Annexe 1 : analyses métallographiques : analysis and metallography of copper alloy metalwork from Onnens VD/Beau Site

Documents

Annexe 1. Analyses métallographiques

Analysis and metallography of copper alloy metalwork from Onnens VD/*Beau Site*

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Twelve pieces of copper alloy metalwork from excavations of Bronze Age contexts at Onnens VD-*Beau Site*, were sampled for metallurgical study. The purpose of the study was to assist in the dating of the contexts in which the items were found and in forming a chronology for the site, to consider the provenance of the items, and to examine the methods of manufacture.

Sampling and analysis

Of the twelve objects submitted the condition of one, K 18973-1 precluded sampling. The remaining eleven objects were identified, labelled, as sampled.

The samples were hot-mounted in a carbon-filled thermosetting resin, ground and polished to a 1 µm diamond finish. Analysis was by electron probe microanalysis with wavelength dispersive spectrometry; operating conditions were an accelerating voltage of 20kV, a beam current of 30nA, and an X-ray take-off angle of 40°. Seventeen elements were analysed as set out in the accompanying table; count times were 20s per element and pure element and mineral standards were used. Detection limits are typically 100-200ppm.

Between five and eight areas, each 30-50 µm were analysed on each sample; the individual analyses and their means, normalised to 100 %, are given in figure 267. All concentrations are in weight percent.

After analysis the cut samples were examined metallographically in both as-polished and etched states (fig. 268); the etch used was an acidified aqueous solution of ferric chloride further diluted with ethanol.

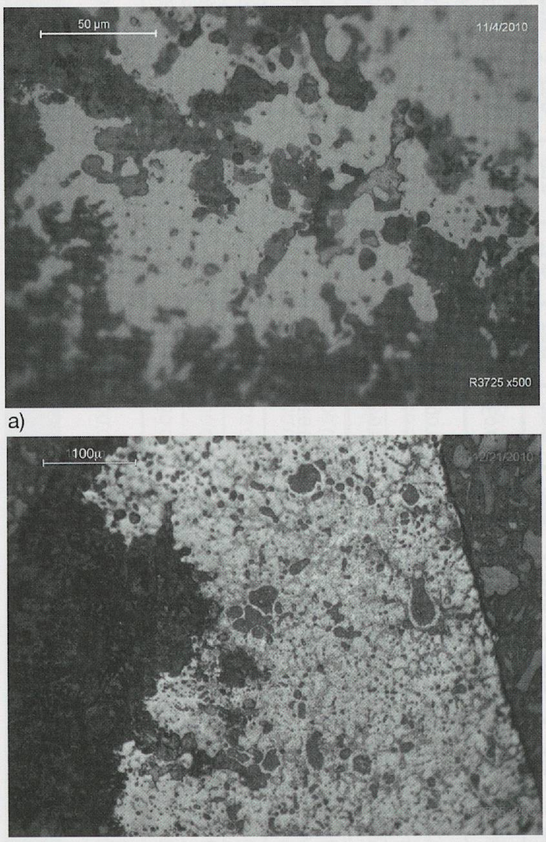
Sample	Object	Part	Fe	Co	Ni	Cu	Zn	As	Sb	Sn	Ag	Bi	Pb	Au	Cd	S	Al	Si	Mn
R3721/1	Knob-headed pin (K 16023-1)	shaft	0.03	0.24	0.36	84.81	0.00	0.78	0.34	12.59	0.23	0.00	0.37	0.09	0.05	0.09	0.01	0.02	0.00
R3721/2			0.07	0.22	0.34	85.28	0.00	0.79	0.34	12.34	0.17	0.00	0.28	0.09	0.00	0.07	0.00	0.00	0.02
R3721/3			0.10	0.28	0.35	84.88	0.00	0.83	0.35	11.99	0.16	0.00	0.58	0.02	0.00	0.44	0.00	0.02	0.00
R3721/4			0.09	0.21	0.35	85.16	0.00	0.79	0.38	12.50	0.16	0.07	0.14	0.00	0.00	0.06	0.00	0.08	0.00
R3721/5			0.09	0.23	0.34	85.04	0.00	0.81	0.37	11.98	0.16	0.00	0.53	0.00	0.00	0.45	0.00	0.00	0.00
R3722/1	Small tool (K 18127-1)	shank	0.13	0.02	0.79	87.61	0.00	0.59	0.16	9.91	0.12	0.00	0.00	0.00	0.00	0.64	0.00	0.00	0.03
R3722/2			0.11	0.05	0.84	87.84	0.00	0.64	0.17	9.96	0.14	0.00	0.00	0.00	0.00	0.23	0.00	0.01	0.00
R3722/3			0.13	0.05	0.94	87.33	0.07	0.54	0.16	10.31	0.12	0.05	0.08	0.00	0.03	0.16	0.00	0.02	0.00
R3722/4			0.52	0.04	0.83	87.76	0.04	0.58	0.19	9.66	0.21	0.00	0.00	0.05	0.00	0.13	0.00	0.01	0.00
R3722/5			0.24	0.04	0.86	88.78	0.00	0.61	0.11	8.75	0.09	0.00	0.00	0.00	0.00	0.46	0.00	0.06	0.00
R3723/1	Square-section rod (K 16101-2)	shank	0.03	0.00	0.16	88.95	0.00	0.15	0.23	10.26	0.03	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.00
R3723/2			0.04	0.01	0.14	89.80	0.00	0.07	0.21	9.58	0.00	0.04	0.00	0.00	0.00	0.08	0.00	0.01	0.00
R3723/3			0.04	0.21	0.30	84.63	0.00	0.76	0.42	12.59	0.11	0.00	0.60	0.06	0.00	0.27	0.00	0.01	0.00
R3723/4			0.03	0.25	0.31	85.76	0.00	0.76	0.38	12.23	0.15	0.00	0.11	0.00	0.00	0.02	0.00	0.00	0.00
R3723/5			0.05	0.00	0.17	89.54	0.00	0.11	0.28	9.50	0.03	0.00	0.02	0.00	0.00	0.23	0.00	0.04	0.02
R3724/1	Roll-headed pin (?) (K 18986-2)	shaft	0.05	0.04	0.23	90.15	0.03	0.12	0.19	8.50	0.05	0.07	0.11	0.00	0.00	0.40	0.00	0.00	0.06
R3724/2			0.05	0.04	0.27	90.28	0.00	0.14	0.18	8.73	0.06	0.00	0.16	0.02	0.02	0.01	0.00	0.00	0.02
R3724/3			0.04	0.02	0.19	90.77	0.01	0.21	0.17	8.40	0.07	0.00	0.00	0.10	0.00	0.02	0.00	0.00	0.00
R3724/4			0.05	0.03	0.20	90.07	0.07	0.17	0.18	8.63	0.08	0.01	0.49	0.00	0.00	0.02	0.00	0.00	0.00
R3724/5			0.04	0.03	0.19	90.38	0.00	0.16	0.14	8.62	0.09	0.01	0.30	0.00	0.00	0.03	0.00	0.00	0.00
R3724/6			0.19	0.03	0.16	87.91	0.06	0.14	0.11	7.72	0.10	0.00	1.04	0.00	0.00	2.52	0.00	0.00	0.01
R3724/7			0.03	0.05	0.19	90.17	0.10	0.14	0.14	8.76	0.04	0.00	0.30	0.01	0.00	0.04	0.00	0.01	0.02

