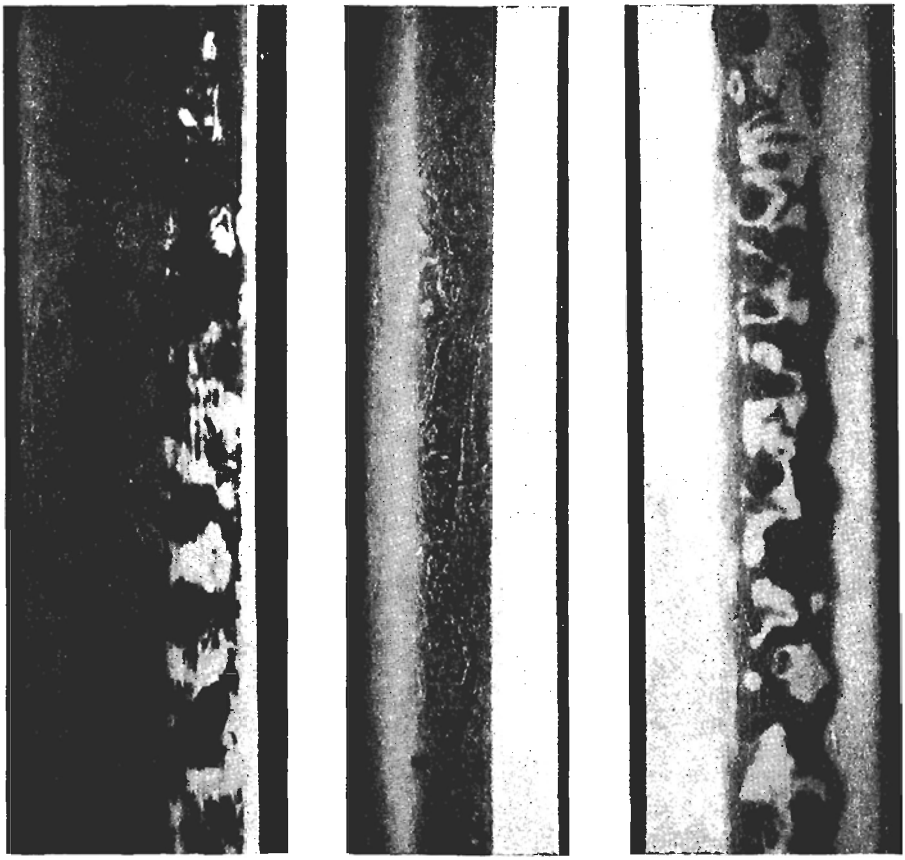

FIG. 30. *Damascus effects on Japanese blades.*

in Europe, in the Frankish and Viking barbarian arms. This is a technique which declines, and practically disappears toward the end of the XIIth century, when a return is made to the old technique of layer-welded damascus.

It does not seem improbable that this return to the older tradition should be ascribed to technical refinements introduced round about the time in defensive armaments, which became heavier and more ef-

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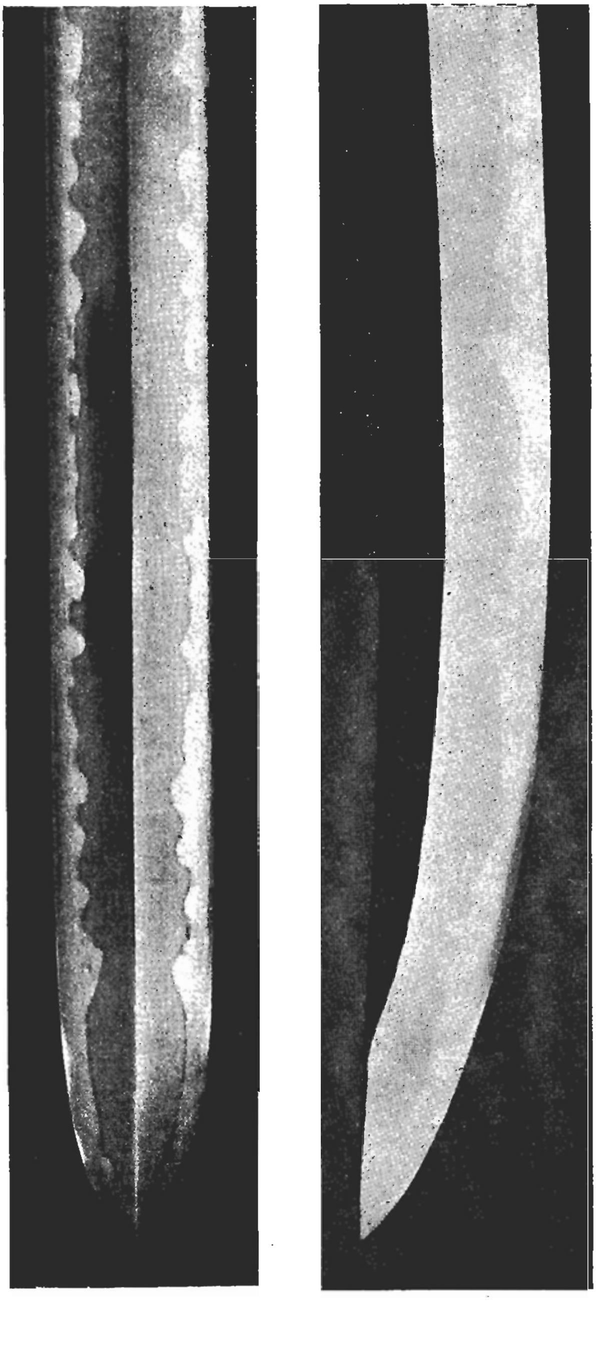

FIG. 31. *Characteristic appearances of «yakiba» in two Japanese blades for pole-arms.*

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ficient, and made necessary the use of offensive media of adequate effectiveness and sturdiness.

