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NOT INVASIVE ANALYSES ON A TIN-BRONZE DAGGER FROM JERICHO: A CASE STUDY

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ABSTRACT

Tin-bronze makes its appearance in Southern Levant during the Early Bronze IV, the post-urban phase of the last centuries of the 3rd millennium BC, when arsenical copper was still the most widespread copper alloy. Only from the following Middle Bronze Age tin-bronze will be the utmost spread alloy. The adoption of tin as alloying metal purports new technological skills, and a changed trade supply system, through new routes, thanks to itinerant coppersmiths. The examination of dagger TS.14.143 found in an EB IV (2300-2000 BC) tomb at Jericho by mean of trace elements and Energy Dispersive X-ray Diffraction analyses, provided info about its metal composition and technology. The detection of tin, testified only by a few specimens at the site so far, allows some reflections about the beginning of diffusion tin-bronze, and the presence of a small-scale melting activity in the post-urban phase in the key-site of Jericho.

KEYWORDS: Jericho, Early Bronze IV, bronze alloy, dagger, not invasive analyses.

1. THE DAGGER TS.14.143 FROM TELL ES-SULTAN/ANCIENT JERICHO

Dagger TS.14.143 (Fig. 1), on temporary exhibit in the Museum of the Near East, Egypt and Mediterranean (Nigro 2016) of Sapienza (n. VO3008/I), was found in the necropolis north of Tell es-Sultan by a villager of the refugees camp, who entrusted it to the Italian-Palestinian Expedition to Tell es-Sultan/ancient Jericho (Rome "La Sapienza" University and MOTA-DACH) (Marchetti and Nigro 1997; Marchetti and Nigro 2000; Nigro and Taha 2006; Nigro and Taha 2009; Nigro et al. 2011). The finding spot (and presumably the location of the tomb which contained it) is Area A of Early and Middle Bronze Ages necropolis of Jericho (Kenyon 1960; Kenyon 1965). The weapon is a fragmentary short dagger, attributable to the group of the Early Bronze IV simple type well-known at the site in funerary repertoires. It dates back to the Early Bronze IVA (2350-2200 BC; Sultan IIId1, according to the archaeological periodization established by the Italian-Palestinian Expedition on the ground of stratigraphy and connected to radiocarbon dates: Nigro 2003a), and it is a short dagger with 4 rivets, tang is 2.5 cm long, and blade is preserved for a length 7.9 cm. Maximum width preserved in the tang is 1.9 cm, in the blade 2.3 cm. The tang is 0.3 cm thick and the blade 0.25 cm. The dagger weight is 23 g. TS.14.143 (Montanari 2014) is preserved little more than half of its reconstructed full length (19.5 cm; Fig. 2). It is damaged on the tang edge, and the tip is unfortunately broken. Four rivets originally were placed on two rows in the tang, as it is still recognizable even though the weapon surface is corroded. In the lower row one rivet hole is visible, and the other one is partially detectable in the fractured section; in the upper row, the first rivet hole is placed 1.3 cm above the other preserved in the lower row, and a second one is symmetrically placed on the opposite end, above the broken part. Cross-section is thin and flattened along its overall length. The tang has a nearly trapezoidal shape showing the maximum width just in front of the upper row of rivets. Holes for rivets, occluded by corrosion products, had a circular shape, as like it is attested in other specimens (Rowe 1935), to accommodate them which usually have a quadrangular cross-section (Nigro 2003b).

It was produced with a bi-valve mould and refined by cold-working and annealing, as also observed in other specimens (Khalil 1980; Khalil 1983).

Figure 1. Dagger TS.14.143 from Tell es-Sultan.

2. SOUTHERN LEVANT EARLY BRONZE IV DAGGERS

In Southern Levant, daggers appear in funerary equipment since the beginning of the Early Bronze Age (3400-2000 BC), made of copper and, in the later stage, of alloyed copper, namely arsenical copper and tin-bronze (Tab. 1).

Daggers are a close-range weapons, characterized by the length of the blade, up to 18 cm in the case of short daggers, and from 20 cm up to 30 cm for the regular type (Maxwell-Hyslop 1946; Philip 1989; Gernez 2007). A further feature used for classification is the shape of the tang or of the stick which allowed to fix the handle to the blade (Tubb 1990): it could be simple, developed, or peduncolar.

