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COPPER COINS OF THE PRINCIPALITY OF ANTIOCH (1103 – 1130): PHYSICO-CHEMICAL ANALYSIS

Abstract. The Purpose and Scientific Novelty of the Article. *The purpose is to do the research on on the development of coin minting in the Crusader states, with a particular focus on the Principality of Antioch, during the first third of the 12th century. For the first time, the authors have conducted a comprehensive physicochemical analysis of copper coins from the Principality of Antioch, utilizing X-ray fluorescence spectroscopy, an MMP-2P model optical metallographic microscope, and a spark optical emission spectrometer Solaris CCD Plus GNR.* ***Conclusions****. We conclude that the copper coins were struck on coin flans produced by casting. All the coins contain lead (Pb). Lead (Pb) was widely used in copper alloys in the Levant during the 11th–12th centuries. Taking into account the uniform technology used for producing flans for all coin types and the use of an alloy with a high lead (Pb) content, the authors conclude that a single mint operated in the Principality of Antioch. The consistent* *presence of lead (Pb) in all analyzed samples of Antiochene copper Crusader coins strongly suggests that lead was deliberately added during the melting process. After casting, the flans underwent further mechanical processing, including the removal of the solidified gating system and the remelting of defective pieces. Only then were the coins struck using a manual minting technique.*

A comparative analysis of the coins of the Principality of Antioch and those of the Seljuks of Syria indicates that the addition of lead (Pb) to the coin alloy was not a practice at the Antiochene mint prior to the Crusader occupation. Significant variations in the content of the primary elements in the coin alloy within a single coin type suggest the use of diverse raw materials in alloy production.

Comparing the results of X-ray fluorescence spectroscopy and optical emission spectrometry, it is important to note that the former allows for more accurate determination of the chemical composition of a metal object, as the assessment is based on radiation from a larger surface area. Furthermore, X-ray fluorescence spectroscopy does not damage the surface of the studied coin.

Keywords: *Principality of Antioch, Crusades, Oriental coins, follis, fals, dirham, numismatics, coin minting, mint, physicochemical analysis.*

МІДНІ МОНЕТИ КНЯЗІВСТВА АНТІОХІЇ (1103 – 1130): ФІЗИКО-ХІМІЧНИЙ АНАЛІЗ

Анотація. Мета і наукова новизна статті. *У статті досліджено проблему становлення монетного карбування в державах хрестоносців, зокрема в князівстві Антіохія в першій третині XII століття. Автори статті, вперше в історіографії здійснили комплексний фізико-хімічний аналіз мідних монет князівства Антіохії першої третини XII століття за допомогою X-ray fluorescence spectroscopy, оптичного металографічного мікроскопа моделі ММР-2Р та іскрового оптичного емісійного спектрометру Solaris CCD Plus GNR.* ***Висновки****. Мідні монети князівства Антіохії першої третини XII століття, карбувалися на монетних фланах виготовлених шляхом лиття. Усі монети князівства Антіохії містять у складі монетної заготовки свинець (Pb). Свинець (Pb) широко використовувався у Леванті в XI–XII століттях у мідних сплавах. Враховуючи єдину технологію виготовлення монетної заготовки для всіх типів монет та використання для цього монетного сплаву зі значним вмістом свинцю (Pb), автори вважають, що в князівстві Антіохія діяв один монетний двір. Враховуючи присутність свинцю (Pb) у всіх досліджуваних зразках антіохійський мідних монет хрестоносців, цілком логічним є висновок, про додавання свинцю (Pb) під час плавлення. Після застигання литих заготовок вони додаткового піддавалися механічній обробці, зокрема, обрубування затверділої ливникової системи та відправлення на переплавку бракованих заготовок. Лише після цього, із монетних заготовок, використовуючи ручну технологію карбування, виготовлялися монети. Порівняльний аналіз монет князівства Антіохії та монет сельджуків Сирії, вказує, що додавання свинцю (Pb) до монетного сплаву не було традицією на Антіохійському монетному дворі до приходу хрестоносців. Суттєве коливання вмісту основних елементів монетного сплаву у межах одного монетного типу свідчить про використання різної сировини для виготовлення сплаву.*

Порівнюючи результати X-ray fluorescence spectroscopy та оптичної емісійної спектрометрірії, необхідно зауважити, що перший метод дозволяє більш точно встановлювати хімічний склад металевого об'єкта оскільки оцінка проводиться на основі узагальнення випромінення від більшої ділянки. Крім того, X-ray fluorescence spectroscopy не наносить шкоди поверхні досліджуваної монети.