In reality pattern-welded damascus, while it brought about the achievement of an esthetic effect which was unquestionably attractive, through the elaborate folding and twisting of a layered faggot of alternating strata of steel and iron, did not manage to produce a homogeneously hard and resistant edge. And in fact, whether in the oldest

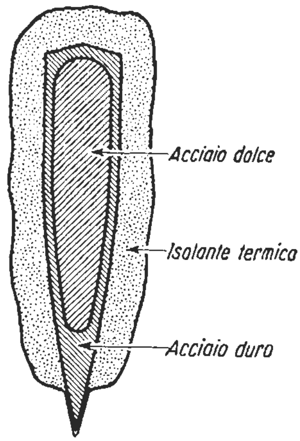

FIG. 32. *Diagram of the system of differential hardening adopted by the Japanese bladesmiths in order to secure the characteristic hardened edge («yakiba») of their blades. (Legend, top to bottom.) Low-carbon steel; Thermal insulation; High-carbon steel.*

examples of the Roman *gladius* found in the Nydam peat-bog (about IIIrd century A. D.) or in the Merovingian, Carlovingian, and Viking blades, only the central part of the flat of the blade was of pattern-welded damascus, while the two edges were of simple hard steel, welded on at a high temperature. In certain respects one must therefore consider that the seeking for a decorative effect represented in these blades was a functional step backward, as regards the technical merits of a good layer-welded damascus blade; a sort of decadent estheticism paid for in barbarian fashion at the cost of quality.

This barbarization phenomenon, by the way, has registered itself in very much the same fashion in the arms of the Far East, where it is precisely a baroque seeking for decorative effects that had led to the spreading of edged weapons considerably less meritorious than those of Japan itself, in which the maked and rational simplicity of the blade took the place of any striving for terrifying or decorative effect.

Among the masters of the baroque art of manufacturing blades of the most diverse and elaborate figured effects, although of strange

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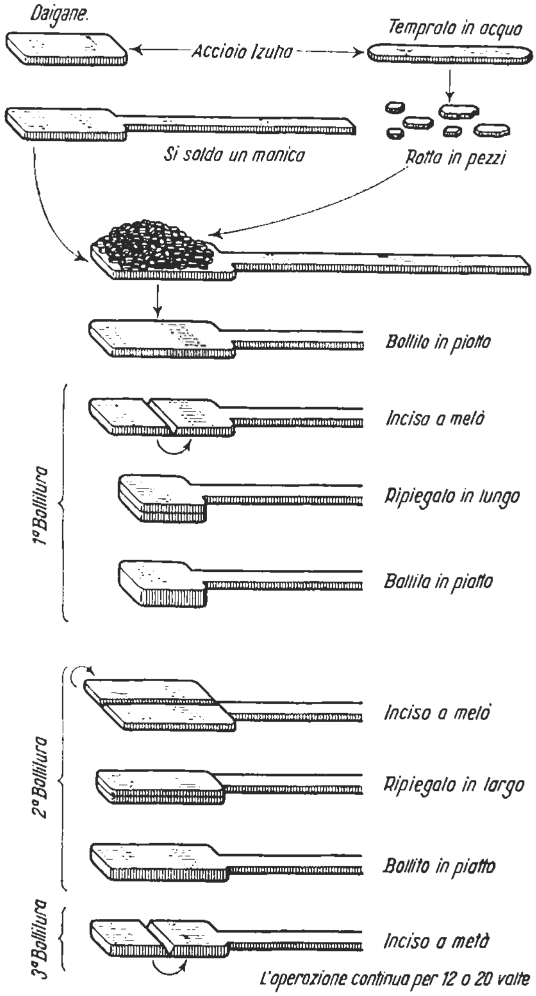

FIG. 33. *Method of preparing the hard steel used for the cutting edge of a Japanese blade of the old school, after Chikashige, «Oriental Alchemy», Tokyo (1936). (Legend top to bottom) Daigana, Izuha steel, Quenched in water; A handle is welded on, Hammered into pieces; (The first welding) Welded to one sheet; Cut in the middle; Folded back; Welded to one sheet; (The second welding) Cut in the middle; Folded back; Welded to one sheet; (The third welding) Cut in the middle. The operation is continued 12 to 20 times.*

shapes, were in fact the smiths of the Indonesian archipelago, in their kriss, almost always with serpentine blades. Figures 23-26 offer a few examples of this art and of the various types of their individual type of damascus, locally called *pamor*.

In these cases, too, what we are dealing with is welded damascus, made up, as regards the central portion, of hard steel, perhaps also

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of meteoric origin (19), and as regards the outer ones, of layers worked in soft steel or in pure iron.

The figured effects are generally obtained in these cases by hollows produced through removal of material from the outlined faggot, through a technique not unlike that described earlier for the Kirk Narduban or «Mohammed's ladder».

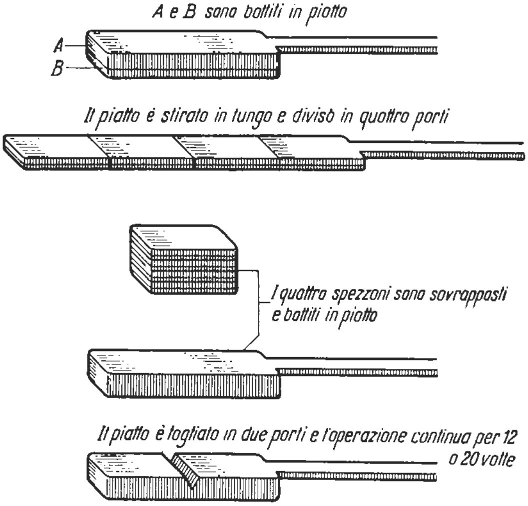

Fig. 34. *Variant on the forging method illustrated in Figure 33. (Legend, top to bottom) A and B are welded together; Forged into an oblong piece and cut into four pieces; The four pieces are piled one upon another and are welded flat; The flat is cut into two pieces and these are piled one upon another, and the operation is continued 12 to 20 times.*

The naked stylistic purity of the blades of ancient feudal Japan, on the other hand, veils a highly refined executional technique and a shrewd striving for functional perfections, which has no comparison with any other technical tradition, oriental or occidental. The technique of layer-welded damascus was indeed carried by the Japanese smiths to a limit of refinement which is today almost inconceivable; suffice it to remark that the steel which made up the dihedral angle of a good *katana* or *tachi* blade was derived from a *stuff* folded through

(19) In 1797 there fell at Prambanan, in the island of Jawa, a gigantic meteor weighing about 8,000 kilograms, analysis of which showed a nickel content of 5.91%. This material, the utilization of which was monopolized by the Sultan of Sulu, was used for the manufacture of numerous kriss blades, some of which are still preserved at the Vienna ethnographical museum. In the greater number of cases this material was, however, used in small quantities, mixed with ordinary iron and steel, in order to obtain particular effects in the *pamor*.