In the Southern Levantine archaeological record, this class began to appear since the initial phase of the Early Bronze Age (EB I), primarily in funerary contexts.

In the Early Bronze I-III, daggers were made mainly of copper, or of arsenical copper (with a low arsenic content). During the Early Bronze IV, they were made mainly of arsenical copper with a ratio of arsenic generally encompassed between 1.5% and <5%, and secondly of tin-bronze with a highly variable percent of tin (Kenyon 1960; Kenyon 1965; Khalil 1980; Philip 1989; Philip - Clogg - Dongworth 2003). This shows that EB IV was the period when the copper alloy was first experimented.

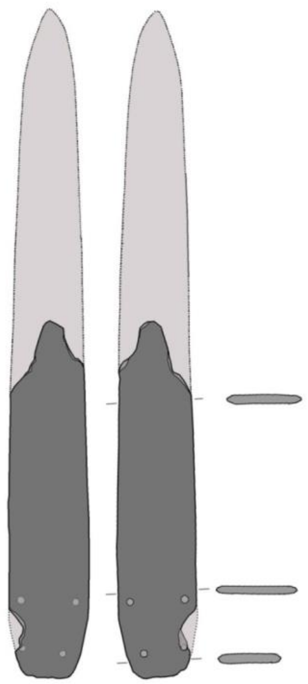

Figure 2. Reconstructive drawing of the dagger TS.14.143 from Tell es-Sultan/ancient Jericho, ratio 1:2.

3. EARLY BRONZE IV DAGGERS FROM JERICHO

Daggers collected in the necropolis of Tell es-Sultan (Tab. 1) may illustrate in a very clear way the simple type of short and long daggers to which TS.14.143 belongs. The tang can be either rounded or quadrangular, wearing in most cases four rivets placed on two rows; in a few cases rivets could be three, arranged in a triangle, or six on three rows. Some blades present midribs. The quadrangular tang is frequently associated to the presence of four rivets and of midribs.

Specimens found in the Jericho necropolis were basically made of copper and arsenical copper, just three (Tab. 1) made of tin-bronze are known. Among arsenical copper items, two clusters can be detected according to the content of arsenic: one with an average percentage of arsenic at 2%, and another with average percentage of arsenic at 4%. As it concerns tin, values detected in Jerichoan specimens are relatively high. In fact, two ranges of tin percent are registered: a lower one, corresponding to 1% or less, and a higher one, with a value encompassed between 8.45% and 15% (Kaufmann 2013).

Table 1. Comparative table of daggers from the Early Bronze IV tombs of Jericho (after Kenyon 1960; 1965; Moorey - Schweizer 1972; Khalil 1980; 1983; Philip 1991; Nigro 1999; Kaufmann 2013).