Ключові слова: *князівство Антіохія, хрестові походи, східні монети, фоліс, фельс, дирхем, нумізматика, монетне карбування, монетний двір, фізико-хімічний аналіз.*

Problem Statement. Among the corpus of coins associated with the Crusader states, the emissions of the Principality of Antioch from the first third of the 12th century stand out in particular. These were issues of coins made from copper-based alloys. The minting of copper coins had its advantages from both economic and political perspectives.

In the 11th century, copper coinage was well known not only in Byzantium but also in the neighboring territories of the Islamic world. Stefan Heidemann notes that the earliest mention of the circulation of Byzantine copper coins on Islamic territory comes from the Tajik-Persian poet of the Seljuk era, Nasir-i Khusrau (Heidemann, 2002, p. 395). When Nasir-i Khusrau arrived in Akhlat (Eastern Anatolia) in November of 1046, "he discovered that business transactions there were conducted with copper money" (Heidemann, 2002, p. 395). At that time, as Heidemann rightly points out, only dirhams were minted in Akhlat, not copper coins (Heidemann, 2002, p. 395). Therefore, according to the German scholar, Byzantine copper coins were in circulation in Akhlat.

After the Seljuk conquest of Asia Minor, Syria, and Palestine, Seljuk rulers began minting copper fals. In particular, before the arrival of the Crusaders, anonymous copper fals of the Seljuks of Syria were minted in Antioch (Album, 2020, p. 102. #779). Thus, copper coins were already familiar to the population of the Principality of Antioch.

In any case, copper coinage posed no issues for the new Antiochene establishment – the South Italian Normans, who made up a significant portion of the Crusaders. In Sicily, by the end of the 11th century, copper – alongside gold – formed the foundation of the monetary system. The emission of copper coins in Sicily had been carried out "over several centuries by Byzantine administrators and later by the Arab and Norman conquerors of the island" (Orlyk, 2011, p. 158).

P. Spufford quite rightly notes that the primary function of Sicilian copper coins was to facilitate minor payments, which were a common feature of urban life (Spufford, 1988, p. 10). The copper coins of the Principality of Antioch served a similar function.

Additionally, the status of *monetary seignior* was of considerable importance, as it emphasized the special position of the prince within the complex feudal hierarchy of the Near East. Equally significant was the fact that minting coins from copper-based alloys was always a profitable endeavor for the minter.

Despite limited publications on the numismatic issues of the Principality of Antioch, new studies periodically emerge, revealing previously unexplored aspects of this important scholarly topic. Researchers have long questioned whether the minting center was located solely in the city of Antioch or whether mints also existed in other cities of the Principality of Antioch (Metcalf, 2006). A detailed study of the evolution of iconography across different coin types, die analysis, and physicochemical analysis of Antiochene coins may provide an answer to this question. In particular, physicochemical analysis – especially the examination of coin alloys using X-ray fluorescence spectroscopy and electron microscopy – makes it possible to reconstruct the technological process of coin minting, from the melting of metal to the production of the final coin.

Methodology: To determine the elemental composition of coins from the Principality of Antioch, we employed X-ray fluorescence spectroscopy. The study was conducted using an Elvax Plus X-ray fluorescence spectrometer (manufactured by Elvatech, Kyiv, Ukraine) under the following parameters:

– element detection range: from 11Na to 92U;
– X-ray tube anode voltage: 40/10 kV;
– tube current: automatic stabilization;
– exposure time: 30/30 seconds;
– total measurement duration: 28 seconds.

X-ray fluorescence spectroscopy "is a well-known, non-destructive, fast and multi-element analytical method" (Markou, Charalambous, & Kassianidou, 2014).

To examine the internal structure of the coin alloy, an MMP-2P model optical metallographic microscope was used, designed for observing and photographing microstructures with a magnification range from 40x to 1250x. Metallographic examinations were performed on polished surfaces of metallographic sections.

Sample preparation for metallographic study included cutting a small template from the coin material, which led to the destruction of the coin. To produce metallographic sections, the metal sample (a coin fragment) was subjected to careful grinding followed by polishing of the cross-sectional surface.

For more detailed analysis of the coin metal's structural features, the section surface was etched using a 4% solution of nitric acid in ethyl alcohol. In the preliminary stages of microsection preparation, the macrostructure was examined on the ground up cross-section of the coin material at magnifications ranging from 25x to 50x. Macrostructural analysis provided information about the structure of oxidation layers on the coin surfaces and the presence of large non-metallic inclusions. We also used a Solaris CCD Plus GNR optical emission spectrometer.