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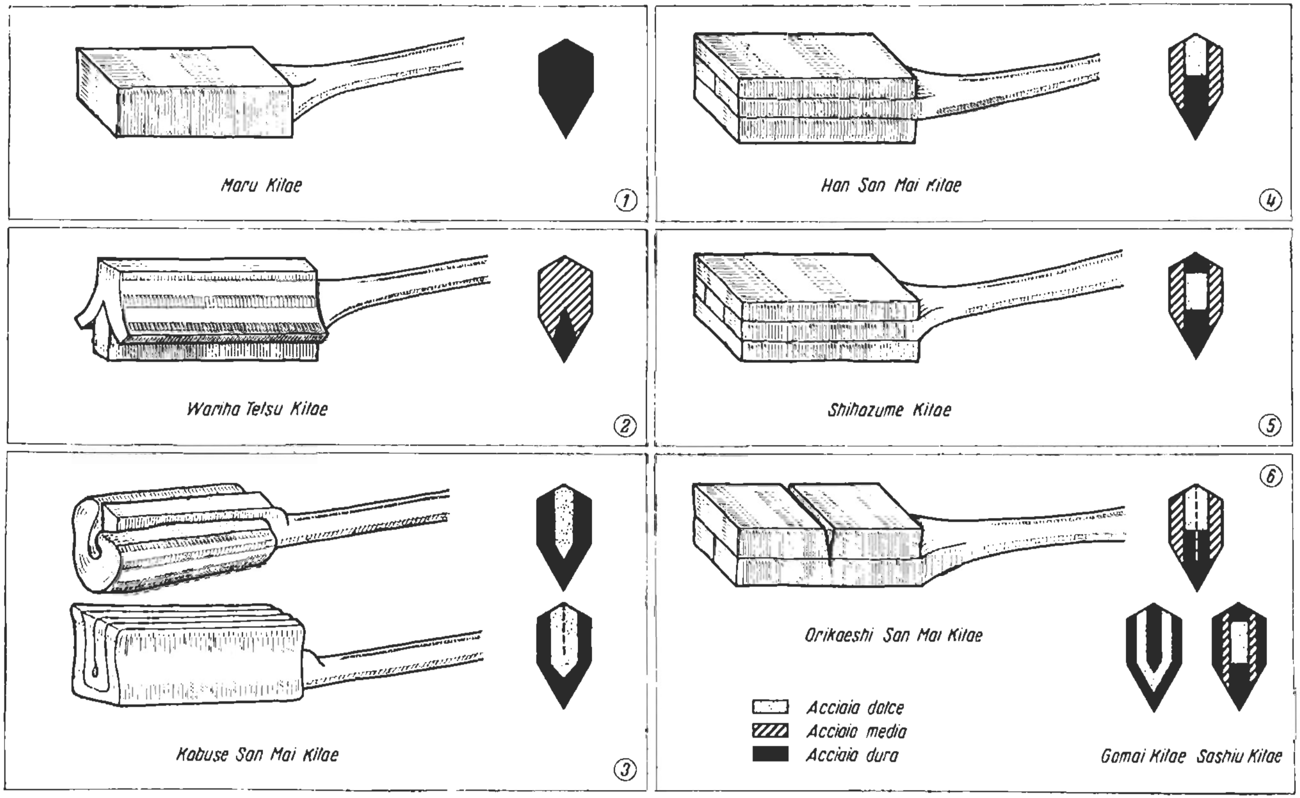

FIG. 35. *Method of making Japanese sword blades, according to various schools. Method 1 was limited to the production of short blades for daggers; the blade could be layer-welded. Method 6 is one of the most elaborate, and is found only in blades of high quality. The «Gomai Kitae» variant pertains to the Old Bizen and Old Soshu schools; that of the diagram to the right («Soshu Kitae») pertains to the school of Masamune of Sagami (about 1288 A. D.), one of the most celebrated Japanese artificers (from W. M. Hawley, 1962). In all the diagrams the hard steel is understood as being prepared according to the techniques illustrated in Figures 33-34.*

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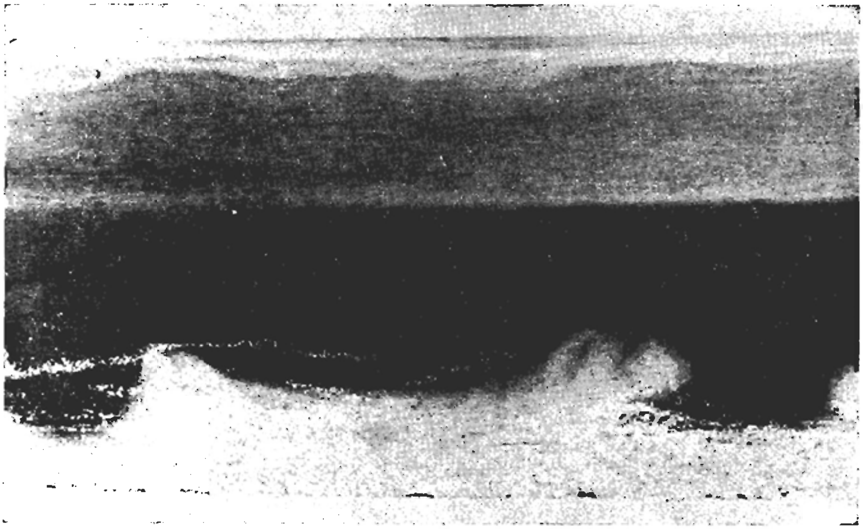

FIG. 36. *Martensitic zone («yakiba») in a Japanese blade of the XVIth century. Nital attack (2.2 diameters) (C. S. Smith; note 20).*

superposition and forged out 12 to 20 times, which brings us to the incredible final number of 4,000 to one million alternating strata (i. e., from two to the twelfth power, to two to the thirtieth power), respectively of more and of less carburized iron, which the incredible dexterity of the smith succeeded in keeping always distinct and differentiated (see Figures 33 and 34).

Moreover, in the cases of various artificers belonging to a single school this extremely elaborate type of steel was made up in various ways with one or more parts of softer steel, as is shown schematically in Figure 35.