TOMB	TYPE (Short; Regular)	TANG AND RIVETS (Simple; Developed)	METAL	WEIGHT (g)	LENGTH (cm)	WIDTH (cm)	THICKNESS (cm)	PHASE
A 23 *Dagger T.*	S	S - 4 rivets	-	-	tang 3.6; blade 17.2; tot. 20.8	tang 2.6; blade 3	blade 0.8	EB IVA
A 110 *Dagger T.*	S	S - 4 rivets	Cu 93.1%, As 1.91%	95	tang 3.8; blade 15.7; tot. 19.5	tang min 2.1, max 3.1; blade 3	tang 0.5; blade 0.5	EB IVA
A 111 *Dagger T.*	S	S	Cu 98.1%, As 1.9%	61	tang 2.7; blade 17.7; tot. 20.4	blade 2.5	blade 0.4	EB IVA
A 132 *Dagger T.*	S	S - 4 rivets	-	58	tang 2.6; blade 16.5; tot. 19.1	tang max 2.4; blade max 2.3	tang 0.3; blade 0.5	EB IVA
L 1 (1:2) *Dagger T.*	S	S - 4 rivets	-	-	tang 2.8; blade 16; tot. 18.8	tang 2; blade 2	tang 0.4; blade 0.4	EB IVA
L 3 *Dagger T.*	S	D - 4 rivets	-	-	tang 3.2; blade 17.2; tot. 20.4	tang 2,4; blade 2	tang 0.4; blade 0.6	EB IVA
L 5 *Composite T.*	S	S - 4 rivets	-	-	tang 4; blade 19.2; tot. 23.2	tang 2.8; blade 2.6	tang 0.6; blade 0.6	EB IVA
L 6 *Dagger T.*	S	S - 4 rivets	Cu 96.04%, As 3.96%	-	tang 2.8; blade 20; tot. 22.8	tang 3; blade 2.8	tang 0.2; blade 0.6	EB IVA
D 1 *Square-Shaft T.*	S	D - 5 rivets	Cu 96.67%, As 2.71%	-	tang 4.8; blade 16.8; tot. 21.6	tang 2.4; blade 3	tang 0.4; blade 0.5	EB IVA
TS.VAT.2 *Dagger T.*	S	S - 4 rivets	Cu 88%, As 11.2%	31.4	tang 2; blade 15.3; tot. 17.3	tang 1.6; blade 1.7	blade 0.4	EB IVA
A 26 (26:2)	R	D - 1 rivet	Cu 95.58%,	96	tang 2.3;	tang 1.7; blade	tang 0.2; blade	EB IVA

Dagger type			As 4.36%		blade 28; tot. 30.3	2.3	0.5	
A 28 *Dagger T.*	R	S - 6 rivets	Cu 98.51%, As 1.49%	-	tang 3.8; blade 20.8; tot. 24.6	tang 3.2; blade 2.6	blade 0,8	EB IVA
A 82 *Dagger T.*	R	S - 3 rivets	-	-	tang 4; blade 21.6; tot. 25.6	tang 2.4; blade 2.8	tang 0.4; blade 0.6	EB IVA
A 86 *Dagger T.*	R	S - 3 rivets	Cu 96.21%, As 3.82%	-	tang 3.2; blade 22.4; tot. 25.6	tang 3.2; blade 2.8	tang 0.4 ; blade 0.8	EB IVA
A 91 *Dagger T.*	R	S - 3 rivets	-	-	tang 3.6; blade 20.8; tot. 24.4	tang 2; blade 2.8	tang 0.8; blade 0.8	EB IVA
A 95 *Dagger T.*	R	S - 4 rivets	Cu 95.28%, As 3.31%	-	tang 2.8; blade 22; tot. 24.8	tang 2.8; blade 3.2	tang 0.4; blade 0.6	EB IVA
A 128 *Dagger T.*	R	S - 4 rivets	-	-	tang 2.8; blade 22.4; tot. 25.2	tang 2.6; blade 2.4	tang 0.6; blade 0.6	EB IVA
A 129 *Dagger T.*	R	S - 4 rivets	-	-	tang 3.8; blade 23.6; tot. 27.4	tang 2.4; blade 2.6	tang 0.4; blade 0.6	EB IVA
A 131 (131:1) *Dagger T.*	R	S - 4 rivets	Cu 97.9%, As 2.1%	162	tang 4; blade 29; tot. 33	tang 2.7; blade 2.7	tang 0.7; blade 0.7	EB IVA
A 131 (131:2) *Dagger T.*	R	S - 4 rivets	Cu 98.72%, As 1.28%	-	tang 4; blade 24.8; tot. 28.8	tang 2.8; blade 2.8	tang 0.4; blade 0.4	EB IVA
A 26 (26:1) *Dagger T.*	R	S - 4 rivets	Cu 95.24%, As 4.76%	145	tang 3.7; blade 24; tot. 27.7	tang 2.9; blade 2.8	tang 0.5; blade 0.7	EB IVA
B 14 *Dagger T.*	R	S 4 rivets	-	-	tang 3.2; blade 22.8	tang 2.6; blade 2.8	blade 0.8	EB IVA
G 83 *Composite T.*	R	D - 6 rivets	Cu 84.9%, Sn 15%	143	tang 5.8; blade 31.9; tot. 37.7	tang 2.7; blade 3	tang 0.3; blade 0.6	EB IVB
K 26 *Bead T.*	R	S - 4 rivets	-	-	tang 3.6; blade 24.4; tot. 28	tang 2.6; blade 2.4	tang 0.6; blade 0.8	EB IVB
L 1 (1:1) *Dagger T.*	R	S - 4 rivets	-	-	tang 4; blade 25.2; tot. 29.2	tang 2.6; blade 2.8	tang 0.6; blade 0.6	EB IVA
L 2 (2:6) *Composite T.*	R	S - 4 rivets	-	-	tang 2.8; blade 21.6; tot. 24.4	tang 2.4; blade 2.4	tang 0.8; blade 0.8	EB IVA
L 2 (2:5) *Composite T.*	R	S - 6 rivets	-	-	tang 6; blade 24; tot. 30	tang 2.8; blade 2.8	tang 0.4; blade 0.4	EB IVA
L 4 *Dagger T.*	R	S - 3 rivets	Cu 87.95%, Sn 8.45%, As 3.6%	-	tang 3.6; blade 21.6; tot. 25.2	tang 2.8; blade 2.6	tang 0.4; blade 0.4	EB IVA
L 7 *Composite T.*	R	S - 4 rivets	-	-	tang 4.4; blade 23.6; tot. 28	tang 2.8; blade 2.8	tang 0.2; blade 0.4	EB IVA
M 13 *Composite T.e*	R	S - 4 rivets	-	-	tang 5.2; blade 21.6 tot. 26.8	tang 2.4; blade 2.4	tang 0.6; blade 0.8	EB IVB
M 16 *Composite T.*	R	D - 6 rivets	Cu	109	tang 6.2; blade 21.4; tot. 27.6	tang min 2 max 2.8; blade 3	tang 0.3; blade 0.5	EB IVB
P 12 *Outsize T.*	R	S 2 rivets	-	-	tang 2.8; blade 22.8; tot. 25.6	tang 2; blade 2	blade 0.3	EB IVA
TS.VAT.1 *Dagger T.*	R	S - 4 rivets	Cu 98%	175.7	tang 3.8; blade 24.8; tot. 28.6	tang 2.8; blade 3	tang 0.5; blade 0.7	EB IVA

