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METAL COMPOSITION OF BRONZE COINS FROM THRACE

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МЕТАЛЕН СЪСТАВ НА БРОНЗОВИ МОНЕТИ ОТ ТРАКИЯ

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Metal composition of bronze coins from Thrace

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Метален състав на бронзови монети от Тракия

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Abstract: In a destructive study involving XRF analyses and electrical conductivity measurements, a non-destructive method for determining the composition of ancient bronze coins was developed (Hourmouziadis 2017). This article summarises data on Classical and Hellenistic coins from Abdera and Maroneia used for this purpose, providing measurement results for both their patinated surface and core material. The newly developed non-destructive method was then tested on three coin types of the Thracian king Teres III.

Keywords: Metal composition, XRF analysis, ancient bronze coins, Abdera, Maroneia, Teres III, Thrace.

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Determining the material composition of bronze coins is particularly difficult due to a relatively thick patina layer with widely varying concentrations of the main components. The earlier methods of chemical analysis inevitably led to the complete destruction of the coins. Modern electronic measurement technologies offer the potential to develop non-destructive methods. In the search for such methods, data was collected from coins with patina and after removal of the patina for comparison purposes. Coins from Thrace were also measured as part of this work, which is reported below.

The study comprised a total of 42 ancient coins from Abdera and Maroneia of the following types:

Abdera	4 pcs.	Type AMNG 215–228	352–323 BC
Maroneia	33 pcs.	Type Schönert-Geiss 598–943	398–347 BC
	2 pcs.	Type Schönert-Geiss 1354–1510	189–45 BC
	3 pcs.	Type Schönert-Geiss 1511–1639	189–45 BC

The analysed objects were heavily worn but could be assigned to these groups. **Figures 1 to 4** illustrate typical representatives of these types that were not included in the measurements. The coins in the study come from the Hourmouziadis Collection and have been published online at the www.hourmo.eu platform with further details and illustrations under the given SHH numbers. They were recently transferred to the Berlin-Brandenburg Academy of Sciences and Humanities and can also be found at www.corpus-nummorum.eu with the CN number provided here.[1]

Fig. 1. Abdera, SHH 364 / CN 7626, Photographer: Vladimir Stolba, AMNG 218.

Fig. 2. Maroneia, SHH 4322 / CN 5443, Photographer: Vladimir Stolba, Schönert-Geiss 721–923.

Fig. 3. Maroneia, SHH 2210 / CN 7588, Photographer: Vladimir Stolba, Schönert-Geiss 1354–1405.

Fig. 4. Maroneia, SHH 995 / CN 7591, Photographer: Vladimir Stolba, Schönert-Geiss 1556–1631.

Tab. 1. Metrological values.

SHH-Nr.	CN-Nr.	Masse, g	Durchmesser, mm		Masse nach Abschleifen der Vs.
			Min.	Max.	
Abdera: AMNG 215–228					
4804	7645	2.46	13.9	14.9	1.90
4805	7646	3.02	14.1	15.2	2.28
4806	7647	4.60	13.7	15.4	3.72
4807	7648	3.90	14.9	16.5	3.14
Maroneia: Schönert-Geiss 598–943					
4792	5444	2.61	14.5	14.9	2.11
4793	5445	3.82	14.6	15.5	3.24
4794	5472	3.99	15.1	15.5	3.20
4795	5473	3.76	15.5	16.5	3.25
5097	5478	3.63	15.2	16.0	3.26

[1] For the SHH numbers, see the provenance field of related entries on the web portal www.corpus-nummorum.eu. With the SHH numbers the coins are also described in the original collection at www.hourmo.eu.