At length the blade after final forging and after shaping with the file and with abrasive stone is subjected to a differential hardening, through a coating of refractory clay, thinned at the parts (the cutting edge) where the blade must be hardest (martensitic). The mirror-like polish to which the blades were finally subjected, through the progressive action of abrasive stones, up to the extremely fine one called *uchigomori,* conferred upon the hardened cutting edge the characteristic effect, called *yakiba,* which might vary as the artificer chose, by reduc-

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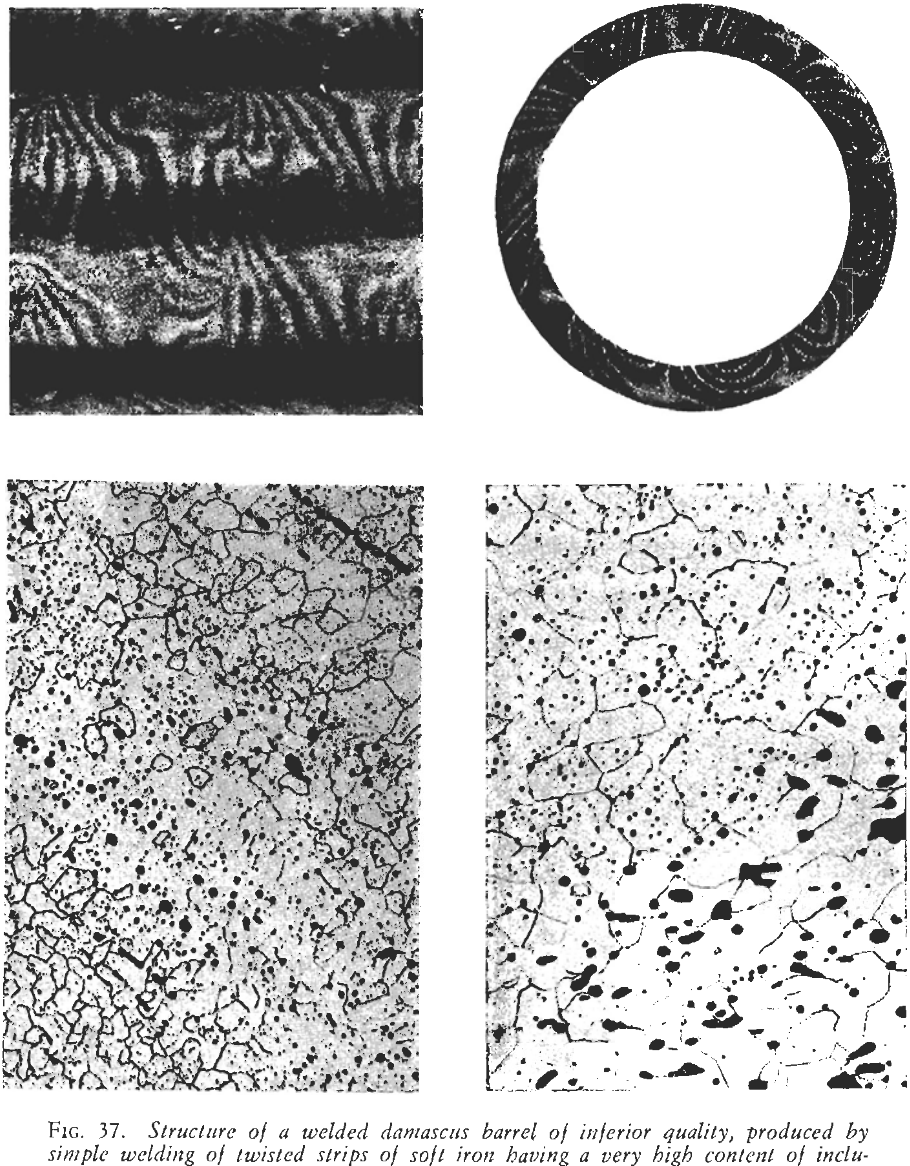

FIG. 37. *Structure of a welded damascus barrel of inferior quality, produced by simple welding of twisted strips of soft iron having a very high content of inclusions. The varied appearance of the waves of damascus is produced solely, in this case, by the diversified inclusion contents of the elements making up the «stuff».* Above: *View, and section, of the barrel.* Below: *(100 diameters) Disposition of the inclusions in one tangential section of the barrel. 5% Nital attack.* Left: *(200 diameters) Transition zone between two bands of ferrite with inclusions of varying sizes and shapes.*

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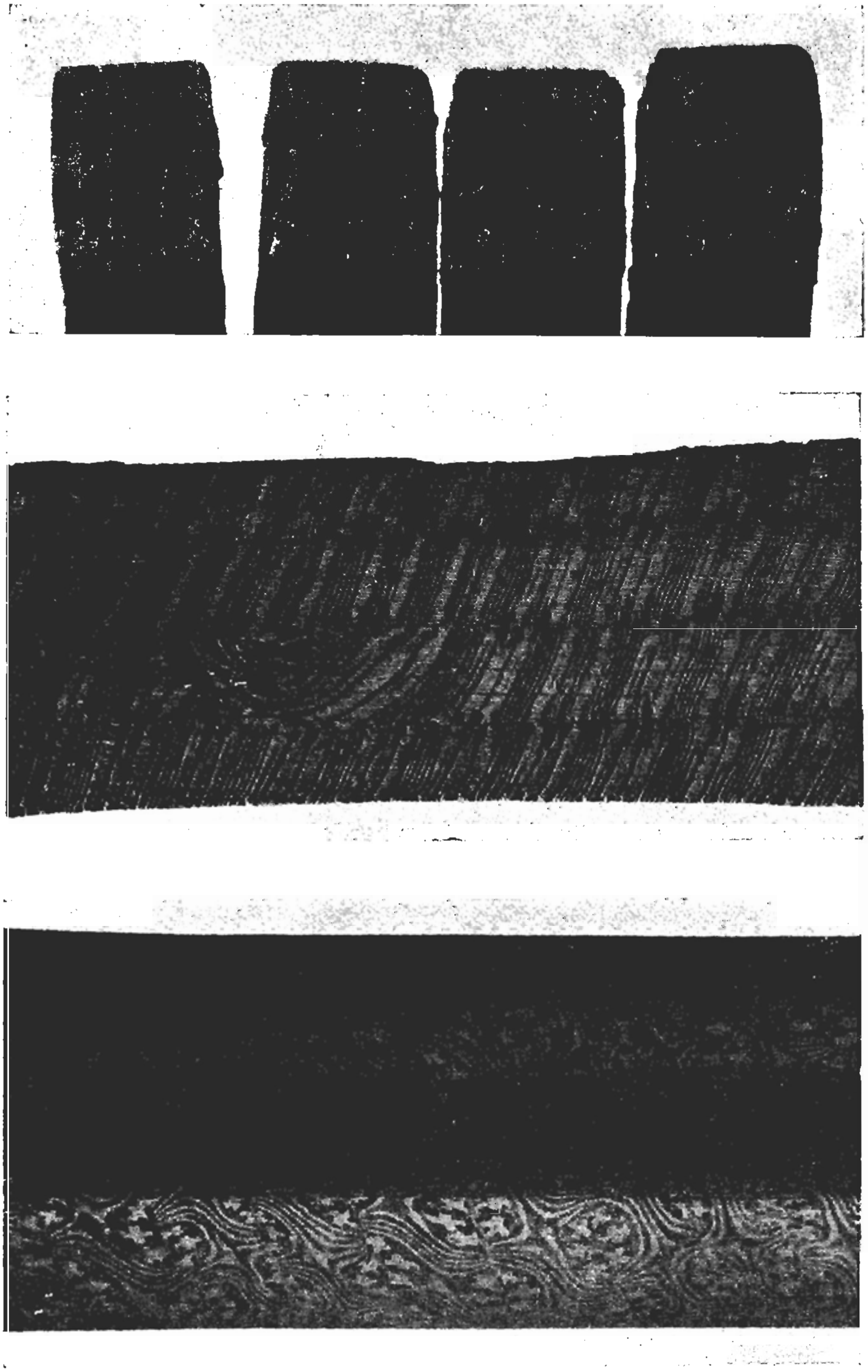