4. NOT INVASIVE ANALYSES ON DAGGER TS.14.143

Chemical analyses on the dagger were carried out in the labs of the Center of Nanotechnology for Engineering of Sapienza (CNIS), directed by Prof. Ruggero Caminiti.

SEM and EXD analyses were conducted on TS.14.143. The dagger was analyzed with a non-commercial X-ray diffractometer (E.D.X.D.) (Rossi et al. 1996), assembled by Prof. Ruggero Caminiti with the collaboration of his research team in the Research Centre for Nanotechnologies Applied to Engineering of Sapienza - CNIS. The fixed measurement angle is 30 degrees in theta.

The source is tungsten (using its white radiation) operating conditions 50 KV and 40 mA. The detector employed a hyper-pure germanium crystal (Ametek). This procedure allowed to obtain in the same time diffraction peaks and fluorescence peaks generated by metals in the sample. 20 measurements were registered at different points of the dagger, on both faces (Fig. 3), in order to understand if the distribution of different metals was homogenous, constant or variable. Calcium (Ca), nickel (Ni), iron (Fe), copper (Cu), and tin (Sn) were clearly detected (Figs. 4-6, 8).

A different angle measurement, 28 degrees in theta, was also tested, but fluorescence peaks had any shift in energy.

On the base of the fluorescence, Ca and Fe are fairly constant; conversely, Ni is highly variable. Moreover, Fe and Ni exhibit similar distribution trends. Peak area of the copper fluorescence indicates that the amount of metal is constant, but in P17 (on the tang) where reaches its maximum, and in P20 (on the blade) where touches its lower value (Fig. 7). Maximum quantity of tin was registered in P20 (Fig. 8), and generally a higher presence of tin is on the blade, in P9-P12.

SEM analyses identified a patina of corrosion composed by carbonates, silicates, phosphates, calcites, and sulphides of copper (Tab. 2). Moreover, copper, iron, and tin were also picked out under the corroded surface (Tab. 3; Fig. 9). Thanks to the SEM distinguished spherical and rod-shaped nanostructures, probably due to some corrosion and recrystallization processes of copper, were observed (Fig. 10).