Sample	Object	Part	Fe	Co	Ni	Cu	Zn	As	Sb	Sn	Ag	Bi	Pb	Au	Cd	S	Al	Si	Mn
R3725/1	Flat ring (K 18311-1)	end	0.07	0.04	0.10	81.90	0.02	0.11	0.11	6.81	0.10	0.00	10.67	0.00	0.00	0.04	0.00	0.00	0.02
R3725/2			0.04	0.03	0.07	75.41	0.07	0.15	0.12	8.81	0.05	0.09	15.16	0.02	0.00	0.00	0.00	0.00	0.00
R3725/3			0.06	0.00	0.12	74.58	0.00	0.17	0.07	8.46	0.09	0.00	16.33	0.00	0.00	0.11	0.00	0.01	0.00
R3725/4			0.07	0.00	0.08	74.61	0.00	0.16	0.13	9.12	0.11	0.00	15.59	0.09	0.00	0.05	0.00	0.00	0.00
R3725/5			0.06	0.01	0.08	80.71	0.00	0.20	0.21	11.06	0.00	0.00	7.47	0.00	0.05	0.16	0.00	0.00	0.00
R3725/6			0.06	0.00	0.10	80.33	0.00	0.24	0.16	11.33	0.09	0.02	7.56	0.00	0.00	0.10	0.01	0.00	0.00
R3725/7			0.04	0.00	0.07	80.71	0.00	0.17	0.18	10.60	0.05	0.00	7.93	0.08	0.00	0.15	0.00	0.00	0.00
R3725/8			0.11	0.03	0.13	84.23	0.00	0.15	0.11	8.50	0.06	0.14	6.46	0.00	0.00	0.07	0.00	0.00	0.02
R3726/1	Pin (K 16026-1)	tip	0.00	0.02	0.05	86.89	0.01	0.06	0.00	12.91	0.03	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.00
R3726/2			0.00	0.04	0.01	86.63	0.00	0.04	0.00	13.19	0.00	0.01	0.04	0.03	0.00	0.00	0.00	0.00	0.01
R3726/3			0.01	0.03	0.03	86.97	0.00	0.09	0.01	12.81	0.01	0.00	0.00	0.00	0.00	0.04	0.01	0.00	0.00
R3726/4			0.01	0.00	0.04	86.79	0.00	0.09	0.00	12.89	0.00	0.05	0.09	0.00	0.00	0.02	0.01	0.00	0.02
R3726/5			0.01	0.03	0.02	87.21	0.00	0.04	0.00	12.44	0.00	0.05	0.07	0.14	0.00	0.00	0.01	0.00	0.00
R3727/1	Waste (K 16137-1)	edge	0.16	0.05	0.84	88.98	0.00	0.34	0.13	9.40	0.02	0.06	0.01	0.00	0.00	0.01	0.00	0.01	0.00
R3727/2			0.17	0.05	0.85	89.23	0.00	0.29	0.17	9.09	0.03	0.03	0.07	0.00	0.00	0.00	0.01	0.00	0.02
R3727/3			0.15	0.02	0.84	90.60	0.00	0.25	0.09	7.88	0.02	0.00	0.13	0.03	0.00	0.00	0.00	0.00	0.00
R3727/4			0.18	0.04	0.87	92.71	0.00	0.16	0.06	5.91	0.01	0.03	0.00	0.01	0.00	0.02	0.00	0.00	0.01
R3727/5			0.23	0.06	1.01	94.91	0.00	0.11	0.03	3.52	0.01	0.00	0.06	0.06	0.00	0.00	0.00	0.00	0.00
R3727/6			0.17	0.04	0.91	91.68	0.00	0.22	0.06	6.61	0.00	0.06	0.22	0.00	0.00	0.00	0.00	0.00	0.02
R3727/7			0.19	0.05	0.93	92.84	0.00	0.16	0.03	5.54	0.00	0.00	0.16	0.09	0.00	0.00	0.00	0.00	0.00
R3728/1	Awl fragment (K 18986-1)	end	0.00	0.02	0.86	85.08	0.00	0.37	0.27	12.91	0.03	0.00	0.00	0.15	0.00	0.28	0.00	0.02	0.02
R3728/2			0.02	0.01	0.82	85.28	0.00	0.36	0.18	12.84	0.05	0.04	0.09	0.16	0.00	0.16	0.00	0.00	0.00
R3728/3			0.01	0.04	0.85	85.25	0.00	0.34	0.19	12.69	0.00	0.00	0.00	0.00	0.00	0.62	0.00	0.00	0.01
R3728/4			0.01	0.03	0.91	85.12	0.01	0.31	0.23	13.12	0.06	0.05	0.10	0.00	0.00	0.04	0.00	0.00	0.01
R3728/5			0.00	0.04	0.86	86.08	0.00	0.33	0.20	12.41	0.06	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00