FIG. 38. *Details of Figure 40 at greater enlargement.* Above: *appearance of the section of small bars at 1, as originally laminated.* Center: *appearance of the surface of the band at 2.* Below: *final appearance of the polished and etched barrel. The cruciform prints of the steel profiling are still visible.*

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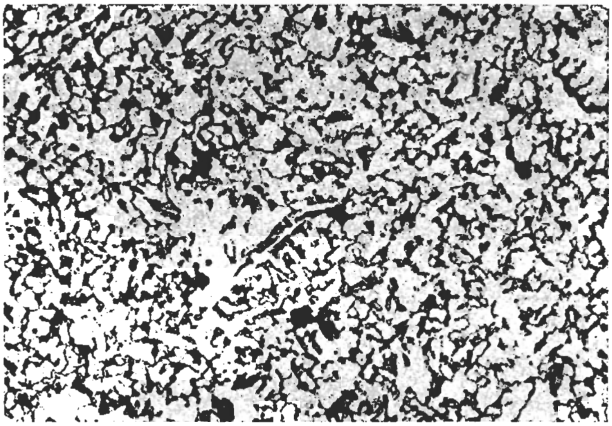

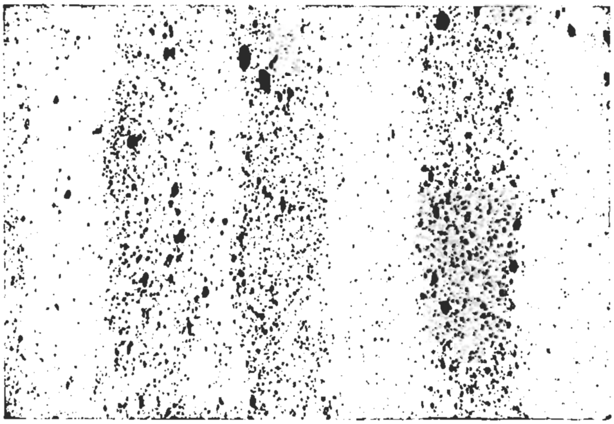

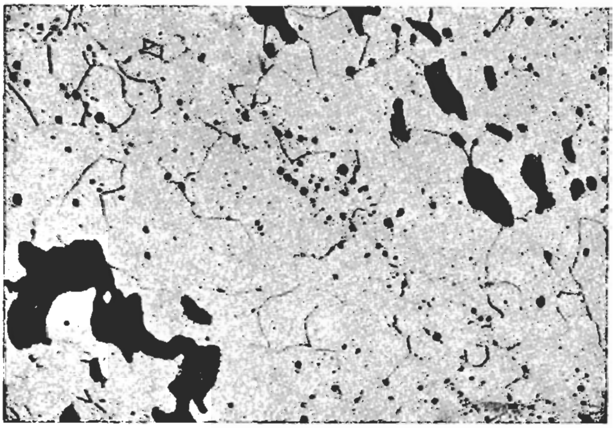

FIG. 39. *Micrographic structure of the Brescian welded damascus barrel illustrated in Figure 40.* Above: *(200 diameters) Ferrite and pearlite in the cruciform steel profiling. 1% Nital attack.* Center: *(25 diameters) Inclusions of slag in the bars of origin. Without attack.* Below: *(200 diameters) Weld zone in the finished barrel, showing abundance of slag inclusions. 5% Nital attack.*

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FIG. 40. *Brescian welded damascus barrel for a hunting shotgun (XIXth century) in the progressive phases of welding. At zone 1 one sees the four bars of the original laminated «stuff», made up of cross-shaped steel profiles and of alternating bands of steel and of soft iron (see Figure 38). At zone 2 one sees the band secured through twisting and subsequent welding together of the laminated bars. Finally, at zone 3 the barrel is welded (spirally) around a mandrel, is turned smooth, and is polished (see Figure 39).*

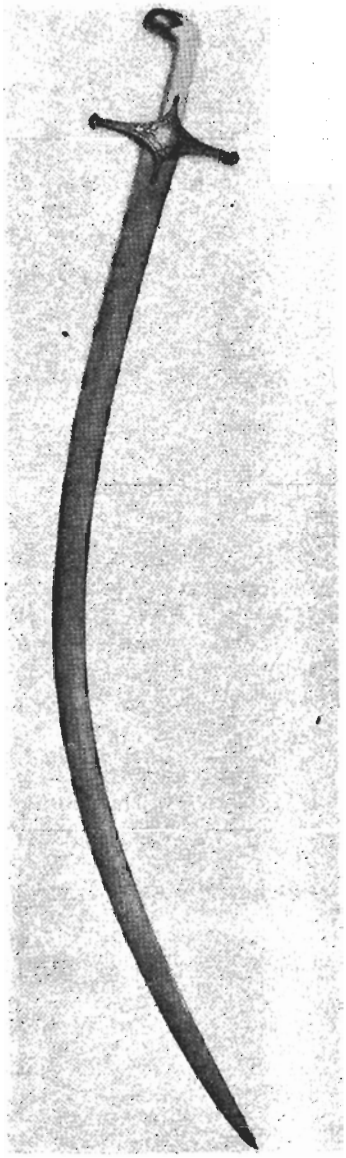

FIG. 41. *«Kirk Narduban» damascus in a Persian blade of the XVIIth century (ISML collection of archeological and historical steels).*

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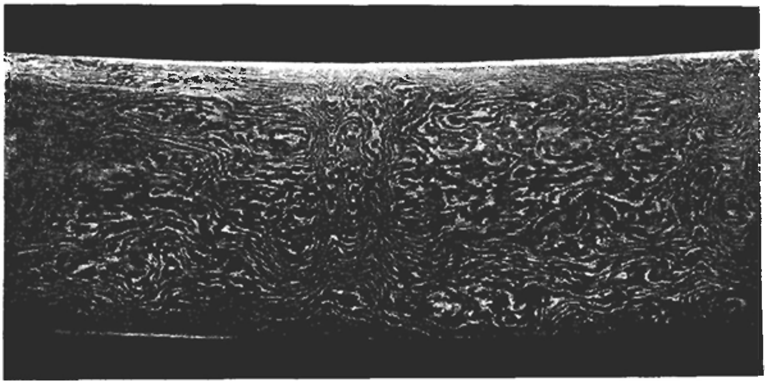

FIG. 42. *Detail of the blade showed in Figure 41: the «steps» characterizing the «Kirk Narduban» are clearly evident at the middle.*

ing in thickness locally, in various fashions (see Figure 32), the refractory coating used in connection with the hardening process (20).