Figure 3. Points analyzed on both faces of dagger TS.14.143 with X-ray diffractometer.

Table 2. Table of elements detected on P6 with SEM.

El	An	Series	norm. C [wt.%]	Error (1Sigma) [wt.%]
C	6	K-series	3.13	1.19
O	8	K-series	1.52	0.61
S	16	K-series	14.35	0.87
Cu	29	L-series	81.00	12.43
			100.00	

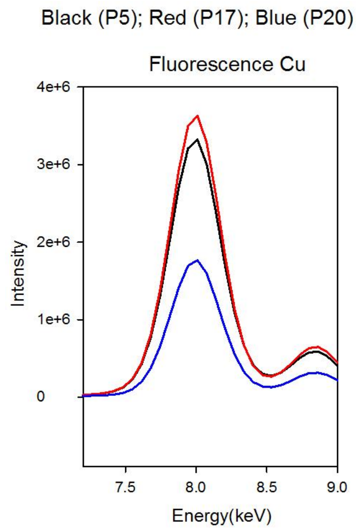

Figure 4. Spectrum of copper on points P5, P17 and P20 sampled on dagger TS.14.143.

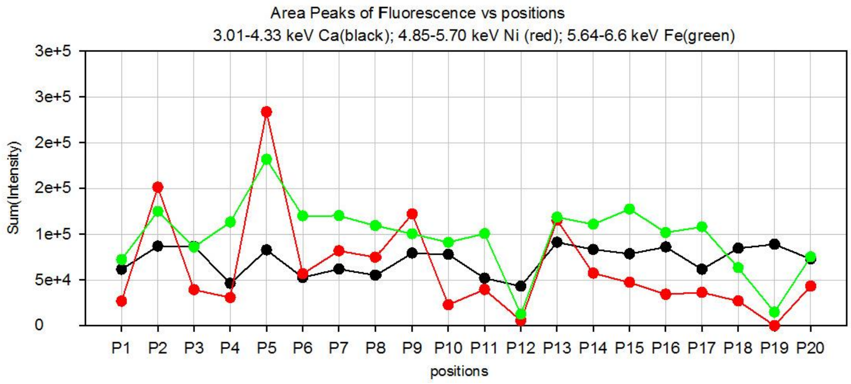

Figure 5. Fluorescence peaks of metals in the 20 points analysed on dagger TS.14.143.

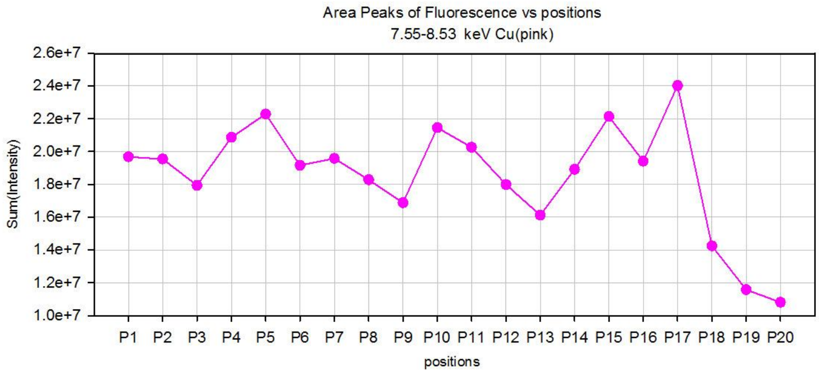

Figure 6. Fluorescence peaks of copper in the 20 points analysed on dagger TS.14.143.