Sample	Object	Part	Fe	Co	Ni	Cu	Zn	As	Sb	Sn	Ag	Bi	Pb	Au	Cd	S	Al	Si	Mn
R3730/1	Hammered bar fragment (K 16138-1)	edge	0.13	0.57	1.34	83.13	0.00	0.16	0.57	13.55	0.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R3730/2			0.18	0.59	1.30	83.39	0.00	0.16	0.50	12.91	0.59	0.00	0.11	0.06	0.00	0.20	0.00	0.01	0.00
R3730/3			1.00	0.44	0.91	81.65	0.00	0.12	0.42	9.91	0.44	0.00	0.00	0.00	0.00	5.08	0.00	0.00	0.03
R3730/4			0.13	0.60	1.26	83.02	0.02	0.16	0.60	13.49	0.59	0.00	0.11	0.02	0.00	0.00	0.00	0.01	0.00
R3730/5			1.19	0.48	0.83	80.80	0.00	0.12	0.29	8.72	0.46	0.00	0.00	0.00	0.02	7.08	0.00	0.00	0.01
R3730/6			0.25	0.58	1.20	83.34	0.00	0.17	0.48	12.69	0.55	0.00	0.00	0.00	0.00	0.63	0.01	0.11	0.00
R3730/7			0.18	0.65	1.41	83.11	0.00	0.20	0.52	13.08	0.66	0.00	0.14	0.00	0.00	0.05	0.00	0.00	0.00
R3730/8			0.49	0.60	1.35	81.63	0.07	0.16	0.53	12.11	0.54	0.00	0.00	0.02	0.00	2.49	0.01	0.00	0.00
R3731/1	Waste (K 18130-2)	edge	0.03	0.03	0.29	91.73	0.00	0.26	0.24	7.18	0.06	0.05	0.04	0.05	0.00	0.01	0.00	0.00	0.03
R3731/2			0.03	0.01	0.00	96.10	0.00	0.13	0.13	2.79	0.00	0.00	0.00	0.00	0.04	0.72	0.00	0.06	0.00
R3731/3			0.07	0.01	0.22	87.88	0.00	0.36	0.45	10.71	0.05	0.00	0.06	0.04	0.00	0.01	0.00	0.12	0.02
R3731/4			0.07	0.02	0.07	90.05	0.00	0.40	0.32	8.76	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.25	0.00
R3731/5			0.03	0.03	0.28	90.21	0.00	0.32	0.34	8.48	0.00	0.00	0.15	0.10	0.03	0.00	0.00	0.03	0.00
R3731/6			0.05	0.03	0.26	88.19	0.04	0.34	0.43	10.00	0.00	0.00	0.01	0.00	0.23	0.01	0.02	0.39	0.00
R3731/7			0.21	0.02	0.05	78.82	0.00	0.51	0.75	16.43	0.00	0.00	0.00	0.01	0.00	2.84	0.00	0.37	0.00
R3731/8			0.03	0.05	0.22	90.59	0.00	0.33	0.32	8.31	0.05	0.02	0.06	0.00	0.00	0.01	0.00	0.01	0.00
R3721/Mean	Knob-headed pin (K 16023-1)	shaft	0.07	0.24	0.35	85.03	0.00	0.80	0.35	12.28	0.18	0.01	0.38	0.04	0.01	0.22	0.00	0.02	0.00
R3722/Mean	Small tool (K 18127-1)	shank	0.23	0.04	0.85	87.86	0.02	0.59	0.16	9.72	0.14	0.01	0.02	0.01	0.01	0.32	0.00	0.02	0.01
R3723/Mean	Square-section rod (K 16101-2)	shank	0.04	0.09	0.22	87.74	0.00	0.37	0.30	10.83	0.06	0.01	0.15	0.01	0.00	0.16	0.00	0.01	0.00
R3724/Mean	Roll-headed pin (?) (K 18986-2)	shaft	0.06	0.04	0.20	89.96	0.04	0.15	0.16	8.48	0.07	0.01	0.34	0.02	0.00	0.43	0.00	0.00	0.02
R3725/Mean	Flat ring (K 18311-1)	end	0.06	0.01	0.09	79.06	0.01	0.17	0.14	9.34	0.07	0.03	10.90	0.02	0.01	0.08	0.00	0.00	0.00
R3726/Mean	Pin (K 16026-1)	tip	0.01	0.02	0.03	86.90	0.00	0.06	0.00	12.85	0.01	0.02	0.04	0.03	0.00	0.02	0.00	0.00	0.01
R3727/Mean	Waste (K 16137-1)	edge	0.18	0.04	0.89	91.56	0.00	0.22	0.08	6.85	0.01	0.02	0.09	0.03	0.00	0.00	0.00	0.00	0.01
R3728/Mean	Awl fragment (K 18986-1)	end	0.01	0.03	0.86	85.36	0.00	0.34	0.22	12.79	0.04	0.02	0.04	0.06	0.00	0.22	0.00	0.00	0.01