As we had indicated toward the beginning, the art of pattern-welded damascus experienced a renaissance in Europe toward the end of the XVIIIth and the beginning of the XIXth century, in two directions; the first intended, in good or in bad faith, to imitate (or to *falsify*, as

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(20) See the complete study of these techniques by C. S. SMITH: «A Metallographic Examination of Some Japanese Sword Blades», in «La tecnica di fabbricazione delle lame di acciaio presso gli antichi», Associazione Italiana di Metallurgia, Doc. e Contributi per la Storia della Metallurgia, Quaderno II, Milan (1957).

Cf. also the very recent work «*Nippon-to;* An Introduction to Old Swords of Japan» (Journal of the Iron and Steel Institute C. C.), pp. 265-282 (1962), which we owe to the celebrated American metallographer Edgar C. Bain, who expresses himself as follows: «The old swords of Japan are probably the best examples of the almost incredible pains taken to produce a superb implement.»

And a little further on: «We would miss any possible delightful aesthetic experience and merely conclude that an admittedly attractive article had been manufactured by a fantastically long and laborious process fraught with innumerable opportunities for serious shortcomings.»

It is symptomatic that the most impassioned western amateurs and collectors of ancient Japanese arms are to be found precisely among the men who, through their scientific background, are best in a position to value their technical merits objectively; and this aside from any external values of esthetic character, pertaining to the minor arts, which contribute to exquisiteness of the decoration of the mountings.

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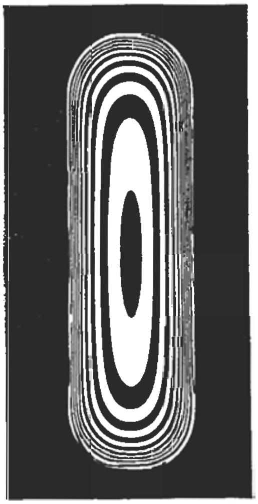
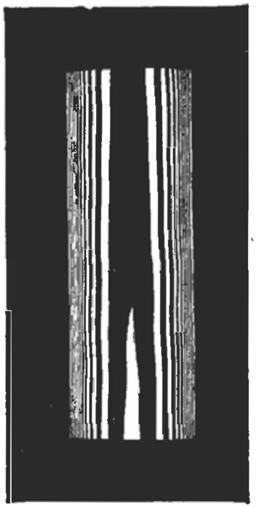
Crivelli puts it) the appearance of oriental damascus in saber blades; the second, for the production of gun and pistol blades, resuming a technique already introduced toward the XVIIth century, with the famous *Lazzarino barrels*, by the celebrated Brescians of the Cominazzo dynasty (21), and also known to the peoples of the Near East.

The fashion of *damascus barrels* in deluxe guns reigned uncontested during the entire XIXth century and ceased only when success was achieved in technically mastering the production of steel barrels from





FIGS. 43-44. *Cross and longitudinal section of the experimental extruded bar used for the investigation on the manufacturing technique of the «Kirk Nardaban». The different layers are clearly shown by the caustic soda etch, which darkens the ones formed with an Al-4% Cu alloy.*

crucible steel. Today this technique, very laborious and obviously pretty expensive, has been dropped entirely; yet it is interesting to read how one of the best-known English arms makers of the past century, the Englishman Greener (22) describes it. He expresses himself as follows:

«The iron for the manufacture of gun-barrels was formerly made from scrap and old horse-shoe nail stubs. In preparing the metal for the old-fashioned laminated steel barrels, a number of scraps were collected of various proportions, the clippings of saws, steel pens, scraps of best iron, and placed in a revolving drum, where they polished by the constant rubbing against each other. The scraps were then cut

(21) A. GAIBI: «I Cominazzi: una famiglia di artefici famosi di Gardone Val Trompia», Armi Antiche, Turin (1960).

(22) W. W. GREENER: «The Gun and Its Development», London (1881).

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into pieces of the same size and placed in a furnace until of a white heat, gathered into a bloom with ravels, and the mass placed under a tilt hammer, and welded into a block of iron which was immediately rolled into bars. The bars were then cut into regular lengths, and the required quantity laid together and fastened into a faggot, and this faggot was again heated in the furnace, hammered under the tilt, and rolled into rods of the size required by the barrel-welders.»

Some figures (see Figures 37-40) which accompany this study document this technique, and also bring to light what risks the users perhaps were running. Such a complicated notwork of welds, the need for carrying out the weldings at very high temperatures, the inevitable abundant interpolation of slag; the frequent use of *stuffs* containing very little steel or nome at all (see Figure 37), and hence having less complex welding adhesion, do in fact bring it about that only the damascus barrels issuing from the most renowned arms factories could assure the uninformed user of a certain reasonable safety.

As regards all the other users, who could not afford the finest arms, they owed a certain protection less to the resistance of the damascus of their barrels than to the loving aid of Saint Hubertus.

Light Metals Experimental Institute.
Istituto Sperimentale Metalli Leggeri (ISML).
Milan-Novara, November 1962.

APPENDIX

After publication of this work on the Italian Magazine «Armi Antiche» of the Accademia Torinese di San Marciano, a number of competent scientists—amongst whom Prof. Cyril Stanley Smith of the Massachussetts Institute of Technology—showed particular interest in my suggested interpretation of the fabrication technique for that variety of Eastern Damascus known as *Kirk Narduban* or «Mohammed's ladder».

Blades of this type, however, are all but frequent, and the Author —tempted as he may have been by technical curiosity—had no heart for sacrifying to metallographic investigations (necessarily destructive or leading to more or less serious damage of the weapon) the exceptionally well preserved specimen that has come to belong to our Institute in fortunate circumstances (see Fig. 9 and 41-42 in the text).