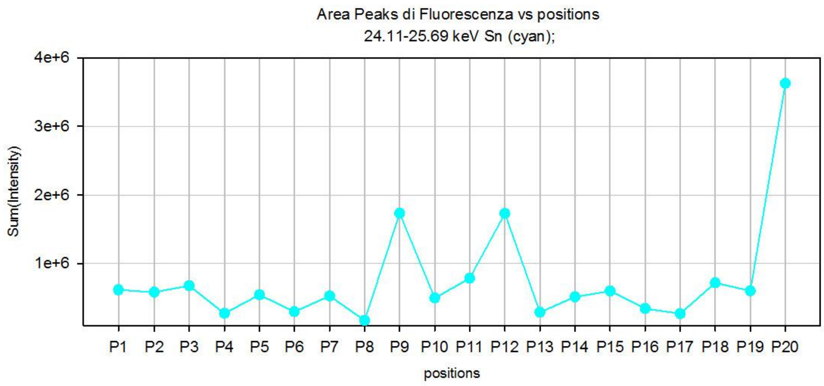

Figure 7. Fluorescence peaks of tin in the 20 points analysed on dagger TS.14.143.

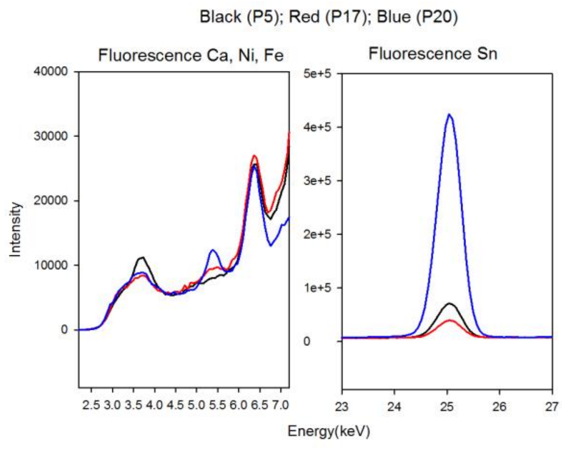

Figure 8. Spectrum of calcium, nickel, iron, and tin on points P5, P17, and P20 sampled on dagger TS.14.143.

Table 3. Table of elements mass ratio detected into TS.14.143 with SEM.

El	wt.%
Cu	93.57%
Fe	0.66%
Sn	5.87%

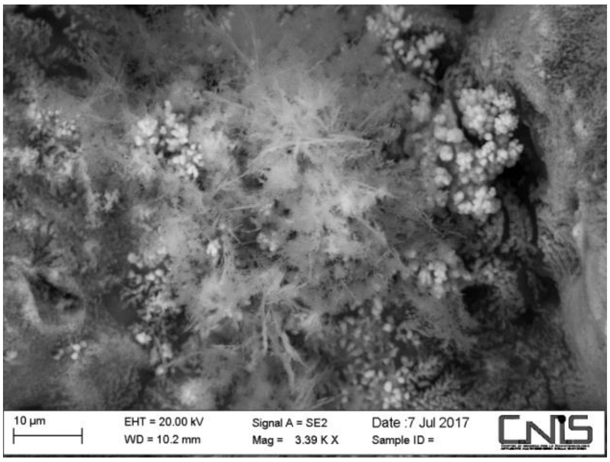

Figure 9. Magnification at SEM of area where Sn was detected on dagger TS.14.143.

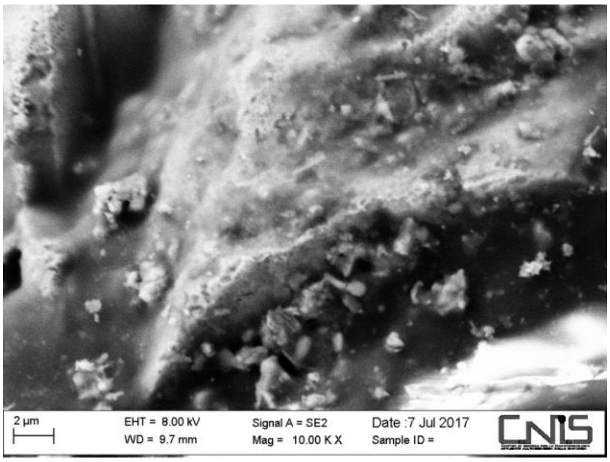

Figure 10. Magnification at SEM of spherical and rod-shaped nanostructures on dagger TS.14.143.