For the metallographic study (a destructive research method), the authors used three coins. Specifically, two coins of the first type from the reign of Tancred of Taranto were examined. From the first coin (Id 3), a metallographic section was prepared with a thickness of 2 mm and a cut length of 8 mm; from the second (Id 10), a section with a thickness of 1.6 mm and a cut length of 10 mm was prepared. Additionally, one coin of Roger of Salerno, Type 1 (Id 32), was used to produce a section with a thickness of 1.2 mm and a cut length of 8 mm.

In addition to X-ray fluorescence spectroscopy and microscopic metal analysis, our study employed methods of direct physical measurement of the coins, particularly their weight and dimensions. For the visual analysis of the coin flan, we used an MBS-10 model binocular microscope.

Review of Recent Literature. Physicochemical analysis of coins began in the 20th century, particularly in the post-war period. One of the earliest significant publications of that era was by Polish physicists Zofia Stos-Fertner and Tadeusz Florkowski, dedicated to radioisotope X-ray fluorescence (XRF) analysis for detecting heavy metal impurities in Kufic silver coins. This research was presented at the Symposium on Archaeometry and Archaeological Prospection held on March 18–22, 1975, in Oxford, England, and was published as a separate brochure in Kraków by the Institute of Physics and Nuclear Techniques (Stos-Fertner, & Florkowski, 1975). The scholars rightly emphasized that spectral analysis "is a valuable method for non-destructive, rapid and sensitive analysis of elemental composition" (Stos-Fertner, & Florkowski, 1975, p. 3).

However, the widespread adoption of XRF research has occurred only in recent decades, largely due to the development of portable X-ray fluorescence spectrometers. The mass production of such instruments "began with the development of compact X-ray tubes with a wavelength of 0.05 to 10 nanometres and an energy range of 0.1 to 25 kiloelectron volts (keV)" (Kropivnyi, Orlyk, Kuzyk, & Kropivna, 2023). As a result, the number of scholarly studies on historical metal artifacts – especially numismatic objects such as coins and coin dies – has increased significantly (Gitler, & Ponting, 2006; Orlyk, 2016; Boiko-Haharyn, & Korpusova, 2017; Inberg, Ashkenazi, Cohen, Iddan, Cvikel, 2018; Jonsson, 2018; Crosera, Baracchini, Prenesti, Giacomello, Callegher, Oliveri, & Adami, 2019; Al-Saad, & Rababah, 2020; Orlyk, 2021; Orlyk, & Prokhnenko, 2023a; Orlyk, & Prokhnenko, 2023b; Orlyk, & Prokhnenko, 2024; Indutny, Pirkovich, & Dyshlova-Hrynyuk, 2024; Orlyk, & Callataÿ, F. (de), 2024; Šmit, & Šemrov, 2025 et al.).

At the same time, no specialized studies have yet been conducted on the elemental composition of the coin metals of the Principality of Antioch.

Purpose of Research. The purpose of the research is to investigate the technological features of the production of coin flans and the minting of copper coins by the Crusaders in Antioch.

Results.

The Beginning of Copper Coinage by the Crusaders in the Principality of Antioch.

In the Principality of Antioch, large copper coins were minted during the reigns of Bohemond I (1099 – 1111), Tancred of Taranto (regent for Bohemond I from March of 1101 to May of 1103, and from late 1104 to December of 1112), Roger of Salerno (regent for Bohemond II from late 1112 to June of 1119), Baldwin II of Jerusalem (regent for Bohemond II from 1119 to 1126), and Bohemond II himself (1126 – 1130).

As mentioned earlier, prior to the arrival of the Crusaders, the Seljuks of Syria had minted anonymous copper fals in Antioch (Fig. 1).

Fig. 1 (Not to scale) (CNG 350, Lot.650.) Seljuks of Syria, Anonymous, Æ Fals, Antioch Mint, Standing Elephant Type, circa AH 480s – 488s (1090s – 1098s.)
Obverse: Elephant with a cloth covering (caparison) facing right
Reverse: Within a hexagon adorned with floral dots, Arabic inscription "sultan"
Weight: 2.67 g **Orientation:** ↑↓ 12 o'clock.

Such coins, alongside Byzantine issues, were used in Antioch both before the Crusaders began minting their own coins and afterward, as evidenced by numerous finds of Seljuk coins during archaeological excavations in Antioch (Miles, 1965, p. 497).

As for Byzantine coins, during the Princeton University archaeological excavations in Antioch in the 1930s, it was noted that the coins of the Crusader rulers "are in the same general fabric as the Byzantine folios of the later eleventh century, of which the excavations produced similar quantities" (Metcalf, 1995, p. 22).