SHH-Nr.	CN-Nr.	Masse, g	Durchmesser, mm		Masse nach Ab-schleifen der Vs.
			Min.	Max.	
5098	5479	2.71	14.0	16.0	2.23
5099	5528	3.92	13.8	14.8	3.31
5100	5529	3.82	16.4	16.6	3.33
5101	5444	4.17	13.5	14.6	3.56
5107	7599	5.00	18.4	19.0	3.76
5108	7600	4.66	15.0	17.0	4.03
5109	7601	6.07	15.6	16.7	5.37
5110	7602	6.53	18.2	19.1	5.15
5111	7603	6.78	19.4	19.9	5.74
5209	5530	3.96	14.6	16.1	3.02
5210	5531	3.57	14.6	15.1	2.49
5211	7543	1.70	13.9	16.7	0.89
5212	7544	3.53	13.7	15.4	3.02
5213	7545	3.78	14.0	15.1	3.06
5214	7546	3.34	14.7	15.1	2.60
5215	7547	2.50	15.1	16.2	1.60
5216	7548	2.60	13.7	15.1	2.10
5217	7549	1.32	13.3	14.5	0.70
5218	7550	3.29	14.7	15.4	2.97
5219	7552	3.17	13.5	14.6	2.62
5220	7553	3.19	12.6	13.7	2.55
5221	7554	3.70	14.2	14.6	3.17
5222	7555	2.07	14.1	14.9	1.30
5223	7556	3.12	14.1	15.6	2.29
5224	7557	4.32	16.0	17.0	3.78
5225	7551	3.61	14.5	15.0	3.23
5226	5319	3.33	13.5	15.0	2.81
5227	7560	2.81	15.1	15.5	2.27
Maroneia: Schönert-Geiss 1354–1510					
4768	7589	7.91	24.1	26.7	5.86
4769	7590	10.72	23.4	26.4	8.75
4770	7595	7.33	17.2	17.8	6.24
4771	7596	8.40	17.2	18.6	7.55
4772	7597	5.21	18.6	20.2	3.69

The coins were cleaned with soapy water and measured (**Table 1**). The material composition of the obverse (obv.) and reverse (rev.) was determined using the OXFORD ED 2000 X-ray fluorescence analyser (XRF) from the Rathgen Research Laboratory in Berlin. The device analyses the average composition of an approximately 0.1 mm thick surface layer over the cross-section of the object. The patina on the front was then rigorously removed with a grinding disc (**Fig. 5**), and the XRF measurement was repeated. The results are summarised in **Tables 2 to 5**. Multiple measurements have a reproducibility better than ±1.5%. These fluctuations are primarily due to the position of the coins in the device's receptacle and the relief slopes.

With the help of the weight loss caused by grinding off the patina, it was estimated that removing a layer of roughly 0.5 to 1.5 mm was required to expose the core material completely. The progress of the corrosion largely determined the thickness of this layer.

Fig. 5. Before and after removing the patina on coin of Maroneia, SHH 4793 / CN 5445, Photographer: Jean Hourmouziadis.

Tab. 2. Abdera, 352–323 BC (AMNG 215–228).

		Mit Patina							Vorderseite abgeschliffen						
SHH-Nr.	**CN-Nr.**	**Cu**	**Sn**	**Pb**	**As**	**Ag**	**Fe**	**Ni**	**Cu**	**Sn**	**Pb**	**As**	**Ag**	**Fe**	**Ni**
		%	%	%	%	%	%	%	%	%	%	%	%	%	%
4804 obv	**7645 obv**	**20.9**	**43.1**	**33.9**	**0.6**	**0.3**	**1.0**	**0.1**	**81.1**	**6.6**	**11.8**	**0.1**	**0.1**	**0.2**	**0.2**
4804 rev	**7645 rev**	**23.8**	**38.6**	**35.4**	**0.8**	**0.3**	**1.0**	**0.1**							
4805 obv	**7646 obv**	**33.5**	**31.1**	**33.5**	**1.0**	**0.2**	**0.5**	**0.2**	**81.5**	**6.6**	**11.5**	**0.2**	**0.1**	**0.1**	**0.1**
4805 rev	**7646 rev**	**30.2**	**32.4**	**36.0**	**0.7**	**0.2**	**0.4**	**0.1**							
4806 obv	**7647 obv**	**64.9**	**24.8**	**8.9**	**0.2**	**0.2**	**0.8**	**0.1**	**87.0**	**10.5**	**2.2**	**0.0**	**0.1**	**0.1**	**0.2**
4806 rev	**7647 rev**	**52.7**	**31.1**	**15.4**	**0.3**	**0.1**	**0.3**	**0.2**							
4807 obv	**7648 obv**	**55.7**	**28.8**	**14.6**	**0.5**	**0.1**	**0.3**	**0.1**	**86.7**	**9.7**	**3.3**	**0.1**	**0.0**	**0.1**	**0.1**
4807 rev	**7648 rev**	**57.1**	**32.1**	**9.7**	**0.4**	**0.2**	**0.3**	**0.2**							

Tab. 3. Maroneia, 398-347 BC (Schönert-Geiss 598–943).