5. COMPARISONS TO THE DAGGER TS.14.143

TS.14.143 can be paralleled particularly with three short daggers and with one long dagger recovered in three tombs of the so-called "Dagger Type" in the necropolis of Tell es-Sultan, namely Tombs A110, A132, and L1, dating back from the Early Bronze IVA (Tab. 1; Nigro 2003a).

The short dagger from Tomb L1 represents the more similar counterpart as it concerns its typological features. In fact, it exhibits the same overall dimensions and shows a very alike trapezoidal tang, with four rivets arranged in a similar way, and a blade that develops in the same manner, but with a thicker trapezoidal cross-section.

Daggers from Tomb A110, made of arsenical copper with tin, and from Tomb A132, exhibit a roughly trapezoidal tang with four rivets, similarly to that of TS.14.143. The dagger found in Tomb A132, however, has a thicker lozenge shaped cross-section.

A specimen from Tomb 64 at Tell el-'Umeiri represents also a possible bronze comparison to Jerichoan dagger (Dubis 2002).

6. FINAL REMARKS

In the large-scale scenario of the development of metallurgy in the Near East between 4th and 3rd millennium BC (Stech Wheeler - Maddin - Muhly 1975; Philip - Clogg - Dongworth 2003), it might be useful to understand the interaction between the easternmost area of the Mediterranean, e.g. Cyprus (Weisberger 1982; Gale 1991; Kassianidou 2008) and the Aegean (Renfrew 1967; Branigan 1974), with Anatolia (Griffitts - Albers - Öner 1972) and the Levant (Hauptmann 2007), as reflected by the attestations of copper alloys and alloying compositions. In this panorama, the dagger from Jericho can offer food for thought.

Metals were present at Jericho since the Pre-Pottery Neolithic Period. Several beads, pendants, and artifacts made of "greenstone" were retrieved in PPNA layers of Tell es-Sultan (Talbot 1983; Wheeler 1983; Hauptmann 2007). These "greenstones" were the ore deposit of the Wadi Faynan (this is the same ore that will be used during the 3rd millennium BC: Hauptmann 2007). Copper and copper-alloy items, with arsenic and tin, probably from Anatolia and Caucasus, were brought to light both on the tell and in the necropolis of the Early and Middle Bronze Ages.

EB tools and items, as like as pins, nails, and rivets, and weapons (axes, daggers, and javelins), collected on the site and in tombs were made basically of copper, of arsenical copper, and more scarcely of tin-bronze (Khalil and Bachmann 1981). Analyses of EB metal weapons and prills show that the isotope pattern mainly match with the one of the Faynan district and, in one case, with the As-Ni rich copper of Ergani Maden (Hauptmann 2007).

Elements detected by the CNIS in this case study testify the presence of tin-bronze in the site of Jericho already at the beginning of the Early Bronze IV, and attest the role of Jericho within the trade of metal items, from southern districts of Wadi Faynan (Levy 2007) and Timna (Hauptmann 2006) along the so-called "Copper Route" (Nigro 2014), to the northern and north-eastern regions from which tin arrived in Palestine. In the southern mining district, active since the beginning of the Early Bronze Age, hemifinished products and copper ingots were melted and cast. They were then distributed through the main urban centers, as like as Arad, Jericho, Bab edh Dhra, Yarmoukh, Batrawy, and Megiddo, by nomad carriers. In the newborn cities small scale secondary melting was performed, in order to accomplish the needs of the centralized palatial economy.

In the following 'post-urban' phase, the Early Bronze IV, according to the numerous metal items discovered both in the site, as shown by the hoard of arsenical copper weapons and tools found by Sellin and Watzinger in a jar hidden under the floor of a house (Sellin and Watzinger 1913, 117-19) and in the necropolis, Jericho maintained its role of hub of metal importation and refining and trade. Finds such as drops, scraps, smelted ores and slags, however, are markers of secondary melting activities and recycling (Khalil 1983), and suggest that metallurgical production and casting processes took place in the areas all around the site (Genz 2000).

The appearance of tin-bronze at Tell es-Sultan/ancient Jericho during the Early Bronze IVA marks the beginning of the diffusion of this alloy in Southern Levant, even though arsenic-copper was still the more spread alloy until the end of the period.

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