Sample	Object	Part	Fe	Co	Ni	Cu	Zn	As	Sb	Sn	Ag	Bi	Pb	Au	Cd	S	Al	Si	Mn
R3730/Mean	Hammered bar fragment (K 16138-1)	edge	0.44	0.56	1.20	82.51	0.01	0.16	0.49	12.06	0.55	0.00	0.05	0.01	0.00	1.94	0.00	0.02	0.01
R3731/Mean	Waste (K 18130-2)	edge	0.06	0.02	0.17	89.20	0.00	0.33	0.37	9.08	0.02	0.01	0.05	0.03	0.04	0.45	0.00	0.15	0.01
R3726/Mean	Pin (K 16026-1)	tip	0.01	0.02	0.03	86.90	0.00	0.06	0.00	12.85	0.01	0.02	0.04	0.03	0.00	0.02	0.00	0.00	0.01
R3723/Mean	Square-section rod (K 16101-2)	shank	0.04	0.09	0.22	87.74	0.00	0.37	0.30	10.83	0.06	0.01	0.15	0.01	0.00	0.16	0.00	0.01	0.00
R3724/Mean	Roll-headed pin (?) (K 18986-2)	shaft	0.06	0.04	0.20	89.96	0.04	0.15	0.16	8.48	0.07	0.01	0.34	0.02	0.00	0.43	0.00	0.00	0.02
R3725/Mean	Flat ring (K 18311-1)	end	0.06	0.01	0.09	79.06	0.01	0.17	0.14	9.34	0.07	0.03	10.90	0.02	0.01	0.08	0.00	0.00	0.00
R3731/Mean	Waste (K 18130-1)	edge	0.06	0.02	0.17	89.20	0.00	0.33	0.37	9.08	0.02	0.01	0.05	0.03	0.04	0.45	0.00	0.15	0.01
R3722/Mean	Small tool (K 18127-1)	shank	0.23	0.04	0.85	87.86	0.02	0.59	0.16	9.72	0.14	0.01	0.02	0.01	0.01	0.32	0.00	0.02	0.01
R3727/Mean	Waste (K 16137-1)	edge	0.18	0.04	0.89	91.56	0.00	0.22	0.08	6.85	0.01	0.02	0.09	0.03	0.00	0.00	0.00	0.00	0.01
R3728/Mean	Awl fragment (K 18986-1)	end	0.01	0.03	0.86	85.36	0.00	0.34	0.22	12.79	0.04	0.02	0.04	0.06	0.00	0.22	0.00	0.00	0.01
R3721/Mean	Knob-headed pin (K 16023-1)	shaft	0.07	0.24	0.35	85.03	0.00	0.80	0.35	12.28	0.18	0.01	0.38	0.04	0.01	0.22	0.00	0.02	0.00
R3730/Mean	Hammered bar fragment (K 16138-1)	edge	0.44	0.56	1.20	82.51	0.01	0.16	0.49	12.06	0.55	0.00	0.05	0.01	0.00	1.94	0.00	0.02	0.01