		Mit Patina							Vorderseite abgeschliffen						
SHH-Nr.	**CN-Nr.**	**Cu**	**Sn**	**Pb**	**As**	**Ag**	**Fe**	**Ni**	**Cu**	**Sn**	**Pb**	**As**	**Ag**	**Fe**	**Ni**
		%	%	%	%	%	%	%	%	%	%	%	%	%	%
4792 obv	**5444 obv**	**50.5**	**47.1**	**0.6**	**1.1**	**0.1**	**0.4**	**0.2**	**93.1**	**6.4**	**0.1**	**0.2**	**0.0**	**0.0**	**0.1**
4792 rev	**5444 rev**	**61.9**	**35.8**	**0.5**	**1.3**	**0.1**	**0.2**	**0.2**							
4793 obv	**5445 obv**	**30.7**	**63.2**	**4.3**	**1.3**	**0.1**	**0.2**	**0.2**	**87.4**	**11.1**	**0.9**	**0.3**	**0.0**	**0.0**	**0.1**
4793 rev	**5445 rev**	**32.1**	**60.8**	**5.2**	**1.4**	**0.1**	**0.2**	**0.2**							
4794 obv	**5472 obv**	**59.5**	**30.2**	**8.4**	**1.0**	**0.1**	**0.7**	**0.1**	**89.3**	**7.6**	**2.7**	**0.2**	**0.0**	**0.0**	**0.1**
4794 rev	**5472 rev**	**63.7**	**26.1**	**8.5**	**0.6**	**0.0**	**0.9**	**0.1**							
4795 obv	**5473 obv**	**68.7**	**18.9**	**11.0**	**0.4**	**0.0**	**0.9**	**0.1**	**91.0**	**6.1**	**2.5**	**0.2**	**0.0**	**0.1**	**0.1**
4795 rev	**5473 rev**	**66.9**	**20.1**	**11.5**	**0.4**	**0.0**	**1.0**	**0.1**							
5097 obv	**5476 obv**	**52.4**	**22.4**	**22.4**	**1.2**	**0.4**	**1.0**	**0.2**	**86.4**	**4.7**	**8.1**	**0.2**	**0.1**	**0.2**	**0.2**
5097 rev	**5476 rev**	**51.6**	**22.2**	**23.7**	**1.2**	**0.3**	**1.0**	**0.1**							
5099 obv	**5479 obv**	**40.6**	**32.1**	**24.6**	**1.0**	**0.1**	**1.4**	**0.1**	**82.1**	**5.3**	**12.1**	**0.1**	**0.0**	**0.2**	**0.1**