Highly informative regarding the circulation of Seljuk coins in the Principality of Antioch is a hoard of 65 copper coins, consisting of 59 Seljuk coins and 6 Byzantine coins (including some from the final years of the reign of Alexios I), which was "found in the American excavations at Corinth" (Metcalf, 2006, p. 294). According to Metcalf, "The hoard almost certainly represents a sum of money carried westwards from Antioch – and not by a Seljuk! The obvious candidate is a crusader returning home after the First Crusade, taking ship from Antioch and transferring across the Isthmus via Corinth" (Metcalf, 2006, p. 294).

The initiation of independent coinage by the rulers of the Principality of Antioch was driven by a number of significant factors, particularly the need – especially among the urban population – for small-denomination coins to pay for services and minor purchases.

The demand for copper coins in the Principality of Antioch was so high that, in addition to locally minted coins, the monetary circulation also included not only Byzantine and Islamic coins of the Levantine rulers but even copper objects resembling coins.

This is evidenced by a coin hoard found near Jubayl (Djubayl), north of Beirut, Lebanon, during the 1970s and 1980s, where, along with coins of the Principality of Antioch – including an anonymous issue (Fig. 5) – a coin-like object (Fig. 2) was discovered that stylistically resembles a coin from the time of Roger of Salerno featuring an image of St. George on horseback.

Fig. 2 (Not to scale)[1]

In numismatic scholarship, there is no consensus regarding the dating of the initial emissions of coins by Bohemond I and his regent Tancred (Schindel, 2023). In our view, the most convincing hypothesis is that of M. Phillips, who suggests that Bohemond I began minting coins "after his release from captivity and before his departure for Europe a year later" (Phillips, 2023, p. 214), meaning between June of 1103 and December of 1104. Tancred, acting as regent for Bohemond I, likely began minting his own coins only after Bohemond's departure – no earlier than 1105. This theory is supported by numismatic evidence, particularly the absence of Bohemond I's coins being overstruck by Tancred's emissions in the first two series. Tancred is recorded to have overstruck coins of Bohemond I only in the third series (Phillips, 2023, pp. 210–211). Thus, while issuing the first two series of his own coins, Tancred, as regent, did not overstrike those of his suzerain. Only after consolidating power in Antioch did he begin overstriking Bohemond I's coins.

[1] Private collection, Ukraine.

Therefore, it is not appropriate to speak of independent Crusader emissions in the Principality of Antioch prior to 1103. Before that, the inhabitants of this Crusader state used copper coins of the Syrian Seljuks and the Byzantine Empire.

Coin Minting Techniques Used by the Crusaders in Antioch. A detailed examination of coins from the Principality of Antioch in the first third of the 12th century shows that some coins were struck on newly cast coin flans of irregular circular shape (e.g., those of Tancred, Roger of Salerno, and Bohemond II), while others were overstruck on previous emissions or on coins of others, including Byzantine folles and Seljuk fals of Syria.

The mint in Antioch operated a full cycle of coin production – from melting ore (or scrap metal) to issuing finished coinage. This included producing coin alloy, casting coin flans in special molds, processing and adjusting the flans, striking coins, and handcrafting the coin dies.

The technology used by the previous rulers of Antioch – the Seljuks of Syria – for preparing coin flans was somewhat different. During the minting of fals in Antioch, the Seljuks used a method whereby a square piece was cut from a hammered metal sheet and then "rounded" by trimming or chopping off the sharp corners (see Fig. 1).

The coin dies in Antioch were handcrafted by engraving mirror images, primarily with the use of a burin. This is indicated by irregularities in the halos of St. Peter, St. George, Jesus Christ, as well as in the outer circles of the obverse and reverse, and in the arms of the cross of St. Peter, among others.

Pre-modern coins often exhibit production defects characteristic of manual minting techniques. These include, in particular, incomplete strikes and die misalignments. Such defects are interrelated. The upper die (used for striking the reverse) typically had a smaller diameter than the lower die (used for the obverse). As a result of misalignment during striking, a portion of the reverse image sometimes extends beyond the coin's surface. This indicates that the flan did not fully receive the kinetic energy from the hammer blow, and thus, insufficient pressure was applied to transfer the full image from the die.

The manual striking technique employed in the Principality of Antioch has been known since antiquity.

As previously noted, the Principality of Antioch undertook a full cycle of coin production. Let us now examine the coin alloys used for minting local currency in Antioch during the first third of the 12th century, based on the primary elemental composition identified through X-ray fluorescence spectroscopy.[2] For this analysis, we consider as primary those elements that constitute more than 3% of the composition in individual specimens (see Table 1).

The main elements of the coin alloys of the Principality of Antioch in this period were copper (Cu), lead (Pb), tin (Sn), and zinc (Zn).