Fig. 267. Onnens-*Beau Site*. Analysis of Bronze Age metalwork.



a)

b)

Fig. 268. Onnens-*Beau Site*. Example of the microstructure of an analysed bronze sample (R3725). a) unetched b) etched.

The alloys

The samples examined were all identified as bronze, the alloy of the droplet (K 16139-1) being identified by the presence of small, uncorroded particles of the d phase. All the others can be described as medium tin bronzes with the exception of the flat ring (K 18311-1) which is a leaded bronze with 9.3 % tin and 10.9 % lead. This alloy is exceptional in a Swiss context. Among the 948 analyses of Middle and late Bronze Age metalwork from Switzerland published by Rychner and Kläntschi (1995) there are no examples with more than 10 % lead, and among the 472 analyses made of later Bronze Age material from the site of Zug ZG/Sumpf only three objects have more than 5 % lead, the maximum being just 10 % (Northover 2004). Thus the making of leaded bronze was not a feature of Bronze Age metallurgy in Switzerland and the source of the metal in this object, if not the object itself, must be elsewhere. The most probable source is ultimately Atlantic France where leaded bronze was the norm from BF IIb (equivalent to HaA2) onwards, use of the alloy then spreading eastwards through the circulation of bronze and through its local adoption (e.g. Northover 1983). A second, and perhaps more remote, possibility is that it could have come from Italy.

All the other bronzes have measured tin contents in the range 6.9-12.9 %: although every care was taken to ensure that analyses were made on uncorroded metal it is still possible than some values are modestly enhanced by the interaction of the electron beam with corrosion products. However, if this has happened its extent will be small and we can regard the results as representative of the tin contents of the objects. Four of the objects have tin contents in the range 12.1-12.9 % (K 16023-1, 16026-1, 16138-1, and 18986-1): tin at this level is not characteristic of the objects analysed by Rychner and Kläntschi (*op. cit.)* which were mainly axes, sickles and knives, but are more common at Zug/Sumpf where they are associated with small wrought products such as pins and small pieces of sheet. In Rychner and Kläntschi's data the mode of the tin distribution reaches a maximum in BzD-HaA1 (1995, p. 61), while at Zug/Sumpf higher tin contents are most consistently associated with *Nadeln mit zwei Halsknoten* which are there assigned to HaA2 to earliest HaB1. Rychner and Kläntschi also note an increase in the lead impurity with time: in the Bronze Moyen over 90 % of objects had lead below 0.20 %, the mean lead content then rising to 0.33 % in BzD-HaA1, and 0.97 % in HaA2. The lead content of one of these objects (knob-headed pin K 16023-1) is 0.35 %, suggesting a date range from BzD onward, while the associated pottery is BzD2. The impurity pattern also can contribute to the chronology of this object (see below). The other three objects with >12 % tin have trace levels of lead (0.04-0.05 %).