		Mit Patina							Vorderseite abgeschliffen						
SHH-Nr.	CN-Nr.	Cu	Sn	Pb	As	Ag	Fe	Ni	Cu	Sn	Pb	As	Ag	Fe	Ni
		%	%	%	%	%	%	%	%	%	%	%	%	%	%
5099 rev	5479 rev	40.3	32.6	24.6	0.8	0.1	1.5	0.1							
5100 obv	5528 obv	72.2	11.9	14.2	0.5	0.0	1.0	0.1	89.7	5.0	4.8	0.2	0.0	0.2	0.1
5100 rev	5528 rev	73.1	10.2	15.1	0.4	0.0	1.1	0.1							
5101 obv	5529 obv	31.3	23.2	41.7	1.7	0.1	1.7	0.1	84.0	7.5	7.9	0.3	0.0	0.1	0.2
5101 rev	5529 rev	33.4	26.1	36.9	1.7	0.1	1.5	0.3							
5107 obv	7599 obv	55.9	39.2	1.9	1.7	0.1	0.9	0.2	89.5	9.1	0.5	0.4	0.0	0.2	0.2
5107 rev	7599 rev	62.8	33.1	1.5	1.4	0.1	0.8	0.2							
5108 obv	7600 obv	53.1	22.1	21.7	1.1	0.2	1.6	0.1	87.0	4.8	7.6	0.1	0.1	0.2	0.2
5108 rev	7600 rev	53.4	22.4	21.0	1.2	0.2	1.7	0.1							
5109 obv	7601 obv	21.3	18.5	42.0	0.6	0.0	17.5	0.1	94.2	3.7	0.3	1.3	0.3	0.1	0.0
5109 rev	7601 rev	20.8	16.8	50.2	0.9	0.0	11.2	0.1							
5110 obv	7602 obv	52.4	42.7	3.2	0.0	0.8	1.0	0.0	87.9	10.1	1.4	0.0	0.2	0.3	0.1
5110 rev	7602 rev	65.8	30.6	2.2	0.0	0.6	0.8	0.0							
5111 obv	7603 obv	62.8	22.9	13.0	0.4	0.4	0.5	0.1	85.2	7.7	6.8	0.0	0.1	0.1	0.1
5111 rev	7603 rev	62.5	22.1	14.3	0.3	0.3	0.3	0.1							
5209 obv	5530 obv	37.2	44.4	15.8	1.5	0.1	0.9	0.1	81.0	3.5	15.2	0.1	0.0	0.0	0.1
5209 rev	5530 rev	40.2	40.2	16.8	1.7	0.1	0.9	0.1							
5210 obv	5531 obv	49.2	13.2	36.0	0.8	0.1	0.6	0.1	87.1	8.2	4.2	0.2	0.0	0.1	0.1
5210 rev	5531 rev	52.6	12.3	33.1	1.1	0.1	0.6	0.1							
5211 obv	7543 obv	36.2	54.6	6.5	0.9	0.2	1.5	0.1	90.4	7.5	1.8	0.2	0.0	0.1	0.1
5211 rev	7543 rev	35.0	54.7	7.3	0.9	0.3	1.8	0.1							
5212 obv	7544 obv	60.1	25.2	10.8	0.8	0.1	2.8	0.1	87.9	8.0	3.7	0.1	0.0	0.3	0.1
5212 rev	7544 rev	57.3	28.0	11.1	0.9	0.1	2.4	0.1							
5213 obv	7545 obv	35.3	4.6	55.1	3.4	0.5	1.2	0.0	78.1	1.3	17.8	2.5	0.2	0.1	0.0
5213 rev	7545 rev	51.1	4.7	38.0	4.7	0.3	1.3	0.0							
5214 obv	7546 obv	46.7	37.8	12.9	1.3	0.1	1.0	0.1	84.1	11.8	3.6	0.3	0.0	0.1	0.1
5214 rev	7546 rev	47.1	37.6	12.7	1.2	0.1	1.2	0.1							
5215 obv	7547 obv	35.8	42.9	17.5	0.9	0.1	2.5	0.1	91.0	5.6	2.9	0.2	0.0	0.2	0.1
5215 rev	7547 rev	36.3	43.3	17.1	0.9	0.1	2.3	0.1							
5216 obv	7548 obv	20.3	70.5	4.1	1.1	0.1	3.7	0.1	85.7	12.8	1.0	0.4	0.0	0.0	0.1
5216 rev	7548 rev	25.0	63.4	4.4	1.4	0.2	5.5	0.2							
5217 obv	7549 obv	16.7	68.2	9.6	0.7	0.3	4.6	0.0	87.2	8.9	3.5	0.1	0.0	0.1	0.1
5217 rev	7549 rev	14.6	69.6	10.2	0.5	0.3	4.8	0.0							
5218 obv	7550 obv	73.4	20.2	0.5	5.3	0.0	0.5	0.1	92.0	6.5	0.1	1.3	0.0	0.0	0.1
5218 rev	7550 rev	76.8	17.6	0.4	4.5	0.0	0.7	0.1							
5219 obv	7552 obv	41.6	30.7	24.2	1.5	0.1	1.9	0.1	83.7	4.9	10.6	0.3	0.0	0.3	0.1
5219 rev	7552 rev	45.1	29.3	22.4	1.5	0.1	1.6	0.2							
5220 obv	7553 obv	28.8	32.4	35.8	1.6	0.2	1.0	0.3	78.2	5.1	15.9	0.4	0.0	0.1	0.2
5220 rev	7553 rev	52.0	15.6	29.5	1.9	0.1	0.6	0.1							
5221 obv	7554 obv	47.2	25.1	23.5	1.7	0.1	2.3	0.1	87.8	6.0	5.3	0.3	0.0	0.4	0.1
5221 rev	7554 rev	44.0	28.6	23.4	1.6	0.1	2.1	0.1							
5222 obv	7555 obv	24.9	67.8	4.3	1.4	0.3	1.2	0.1	86.6	11.6	1.2	0.4	0.0	0.1	0.1
5222 rev	7555 rev	22.3	70.7	4.0	1.3	0.3	1.4	0.1							
5223 obv	7556 obv	28.2	51.6	16.7	0.8	0.3	2.3	0.1	88.1	8.6	2.6	0.2	0.1	0.2	0.1
5223 rev	7556 rev	29.3	51.9	15.3	0.8	0.3	2.2	0.1							