In addition to the actual alloy elements, the coin surfaces also contain residual particles of sand: silicon (Si), aluminum (Al), and dirt – phosphorus (P) – which may have entered the coin materials from the sand-clay mixture used in coin flan molds, as well as from slag produced during the melting process.

It is important to note that a significant amount of silicon remains on the surface of the analyzed coins even after mechanical cleaning – provided that the patina was not damaged. The same applies to the presence of aluminum on the coin surfaces. Aluminum oxide (Al_2O_3)

[2] All coins from the Ukrainian private collection were provided by the owner for research purposes and with permission to publish their photographs.

is a component in the chestnut soils commonly found in northern and western Syria, the region in which the coins of the Principality of Antioch were struck.

Given the cultural and historical value – and, in some cases, the rarity – of the coins under study, all X-ray fluorescence spectroscopy measurements were performed without damaging the surface or patina of the coins.

A macrostructural study of the coin of **Roger of Salerno, Type 1 (Id 32)**, carried out using a destructive method, revealed a considerable amount of aluminosilicate inclusions (ranging in size from 0.10 to 0.15 mm) embedded in the surface oxide layer. These inclusions could significantly affect the accuracy of the chemical composition measurements conducted using X-ray fluorescence spectroscopy (see Fig. 3).

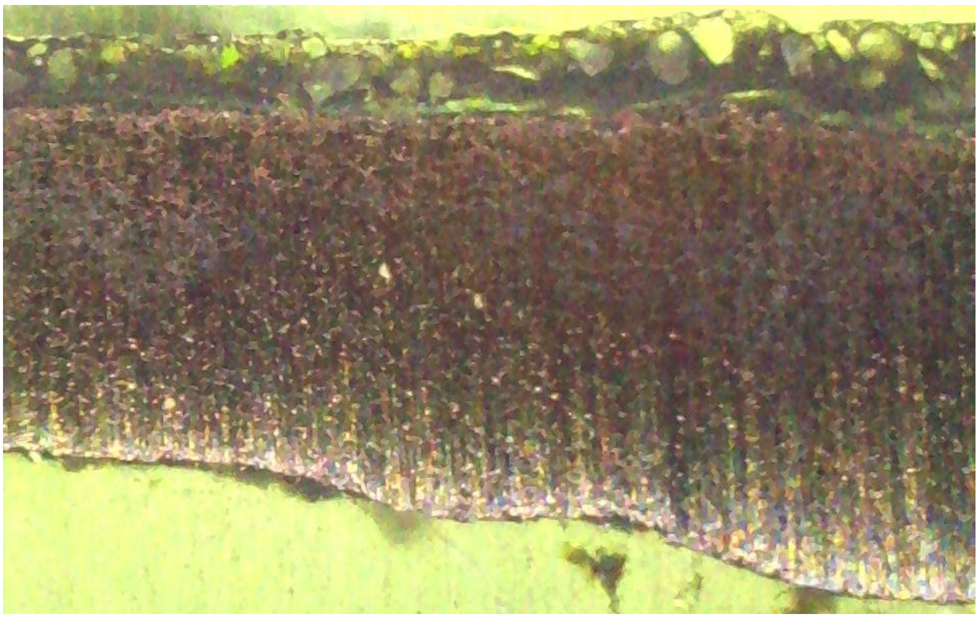

Fig. 3 Macrostructure of coin metal (Id 32) (50x magnification), indicating the fixation of aluminosilicate inclusions in the surface oxide layer

In addition to the elements listed in Table 1, the coin alloys also contain other chemical elements characteristic of various ore deposits; however, the percentage of such elements in the coin alloy is insignificant.

Table 1 presents a systematic overview of the chemical elements detected on the coin surfaces, organized according to the chronology of emissions and coin types.

A control analysis of the chemical composition of the coin material (Id 3), struck on a cast coin flan, was carried out using a spark optical emission spectrometer Solaris CCD Plus GNR. The analyzed specimen was in poor condition (Good/Poor). It was determined that the coin material was bronze containing approximately 6% tin, over 30% lead, about 2% phosphorus, with the remainder being copper. These contents should be considered approximate, since no standard reference samples of tin-lead bronze were available for spectrometer calibration. The analysis lasted thirty seconds.