Therefore, the Author has endeavoured to obtain for his hypoth-

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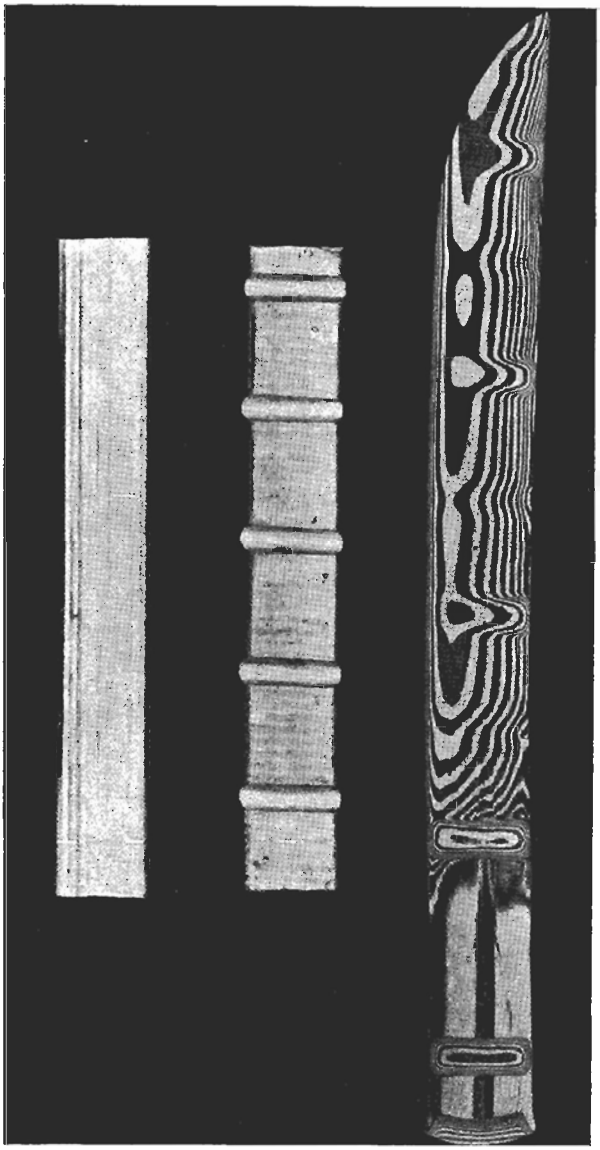

FIG. 45. *Manufacturing technique and design produced by a series of parallel hollows, equally spaced, obtained with a round file and subsequent hammering in a flat blade. The design shows evident analogies with the kriss blades, reported in Figures 23 and 25.*

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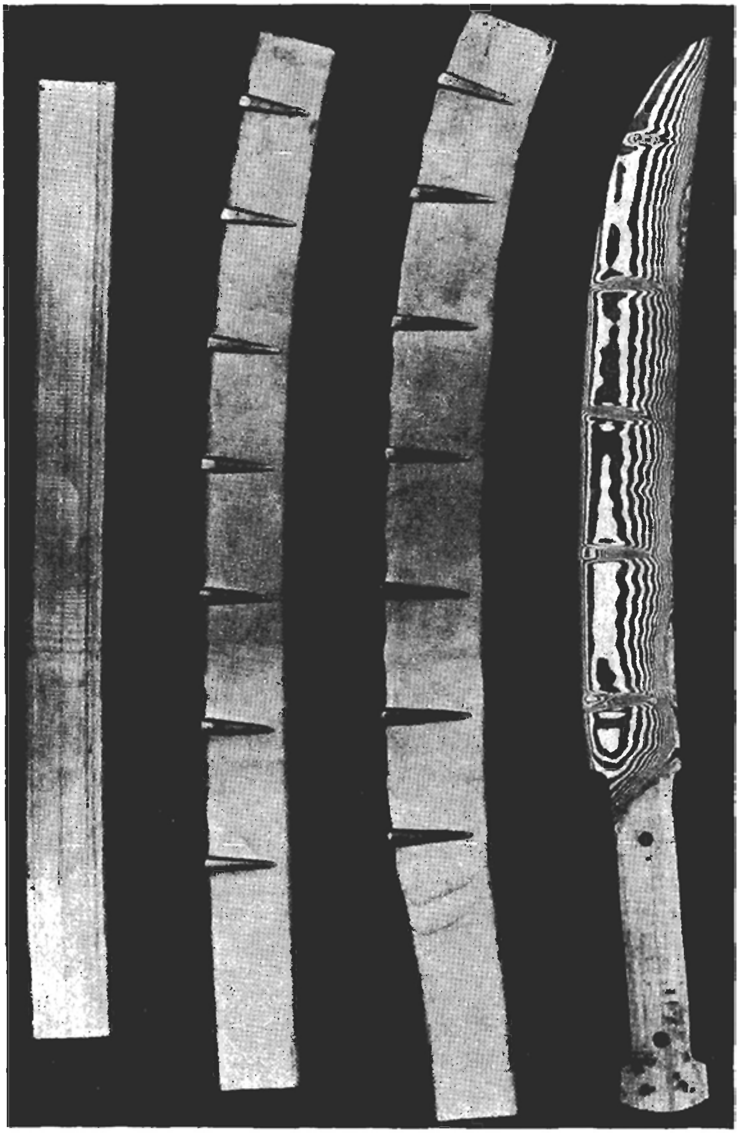

FIG. 46. *Manufacturing technique and design produced by means of a swage or chisel having a well rounded edge, worked at an angle to the plane of the bar. In this case, the resulting structure shows a clear analogy to the structure of the original «Kirk Narduban» damascus blade, a magnified detail of which may be seen in Figure 42.*

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esis an indirect proof, which he thinks may appear as sufficiently stringent to the competent reader.

On this purpose, he prepared an extrusion billet made up of discs 60 mm in diameter and 3 mm thick, and the discs were of two different aluminium alloys (one of which contained 4 % Cu) having a similar degree of plasticity.

The composite billet, wrapped up in aluminium paper 0.1 mm thick, was pre-heated to 440° C in a thermostatically controlled electric oven, and was subsequently extruded to a flat bar with rounded edge, 28 mm in width by 8 mm in thickness.

This bar had a fine multilayer structure, which is clearly shown on the transverse section (Fig. 43) and on the longitudinal section (Fig. 44) after a caustic soda etch (20 %, 80° C) that darkens the copper—containing layers only.