The next band of tin contents spreads from 8.5 % to 10.8 %, and, excluding the leaded bronze flat ring already discussed, comprises two pins (K 18127-1 and K 18986-2), a length of square-sectioned rod, part of a shaft of a pin (K 16101-2), and a piece of waste

(K 18130-2). They have lead contents which vary from 0.02 % to 0.34 %, suggesting that they might be spread over more than one period of the Bronze Age, and the variety of their impurity patterns, in fact all different, support this. The question of the extent to which they represent metalworking on the site will also be discussed below.

The remaining analysed item is a piece of waste with 6.9 % tin and 0.09 % lead (K 18137-1). Depending on how homogeneous the piece was overall the mean tin content might be higher. The alloy is most typical of the Bronze Moyen.

Impurity patterns

The impurity patterns of Swiss Middle and Late Bronze Age metalwork were classified by Rychner in Kläntschi (1995, p. 33) into seven groups, each subdivided into three bands based on the total of arsenic, antimony and nickel: *pauvre* (low) up to 0.42 %, *normale* (standard) 0.43 % to 3.99 % and *riche* (high) from 4 % upwards). A rather different system was adopted for the publication of Zug/Sumpf (Northover 2004) because of the importance there of cobalt as an impurity. For the discussion of the bronzes from Onnens-*Beau Site* the scheme of Rychner and Kläntschi will in general be followed, although cobalt is a significant impurity in two cases (the pin K 16023-1) and the hammered bar fragment (K 16138-1).

The leaded bronze (K 18311-1) has already been assigned to the later Bronze Age and is certainly no earlier than HaA2. The impurity pattern is 1P (just, the As/Sb/Ni total being 0.40 %): group 1 is typical of both Bronze Moyen to BzD-HaA1 and HaB2-B3: the combination with leaded bronze ensures that this must be dated to HaB2. The impurity patterns of the other analysed pieces are listed on figure 269.

Of these nine pieces six belong to Groups 1-3, those most associated with the Bronze Moyen and BzD-HaA1. However, matters are not quite that simple and other impurities, such as cobalt, silver, and sulphur, must be brought into the picture to give us a full understanding. For the knob-headed pin (K 16023-1) we have already noted lead content of 0.38 % and to this we should add a cobalt content of 0. 24 %, silver 0.18 %, and sulphur 0.22 %. In the histograms presented by Rychner and Kläntschi (1995, p. 28) cobalt contents reach this level in HaA2 and effectively do not occur before that. They then begin to tail off through HaB1 and are becoming uncommon again in HaB2-B3. Thus a date of HaA2-B1 is appropriate on metallurgical grounds for this pin, but the context would suggest a slightly earlier date. One other piece of bronze from *Beau Site* has a high cobalt content and that is the bar fragment (K 16138-1) with 0.56 % and associated with 0.44 % iron, 1.20 % nickel, 0.55 % silver, and 1.94 % sulphur. The iron and sulphur are typical of freshly produced copper newly alloyed into bronze, and in Rychner

Analysis	Inventory n°	Plate	Object	Sampling	Impurity pattern
R3721	K 16023-1	pl. 1/5	Knob-headed pin	Drilled from shaft	1N
R3722	K 18127-1	pl. 1/7	Roll-headed pin fragment	Drilled from shaft	3N
R3723	K 16101-2	pl. 1/8	Square-sectioned pin shaft	Drilled	1N
R3724	K 18986-2	pl. 1/6	Roll-headed pin fragment	Cut from end	4N
R3725	K 18311-1	pl. 68/1019	Flat ring	Cut from edge	
R3726	K 16026-1	pl. 1/9	Pin fragment	Cut from tip	2P
R3727	K 16137-1	pl. 1/2	Waste	Cut from edge	3N
R3728	K 18986-1	pl. 1/4	Awl	Cut from end	3N
R3729	K 16139-1	-	Droplet	Whole droplet	
R3730	K 16138-1	Pl. 1/3	Hammered bar fragment	Cut from edge	4N
R3731	K 18130-2	pl. 1/1	Waste	Cut from edge	6N

Fig. 269. Onnens-*Beau Site*. Sampling, analysis and impurity patterns of bronze objects.

and Kläntschi's data the cobalt concentration is most likely to place the piece in HaA2, but the high nickel and silver are more common in HaB1. A dating of HaA2-B1 is also supported by the results from Zug/Sumpf (Northover 2004).