Table 1

Elemental composition of the coin surface of the principality of Antioch in the first third of the 12th century

Id	Coin types	The chemical elements %						
		Cu	Pb	Si	Sn	Zn	Al	Fe
1	2	3	4	5	6	7	8	9
1	Bohemond I (Fig.6.1)	60.341	2.673	28.781	0.609	0.517	5.008	1.123
2	Tancred, Type 1 (Fig.6.2)	57.236	14.235	20.027	2.756	1.727	1.837	1.001
3	Similar	34.823	37.475	11.847	7.721	2.752	3.293	0.983
4	Similar	50.556	25.752	9.654	6.050	4.061	1.258	1.019
5	Similar	37.931	6.925	35.220	1.474	1.195	12.815	3.342
6	Similar	50.867	10.727	24.481	2.525	1.820	6.145	1.944
7	Similar	62.091	11.633	15.509	2.203	3.870	3.172	0.885
8	Similar	73.931	0.838	17.317	0.860	5.203	1.312	0.284
9	Similar	38.670	38.478	11.337	3.721	1.316	3.707	1.341
10	Similar	61.346	19.847	7.530	3.135	1.025	4.027	1.019
11	Similar (Fig.6.3)	63.265	17.092	8.230	2.418	1.765	4.168	0.993
12	Similar (Fig.6.4)	48.468	18.586	20.189	5.402	2.252	2.901	1.013
13	Similar (Fig.6.5)	57.194	10.397	23.275	4.205	0.910	2.474	0.774
14	Similar	62.976	16.086	6.969	3.619	2.909	3.883	0.858
15	Similar	67.139	10.676	9.740	3.031	1.001	5.753	0.869
16	Similar	68.507	9.374	12.362	5.091	1.930	1.295	0.536
17	Similar overstrikes on a Byzantine anonymous follis	72.463	5.528	14.475	1.756	1.176	3.448	0.604
18	Tancred, Type 2	73.529	16.680	3.465	2.453	1.190	1.986	0.225
19	Similar	31.303	13.992	31.846	2.222	0.376	15.992	3.221
20	Similar	42.231	22.633	19.071	4.150	2.163	4.671	1.156
21	Similar	29.037	21.037	30.972	1.745	0.647	13.179	1.803
22	Similar	54.251	15.630	20.630	3.587	0.875	2.169	0.899
23	Similar	63.415	1.143	28.389	0.579	1.055	4.073	0.797
24	Similar (Fig.6.6)	52.362	24.931	10.574	7.118	0.369	2.980	0.624
25	Similar	52.550	11.035	23.191	2.718	4.079	4.425	0.938
26	Tancred, Type 3 (Fig.6.7)	86.822	5.283	0.416	2.985	3.255	0.295	0.385
27	Similar	45.820	3.679	34.050	2.751	1.049	10.290	1.853
28	Similar, overstrikes on Fals Seljuk of Syria	96.463	0.740	1.313	0.421	0.279	0.357	0.146
29	Seljuks of Syria, Fals, Antioch Mint, Standing Elephant Type (Fig.6.8)	93,679	0,928	3,211	0,566	0,868	0,306	0,149
30	Tancred, Type 4 (Fig.6.9)	55.916	24.108	11.011	2.589	2.175	1.175	0.653
31	Similar	68.622	21.571	1.992	3.761	1.027	0.384	0.670
32	Roger of Salerno, Type 1 overstrikes on Fals Seljuk of Syria	40.696	2.648	33.234	0.865	2.062	18.236	1.780

Table 1 (Continued)

1	2	3	4	5	6	7	8	9
33	Similar	39.465	1.043	35.627	1.092	1.047	19.494	1.717
34	Similar	81.472	3.001	9.304	0.795	1.785	1.905	0.591
35	Similar	71.182	1.152	24.013	0.640	0.305	1.941	0.438
36	Similar	44.360	11.110	31.093	3.344	1.260	5.501	2.468
37	Similar overstrikes on Tancred, Type 4 (Fig.6.10)	42.231	22.633	19.071	4.150	2.163	4.671	1.156
38	Roger of Salerno, Type 2	82.905	2.047	9.036	0.890	2.046	1.510	0.721
39	Similar (Fig.6.11)	35.905	34.691	15.999	5.213	0.851	4.305	1.176
40	Roger of Salerno, Type 3 (Fig.6.12)	52.861	15.224	21.424	2.535	1.968	2.396	1.698
41	Bohemond II	71.706	7.612	6.404	3.701	1.464	3.826	0.430
42	Similar (Fig.6.13)	33,795	37,924	2,463	18,169	0,391	1,251	1,207
43	Similar (Fig.6.14)	53.185	19.810	18.287	3.511	1.565	1.461	1.085
44	Anonymous (Fig.6.15)	68.168	7.161	17.458	0.280	0.238	3.351	2.760

Following the procedure, a burn mark from the spectrometer's spark discharge remained on the coin surface, up to 5 mm in diameter, resulting in the loss of the coin's historical value.