		Mit Patina							Vorderseite abgeschliffen						
SHH-Nr.	CN-Nr.	Cu	Sn	Pb	As	Ag	Fe	Ni	Cu	Sn	Pb	As	Ag	Fe	Ni
		%	%	%	%	%	%	%	%	%	%	%	%	%	%
5224 obv	7557 obv	47.7	38.7	11.0	1.0	0.1	1.3	0.1	87.3	8.6	3.8	0.1	0.0	0.1	0.1
5224 rev	7557 rev	51.4	35.2	11.0	0.9	0.1	1.2	0.1							
5225 obv	7551 obv	77.8	19.9	1.0	0.7	0.0	0.5	0.1	90.5	8.7	0.4	0.2	0.0	0.0	0.1
5225 rev	7551 rev	76.5	21.4	0.9	0.6	0.0	0.5	0.1							
5226 obv	5319 obv	61.8	26.9	5.8	1.3	0.0	4.0	0.1	90.1	8.3	1.3	0.2	0.0	0.1	0.1
5226 rev	5319 rev	59.7	27.8	6.1	1.2	0.0	5.1	0.1							
5227 obv	7560 obv	26.1	52.9	15.5	1.2	0.1	4.1	0.1	84.6	10.6	4.4	0.2	0.0	0.1	0.1
5227 rev	7560 rev	29.7	49.9	14.9	1.2	0.1	4.1	0.1							

Tab. 4. Maroneia, 148-45 BC (Schönert-Geiss 1354–1510).

		Mit Patina							Vorderseite abgeschliffen						
SHH-Nr.	CN-Nr.	Cu	Sn	Pb	As	Ag	Fe	Ni	Cu	Sn	Pb	As	Ag	Fe	Ni
		%	%	%	%	%	%	%	%	%	%	%	%	%	%
4768 obv	7589 obv	38.1	42.9	17.3	0.6	0.3	0.6	0.2	85.9	7.5	6.2	0.1	0.1	0.1	0.2
4768 rev	7589 rev	48.6	33.9	15.7	0.8	0.2	0.6	0.2							
4769 obv	7590 obv	44.3	19.3	33.9	0.9	0.1	1.4	0.1	81.5	6.0	11.9	0.1	0.0	0.4	0.1
4769 rev	7590 rev	33.1	27.9	36.2	0.7	0.2	1.8	0.1							

Tab. 5. Maroneia, 148-45 BC (Schönert-Geiss 1511–1639).