Three objects, the roll-headed pin (K 18127-1), a piece of waste (K 16137-1), and an awl fragment (K 18986-1), can be placed in the very large group 3N. This was subdivided by Rychner and Kläntschi (1995, pp. 39-41) into three groups based on nickel content: 3N1 has nickel above 1 % and mainly belongs to HaA2 (cf. K 16138-1), while 3N2 with nickel below 0.5 % and 3N3 with nickel between 0.5 % and 1 % belong almost entirely to the Bronze Moyen. It is not possible, though, to place all three in Bronze Moyen because of another aspect of their composition, and that is that the Bronze Moyen material has silver at a trace level only, almost all below <0.05 %. On this basis the waste and the awl fragment can be assigned to Bronze Moyen, but the roll-headed pin, with 0.14 % silver, belongs to HaA2. Group 3N1, as noted above almost entirely belonging to HaA2, has silver in the range 0.10-0.20 %, and Rychner and Kläntschi place three objects in Group 3N3 with 0.09-0.15 % silver into HaA2. Their nickel contents are 0.86-0.92 %, and one has an antimony content of 0.16 %; the only point of difference is the low level of lead (0.05 %).

The next three objects to consider are the square-sectioned rod (K 16101-2), the roll-headed pin fragment (K 18986-2), and a piece of waste (K 18130-2). Strictly applying the same classification they belong, respectively, to Groups 1N, 4N, and 6N, but they are broadly similar save K 18986-2 has lower arsenic and antimony, and K 18130-2 has lower lead. Group 1N divides primarily between Bronze Moyen and HaB2, but those that match this composition best in that group with low silver and lead are in Bronze Moyen. Group 4N mainly has much higher nickel than is found in K 18986-2 but sub-group 4N3 does encompass the 0.20 % of this fragment. Mostly this group belongs to later periods but there are three objects with low lead, two of which have trace silver like K 18130-2, which belong to Bronze Moyen. Group 6N, in particular sub-group 6N2, while mainly dating to HaB-B2 does also incorporate a small number of objects with low lead and otherwise similar compositions that belong to Bronze Moyen. Thus we may reasonably place K 16101-2 and K 18130-2 in Bronze Moyen: however, the roll-headed pin fragment (K 18986-2) typologically and by context belongs to HaA2-B1, but could have been made using re-cycled, older metal.

Last to be discussed is the pin K 16026-1 which lies in Group 2P: the P sub-groups overwhelmingly occur in Bronze Moyen and BzD-HaA1 and there is every reason for this pin to do so also. The trace levels of silver and lead would tend to favour assigning this pin to Bronze Moyen, although a somewhat later date is still possible. With this possible exception there is very much a gap between metalwork of probable Bronze Moyen manufacture and the later material from HaA2 onwards. It is possible that some of the Bronze Moyen metalwork was either used or re-used in BzD-HaA1 but within the range of objects studied here there really does appear to be a minimum in activity. On the basis of their compositions the objects analysed can be arranged chronologically as on figure 270.

BzB	R3727	K 16137-1	Waste, pl. 1/1	3N
	R3728	K 18986-1	Awl, pl. 1/4	3N
	R3722	K 18127-1	Roll-headed pin fragment, pl. 1/7	3N
	R3723	K 16101-2	Square-sectioned pin shaft, pl. 1/8	1N
	R3731	K 18130-2	Waste, pl. 1/1	6N
BzB-BzD-HA1	R3726	K 16026-1	Pin fragment, pl. 1/9	2P
HaA2-B1	R3721	K 16023-1	Knob-headed pin, pl. 1/5	1N
	R3724	K 18986-2	Roll-headed pin fragment, pl. 1/6	4N
	R3730	K 16138-1	Hammered bar fragment, pl. 1/3	4N
HaB2-B3	R3725	K 18311-1	Flat ring, leaded bronze pl. 68/1019	1P

Fig. 270. Onnens-*Beau Site*. Dating of bronze objects.

Metallography

Because of the small size of the samples and their corroded condition it was not possible to collect a sufficiently full set of metallographic data to compile a comparative table. The microstructures are illustrated in fig. 268 and are discussed below in the chronological order given above (fig. 271).