On the other hand, the presence of insoluble discrete lead particles uniformly distributed within the copper-containing matrix creates an attenuating, shielding effect on the intensity of spectral lines of the chemical elements comprising the coin metal when using traditional spectrographic methods for alloy composition analysis. X-ray radiation emitted by copper atoms is weakened as it passes through large lead inclusions, which leads to artificially inflated lead values during computer processing of inputs.

Compared to values obtained through quantitative metallography and XRF analysis, spark spectrometry may overestimate lead content by up to 7%. The accuracy of the result at any given point is influenced by the degree of dispersion of lead inclusions and the extent of its segregation throughout the coin's mass. Where lead is finely dispersed, the measurement error may range from 1% to 2%.

In practice, when conducting technical measurements, reference samples with chemical composition close to that of the analyzed sample are typically used. In this context, the use of XRF express analysis for determining the metal composition of coins is most appropriate, as it provides an averaged result across the sample's volume.

The first coinage of the Principality of Antioch was most likely issued, as noted above, from mid-1103 – 1104 by Bohemond I, after his return from captivity. Because such coins are exceptionally rare, we were able to examine only a single specimen (Id 1), which Phillips classifies as Type 1 (Fig. 6.1). The piece was struck on a flan and retains 28.781% surface sand. The Cu-to-Pb ratio in the alloy is 22.57 : 1. Lead was deliberately introduced, for "lead was sometimes added to copper alloys in order to improve the fluidity and lower the melting temperature, properties which facilitated casting, particularly the filling of large and complex moulds" (Yahalom-Mack, Langgut, Dvir, Tirosh, Eliyahu-Behar, & Erel, et al., 2015). This practice goes back to antiquity: "first and foremost lead ores were a major source of silver, and lead was merely the by-product of silver extraction" (ibid.). Matthew Ponting's study of Fatimid-period copper-alloy metalwork records objects (a lamp tray, animal foot, single foot, long foot, small bucket, small dipper, handle, mortar, sword ferrule, etc.) containing 7.29 % – 41.40 % lead (Ponting, 2003, pp. 101–103). The celebrated 10th–11th-century Islamic scholar Abū Rayḥān Muḥammad ibn Aḥmad al-Bīrūnī called a copper-lead alloy *baṭrūy* – "bad copper" – observing that it had a pale colour and "could not withstand extensive hammering or fierce fire" (al-Bīrūnī, 2011, p. 298).

The Bohemond I coin studied here was struck by the same technique used for late Byzantine anonymous folles and tetartera. Indeed, the metrology of Antioch's copper coinage is closest to those Byzantine types. Byzantine copper coins, like many Near-Eastern issues, including Sasanian issues (Van Ham-Meert, Rademakers, Gyselen, Overlaet, Degryse, & Claeys, 2020, p. 52) and Abbasid issues (Smirnova, 1963, p. 52), traditionally contained lead. The earliest tetarteron *noummion* issues were struck entirely in lead (Hendy, 1999, p. 231).

The coins of Tancred generally show a high lead content, reaching a maximum of 38.478% (Id 9). Because X-ray fluorescence spectroscopy consistently reveals a substantial percentage of lead, we conducted a supplementary investigation of one Tancred Type 1 coin using an electron microscope.

A destructive metallographic study of coin Id 10 was carried out on polished sections with an MMP-2P microscope at 100–250× magnification. The examination confirmed that the coin was struck on a cast flan. The matrix is an α-tin-in-copper solid solution containing lead inclusions (the dark and grey areas, see: Fig. 4). Lead is virtually insoluble in solid copper alloys, appearing in the microstructure as a dispersion of discrete particles; the size of these inclusions and the spacing between them are directly related to the lead content and the cooling rate during solidification. The absence of any anisotropy in the shape of the lead inclusions shows that the cast coin flans underwent no pre-strike forging. A similarly undistorted, non-metallic inclusion, visible in the macrostructure, also indicates that the flan experienced no bulk deformation before striking.

In hot striking, lead-rich bronze coins would exhibit molten lead inclusions. The lack of cavities between the low-melting lead inclusions and the lighter copper-rich lattice demonstrates that the flan was not reheated prior to striking.