		Mit Patina							Vorderseite abgeschliffen						
SHH-Nr.	CN-Nr.	Cu	Sn	Pb	As	Ag	Fe	Ni	Cu	Sn	Pb	As	Ag	Fe	Ni
		%	%	%	%	%	%	%	%	%	%	%	%	%	%
4770 obv	7595 obv	39.0	33.1	25.3	0.5	0.5	1.4	0.1	80.8	8.1	10.3	0.1	0.2	0.4	0.1
4770 rev	7595 rev	39.6	31.5	26.6	0.5	0.5	1.2	0.1							
4771 obv	7596 obv	46.7	19.5	28.6	2.3	0.9	1.9	0.1	84.3	3.7	10.7	0.7	0.2	0.4	0.2
4771 rev	7596 rev	76.5	5.3	16.4	0.8	0.2	0.7	0.1							
4772 obv	7597 obv	55.3	23.4	20.1	0.0	0.4	0.7	0.1	86.2	7.3	6.1	0.0	0.1	0.2	0.1
4772 rev	7597 rev	32.6	41.3	24.0	0.1	0.9	1.0	0.1							

An 11-17% iron content was measured in the patina of object SHH 5109 (CN 7601). Iron could be present as smelting residue or absorbed from the mould or the environment, in which the coin was deposited. The coin was, therefore, not included in the following analyses. Zinc was not used in coin production before the 1st century BC. Arsenic was added in small quantities to lead bronzes to increase the hardness. Only one object, SHH 5213 (CN 7545), was found to contain more than 2% arsenic (As) in the core material.

During the natural patination process, copper (Cu) is released from the surface into the environment and tin (Sn) and lead (Pb) accumulate there accordingly. The copper content decreases by 20% to 60%, while the tin and lead content is up to four times higher than in the core material (cf. Beauchesne et al. 1988). This observation was confirmed in the more than 100 coins analysed as part of the project. **Figure 6** illustrates this phenomenon in the analysed specimens. The straight lines indicate equal proportions in the patina and the core material.

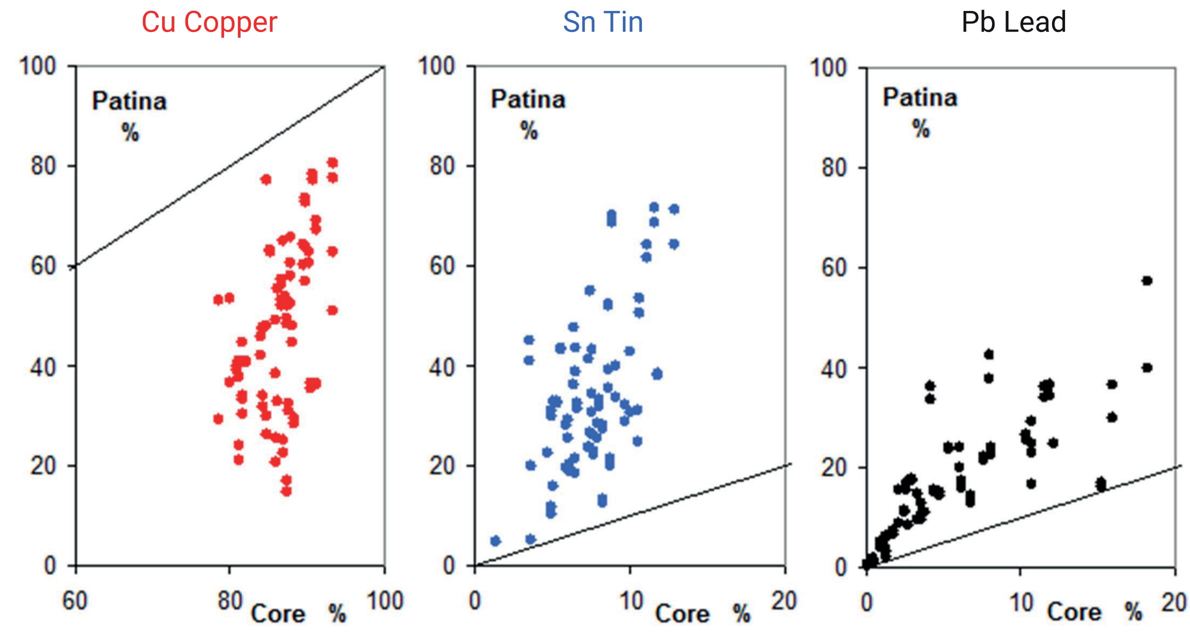

Fig. 6. Element concentrations in the patina and the core material.