BzB
R3727, K 16137-1, pl. 1/2, waste As-cast structure, with extensive interdendritic corrosion attacking the ad eutectoid, together with some transgranular corrosion; no sulphide inclusions are visible. It is possible that this waste fragment has been subsequently affected by heat.
R3728, K 18986-1, pl. 1/4, awl Intergranular corrosion near surface, and numerous sulphide inclusions; fully recrystallised grain structure with annealing twins; no coring or residual cold work; grain diameter = 50-100 µm; this is large for a small working tool and suggests some exposure to heat after use.
R3722, K 18127-1, pl. 1/7, roll-headed pin Drilled sample, so no metallography was possible.
R3723, K 16101-2, pl. 1/8, square-sectioned rod Although this sample was drilled its state of corrosion meant that some of the metal fragmented and could be examined metallographically. Extensive intergranular corrosion; fully recrystallised equiaxed grain structure with annealing twins and residual cold work; grain diameter = 20-30 µm, final cold reduction = 15-20 %.
R3731, K 18130-2, pl. 1/1, waste Sample completely penetrated by intergranular corrosion, with some grains massively corroded; small clusters of sulphide inclusions; structure is homogenised with some twinned grains, most probably the result of high temperature affecting cast waste containing some residual stresses.
BzB-BzD-HaA1
R3726, K 16026-1, pl. 1/9, pin Massive surface corrosion, with some penetration around inclusions; fully recrystallised equiaxed grain structure with annealing twins and some residual cold work.
HaA2-B1
R3721, K 16023-1, pl. 1/5, knob-headed pin Drilled sample, so no metallography was possible.
R3724, K 18986-2, pl. 1/6, roll-headed pin fragment Massive surface corrosion with sulphide inclusions preserved; short parallel bands of massive corrosion with both inter- and transgranular corrosion; fully recrystallised grain structure with residual cold work suggesting a cold reduction of 20-25 %; grain structure could not be satisfactorily etched because of the corroded state of this small sample.
R3730, K 16138-1, pl. 1/3, bar fragment Pitted surface, with sulphide inclusions preserved in surface corrosion products; homogenised structure with numerous sulphide inclusions; some twinned grains at the surface; possible cast bar being broken up by hot chiselling.
HaB2-B3
R3725, K 18311-1, pl. 68/1019, *flat ring*
Undated
R3729, K 16139-1, droplet This droplet was too corroded to reveal a microstructure, or provide any evidence for dating by its composition.

Fig. 271. Onnens-*Beau Site*. Microstructures of the analysed bronze samples.

Discussion

The study of the metalwork from Onnens-*Beau Site* has provided information about both chronology, and about the use of metal on the site. The analysed objects belong primarily to Bronze Moyen and HaA2-B1. One heavily leaded bronze is firmly dated to HaB3 and is most unusual in Switzerland because of that lead content. The alloy very probably came from outside Switzerland, almost certainly from France, and the object itself could be an import. All the other bronze is unleaded and tends to follow the progression of lead contents with time noted by Rychner and Kläntschi (*op. cit.*). This leaves the question of the gap in metal activity at the end of Bronze Moyen: as noted above, it is possible that some of the metal was made or used early in BzD but comparison with all the available data make it seem quite clear that there metal securely datable to BzD-HaA1 has either not been recovered from the excavated area and thus was not deposited.

The metal analysed two intact, although clearly used pins, and a number of fragments both of finished artifacts and of metalworking waste. There is no evidence of the special deposition of any artifact and some may well have simply been lost, or thrown away. Neither are any of the pieces that might be associated with metalworking linked to any other evidence for a metallurgical process such as crucible fragments, furnace residues etc., and none are unalloyed metal such as ingot copper. The most interesting piece is the HaA2-B1 bar fragment (K 16138-1). With its high iron, cobalt, nickel, and sulphur contents this appears to be newly smelted and refined copper alloyed with tin. Analysis of metal residues of Bronze Moyen date from Erlenbach ZH/Obstgartenstrasse (Northover 1997) revealed raw copper, copper refining slags, bronze and also copper and bronze droplets trodden into a workshop floor. The site was interpreted as relating to a workshop where raw copper was imported from a distant smelter and alloyed with tin to make bronze for local use. The same publication notes hints of this pattern at other sites, for example at Pfäffikon ZH. The bar from *Beau Site* could be the output of a similar workshop, either close to the excavated area and made for local use, or imported as an ingot from another site for conversion into finished artifacts at *Beau Site*.

The bar K 16138-1 suggests the possibility of a small amount metalworking activity in HaA2-B1, supported by the unanalysed droplet (K 16139-1), which was found nearby, the evidence from Bronze Moyen contexts is stronger. This is in the form of melting waste (K 16137-1) and a semi-finished product in the shape of the square-sectioned rod (K 16102-1). We may conclude that there were periodic episodes of metalworking activity at *Beau Site*, but these were very modest in scale. We have identified two possibilities, one in Bronze Moyen and one in HaA2-B1, but there could have been others with no recoverable traces.