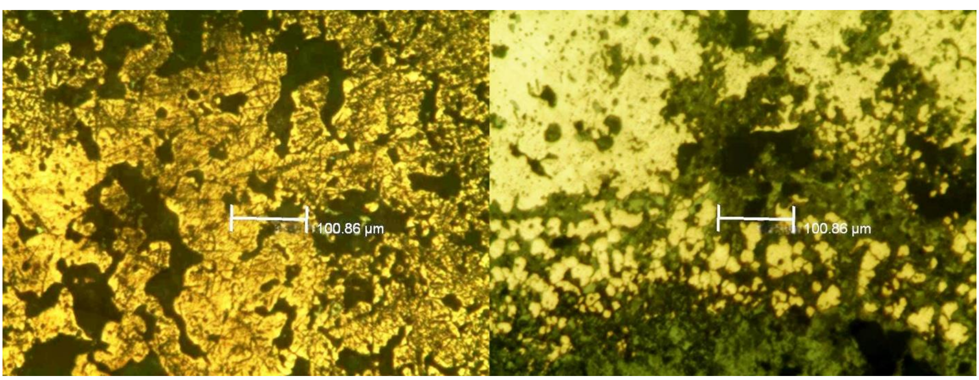

Fig. 4. Microstructure of coin metal (Id 3) (150x magnification):
a) central part of the coin; b) edge of the coin

Fig. 5 Macrostructure of the coin metal (Id 10) (25× magnification) showing a non-deformed slag inclusion in the right section of the coin's cross-section

The addition of lead to bronze alloys improves casting properties, especially fluidity, and also facilitates cold striking. Lead can serve as a thinning agent, since a coin containing 20% lead allows for a 20% reduction in copper usage. However, it is unlikely that the alloy was chosen solely for its workability.

Regarding the coins of Roger of Salerno, those that show signs of being overstruck on earlier coins have a chemical composition that is significantly different from other coins of the Principality of Antioch. Specifically, the lead (Pb) content in these alloys ranges only from 1.043% to 3.001% (Id 32–35, 38). Unfortunately, it is not possible to identify the original coins that were overstruck by the analyzed Roger of Salerno issues.

In contrast, **coins of Roger of Salerno struck on new cast flans** (Id 36-37, 39–40) contain between 11.110% to 34.691% lead – typical for most coins of the Principality of Antioch.

All three analyzed **coins of Bohemond II** (Id 41–43), struck on newly cast flans, also contain lead, ranging between 7.612% – 37.924%.

Besides copper coins of the Principality of Antioch that are clearly identified in modern scholarship issuer-by-issuer, we also examined **an anonymous coin** (Id 44) featuring a bust of St. Peter on the obverse and two monograms (Fig. 6.15). This coin type was described by Gustave Schlumberger in the appendices to his work, with an illustration on Plate XIX, 1. The eminent French numismatist attributed this type to the "Principality of Antioch and the earliest days of Latin occupation." (Schlumberger, 1954, p. 493) Metcalf suggests this type may have been struck "during the reign of King Baldwin II? – or after 1130?." (Metcalf, 1995, p. 28) The elemental composition of the metal indicates that this coin is closest in alloy to those of Bohemond II, though its flan is noticeably thinner than any of the other emissions analyzed from the Principality of Antioch. This strongly suggests that the coin was struck after the death of Bohemond II – i.e., after February of 1130.

Conclusions. Our research indicates that the Principality of Antioch most likely operated a single mint, as evidenced by the consistent casting technology used for coin flans across all coin types. The elemental composition also shows no significant variation – all coins from the principality contain lead (Pb) in their flans. Lead was widely used in copper alloys in the Levant during the 11th – 12th centuries. Its presence improved the casting and striking properties of the flans and also offered a cost advantage, as lead – being a by-product of silver extraction – was much cheaper than copper.

Fig. 6

A comparative analysis of coins from Antioch and those of the Syrian Seljuks shows that the addition of lead was not a practice at the Antiochene mint before the arrival of the Crusaders. The significant variation in the elemental composition of a single coin type suggests that different raw materials were used for alloy production.

Given the lack of local copper deposits in the Principality of Antioch, it is highly likely that the Crusader mint worked with scrap copper, which was melted down and poured into molds. The presence of lead (Pb) in all analyzed samples of Antiochene Crusader copper coins supports the conclusion that lead was intentionally added during the melting process.

After casting, the flans were further processed: sprues were trimmed, defective flans remelted, and only then were coins struck using a manual minting technique.

When comparing X-ray fluorescence spectroscopy (XRF) with optical emission spectrometry, it is important to note that the former provides more accurate results regarding the chemical composition of metallic objects, as it evaluates a broader area. Furthermore, XRF does not damage the surface of the coin being analyzed.

The physicochemical analysis conducted by the authors confirms Phillips' thesis that the coin bearing Bohemond's name belongs to the first emission of the Crusader mint in Antioch. This emission was followed by mass coinage under Tancred of Taranto, which became possible only after 1104. The composition of the anonymous coin with the image of St. Peter suggests that it was minted after the cessation of Bohemond II's coinage – i.e., after his death in February of 1130.

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