The effect of the patination process on the composition of the outermost 0.1 mm-thick layer of the coin, which is recorded by the XRF measurement, is most clearly shown in the three-component representation in **Fig. 7**. The proportion of copper varies between 20 and 80%, of tin between 0 and 80%, and of lead between 0 and 60%. These measured values do not allow any conclusions to be drawn about the composition of the core material.

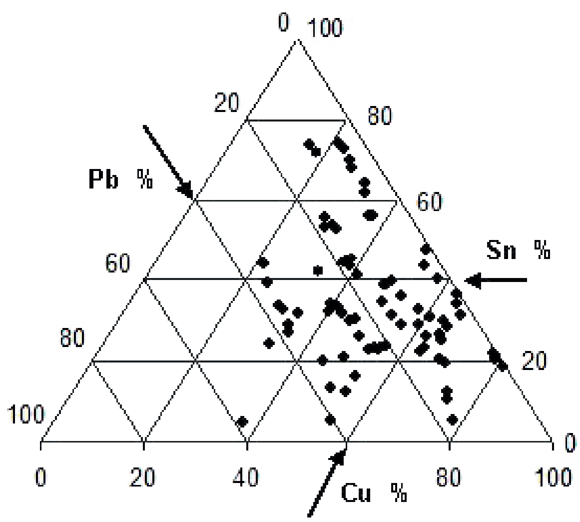

Fig. 7. Three-component diagram of patina.

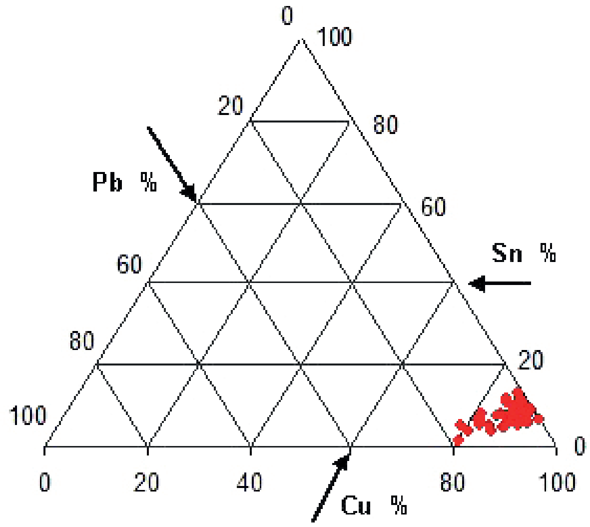

Fig. 8. Three-component diagram of core material.

This wide variation is partly due to the composition of the base material. The higher the original copper content, the higher the copper concentration in the patina. The oxidation processes can cause the removal of a significant ammount of copper from an object made of pure copper without this being noticable in the copper proportion.

However, the leading causes of these fluctuations are the deposition history and environment. Moisture, atmospheric oxygen, and acid-generating salts can significantly influence the extent and the type of corrosion.

In contrast to this result, the measured values for the core material (**Fig. 8**) lie in a narrow range in the bottom right-hand corner of the diagram, with a copper content of 80 to 95%. A close-up of this area is shown in **Fig. 9** for a better overview.

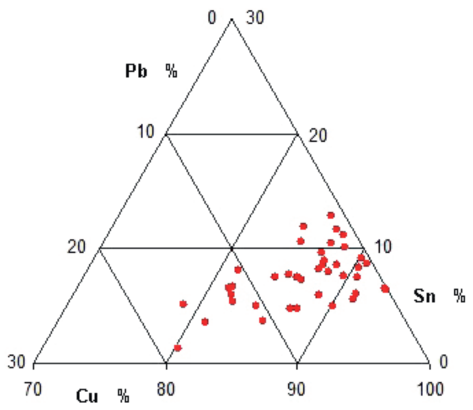

Fig. 9. Three-component diagram of core material.

The analysed objects show a uniform material composition. The differences are more likely due to different batches of raw material. No groups could be identified, for example, according to the coin types in **Figs. 1 to 4**. The measurements also included Philip II bronze coins that are not listed here (see Hourmouziadis 2017). No differences could be identified in these pieces either. In the 4th to 2nd century BC, the same coin production technology seems to have been employed on the Aegean coast of the southern Balkans.