From this bar the Author obtained two samples, 150 mm long, for the tests hereafter described.

A series of parallel hollows, equally spaced, were ground into both faces of one specimen by means of a round file; subsequently, this specimen was heated to 350° C and hammered flat again. It was then worked with a file to the wedge shape typical of a blade, polished, and etched in NaOH solution. The etch figures clearly show (Fig. 45) that in the area corresponding to the primitive hollows produced by filing the multilayer structure is wider than near the cutting edge, and bears a marked analogy to some malayan kriss blades (see specially Figures 23, 25).

On the second specimen, instead, a series of round impressions was produced by means of a swage having a wellrounded end, worked at an angle to the plane of the blade.

A naturally curved rough-shaped blade was thus obtained, which was then hammered flat and etched as in the former case (Fig. 46).

In this case, the resulting structure shows a clear analogy to the structure of the original Kirk Narduban blade, a magnified detail of which may be seen in Figure 42.

The two typical structures obtained in coincidence with the steps of the «ladder» are shown in more detail in Figure 47 (filed hollows method) and in Figure 48 (local constrictions by rounded swage).

In the Author's opinion, after these tests no doubt should remain about the technique used in the East for production of Kirk Narduban or «Mohammed's ladder» damascus; at the same time, this evidence confirms the theory—accepted, amongst others, by Prof. C. S. Smith—on the fabrication technique of the typical *pamor* observed in some Malayan kriss blades, which was certainly produced by means of hol-

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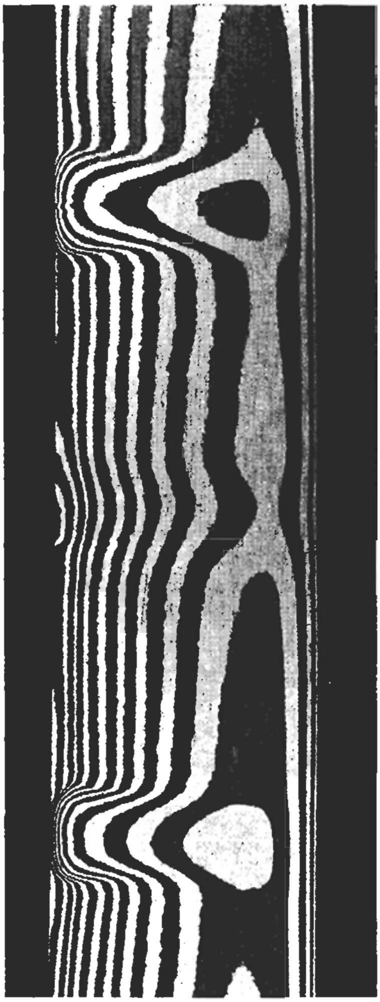

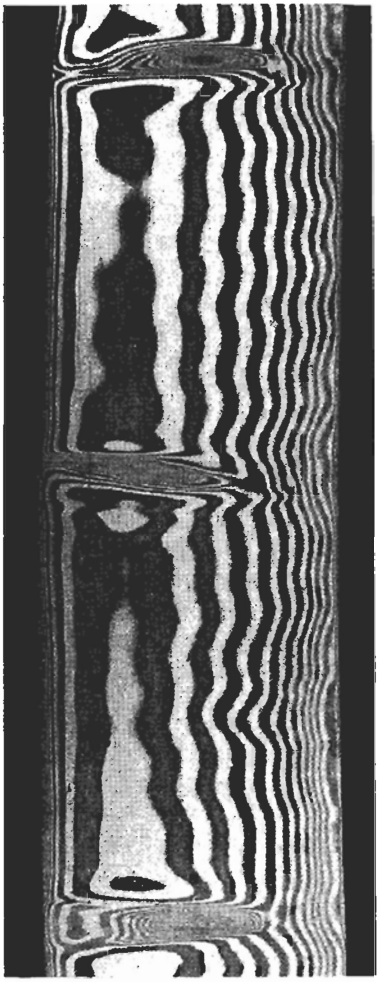

FIG. 47. *Typical structure in coincidence with the steps of the «ladder» obtained with the filed hollows method illustrated in Figure 45.*

FIG. 48. *Typical structure in coincidence with the steps of the «ladder» obtained with the local constriction by rounded swage or cisel, as illustrated in Figure 46.*

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FIG. 49. *Pistol barrel of welded damascus, probably of Turkish fabrication.*

FIG. 50. *Area with a higher carbon content (dark areas of the Figure 49).*

FIG. 51. *Area with low carbon content (almost pure iron) of the white areas of the Figure 49.*

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lows filed into the surface of the rough-shaped blade before the last forging operation.

Another subject, which perhaps may deserve some wider discussion than in the first Italian edition of this work, is the use of Eastern Damascus for the manufacture of rifle and pistol barrels. Because of the reason described in the text, the eastern craftsmen did not use for this purpose their *poulad jauharder* which was too hard and too little tenacious, but they rather employed a welded damascus obtained by a harmonic blend of hard steel and soft iron.

Notwithstanding their typical Eastern inclination towards aesthetical effects, Turkish and Persian craftsmen appear to have profited from practical experience much more than their western colleagues.

In the search for more and more sophisticated exterior appearance effects, the western craftsmen stressed to extreme consequences the technique of wire welding—basically a quite rational one in itself—by employing thinner iron and thinner steel wires with complex section (Figure 38), which nearly always underwent deep oxidation and decarburisation during the numerous consecutive heating operations required for welding (Figs. 37-39).

Eastern craftsmen, on the contrary, preferred as a rule to build up their damascus with larger section elements, which were less liable to decarburisation, and a more functional barrel was so obtained, although the aesthetical effect was more macroscopic.

In this connection, it may be interesting to observe Figure 49, showing a pistol barrel—probably of Turkish fabrication—which the Author recently had a chance of examining. The parts that stand out white against the dark background after chemical etch are pure iron, while the dark ones are steel with a rather high carbon content (about 0.5-0.6 % C).

Figures 50 and 51 (x 100; Nital 1 % etch) show the typical structure of this barrel. The areas with a higher carbon content have a mostly pearlitic structure and a Vickers hardness comprised between $HV_{10} = 157$ kg/mm^2 and $HV_{10} = 187$ kg/mm^2, while the ferritic areas have a HV_{10} hardness of 93-98 kg/mm^2.

As Figure 51 clearly shows, the craftsmen obtained an excellent welding, at the same time substantially avoiding steel decarburisation and carbon diffusion from steel to iron.

This is evidently a symptom of a considerably advanced and refined technical level.

C. P.