One striking and unexpected result is the high lead content, up to 20%, which is higher than that of tin. It is unclear whether this is due to the raw material's poor smelting or intentional additions to improve workability.

The data compiled here was created as part of a project to develop a non-destructive method for determining the original composition of bronze coins (Hourmouziadis 2017). In addition to the measurements of the outer patina layer using XRF, the electrical conductivity was also determined using the Eddy Current Testing. This measurement also provides information about the interior of the object. The combination of these two methods makes it possible to determine the copper content in the core material with an accuracy of better than 5%. A comparison of the calculated approximation with XRF measurements of the core material and the patina is shown in **Fig. 10**. Due to the available coin material, the results are limited to lead bronze with less than 2% arsenic (As) and iron (Fe) and without zinc (Zn).

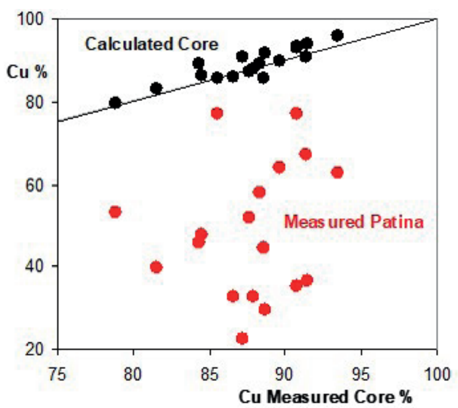

Fig. 10. XRF measurements and comparison with calculation.

Using the newly developed non-destructive method the composition of the bronze coins of the Thracian king Teres III (351–341 BC) was also determined. The three types shown in **Fig. 11** were analysed (Hourmouziadis & Ilieff 2017).

Fig. 11a–c. Coin types of the Thracian king Teres III, / a - CN 26878; b - CN 49267, Photographer: Vladimir Stolba; c - Gerhard Hirsch Nachfolger 272/161.

Three objects with an arsenic (AS) content of more than 2% were found from the XRF measurements. One coin was identified as a forgery due to its zinc content. As mentioned above, brass was not used in coin production before the 1st century BC. Today, it is a popular counterfeit material due to its favourable casting properties.

The results are shown in the three-component diagram (**Fig. 12**). The striking scatter, even with individual values for tin and lead below 0%, is due to the aforementioned limited accuracy (better than 5%) of the approximation method.

No differences were found between the three types. The temporal emission sequence probably associated with the types obviously did not affect the manufacturing process.

Even in comparison with the coins of Abdera and Maroneia, no apparent differences in material can be recognised. This, also confirms Youroukova's (1972) and Schönert-Geiss' (1982; 1987) assumption that the Thracian kings had their coins produced in the Greek cities.

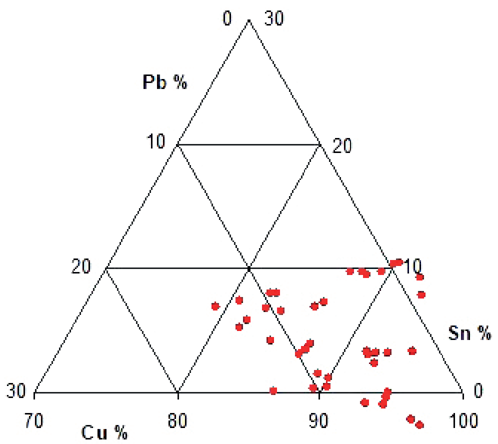

Fig. 12. Three-component diagram of coins of Teres III.

To summarise, the technology for producing bronze flans was consolidated on the coasts of the northern Aegean from around the 4th century BC. The analysed coins from Abdera, Maroneia, the Thracian king Teres III, as well as those of the Macedonian king Philip II, which are not listed here, have the same raw material composition: c. 80-95% Cu, c. 0-15% Sn, and c. 0-20% Pb.

The high proportion of lead (Pb), already known in antique bronzes, is somewhat unexpected. This alloy component increases the material's gliding properties. Presumably, its use also improved the striking ability.

Individual values vary significantly from coin to coin. It was impossible to establish a grouping of the different types, and a chronological grouping could not be made as the minting times are unknown.

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