PRE-INDUSTRIALISATION OF BRONZE MELTING DURING THE NEW EMPIRE PERIOD

Melting ovens, Qantir, Ramesside period, N-S, stratum B3a
Excavations and experiments

Four melting batteries

Structural dimensions	30cm deep	65cm large	15m long
Functional dimensions	16cm deep	35cm large	15m long

Simple structure with two parallel walls built in bricks, with no mortar, on a sand heart, in the bottom of the pit/ditch. These walls were likely of a maximum height of two bricks: since the upper part shows the colorimetric II orange stratum (due to a secondary firing) and a few tuyeres still resting on the upper part of these walls in small empty holes. This height would also determine the working surface receiving the bellows. From these tuyeres, bamboos would connect with the pot bellows. Since the tuyeres were on a horizontal position, jets, leaning towards the centre of the fire, were needed. This way, the oxygen went along the outer side in order to keep a semi-reductor environment. Charcoal covered everything, including the tuyeres heads, which explains their erosion. The pot bellows were activated through an alternative movement of the feet. Each crucible could have functioned with four tuyeres and was thus supplied with pressured air, thanks to the jets. This ventilation complex is mobile. First, the tuyeres were installed after the crucible was set. Then, during the handling of the crucible, one only needed to remove the tuyeres, which facilitated the use of the crucible extraction instruments.

Colorimetric stratigraphy found during the excavations

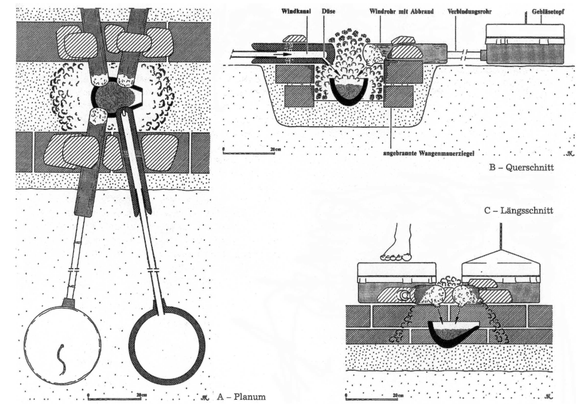
These are temperature and functionality indicators. They are thus interpretative elements during the excavations. They are identical to the ones of our experimental oven.

From the top to the bottom

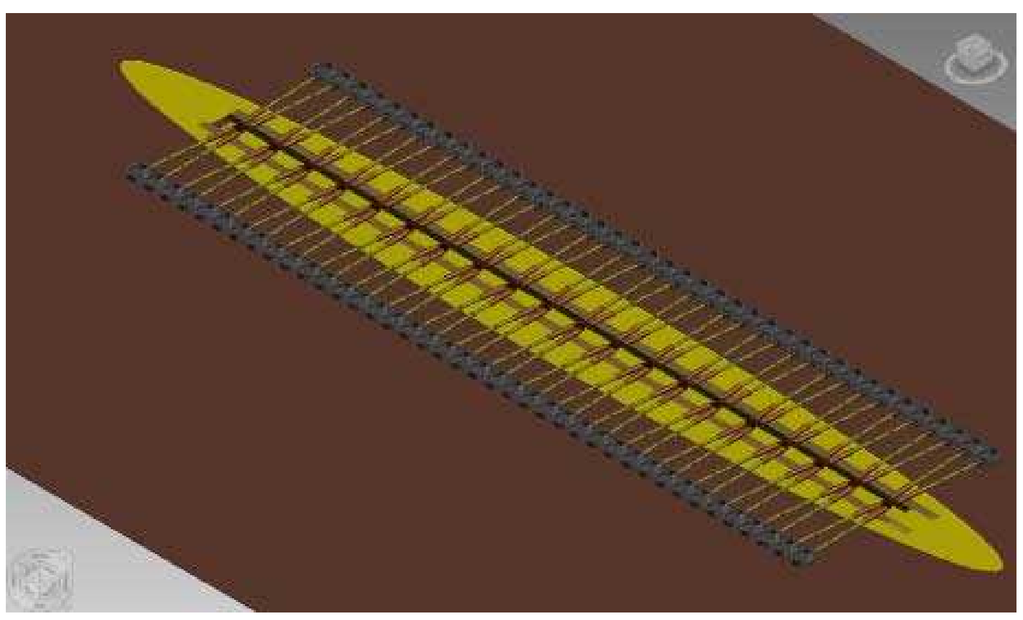
Stratum	Colorimetry	Characteristics
Stratum I	Grey/black zone, burn-free	Upper part of the wall, no charcoal and no overfeeding in oxygen, ± 300° C, oxidizing zone
Stratum II	Orange zone	Transition zone with occasional charcoal, light fire traces by radiation heat, ± 800° C, oxidizing zone
Stratum III	Red/brown zone	Presence of charcoal with a high level of oxygen supply, highest zone of heating with vitrification, ± 1200° C, semi-reductor zone, melting possible thanks to the Boudouard reaction => position of the crucible
Stratum IV	Grey/white zone	Presence of charcoal with a lesser oxygen supply, transition zone towards the slow-pace combustion zone, ± 750° C, oxygen lowering zone
Stratum V	Black zone	Lowest part of the wall, charcoal burning slowly, ± 600° C, oxygen-free zone

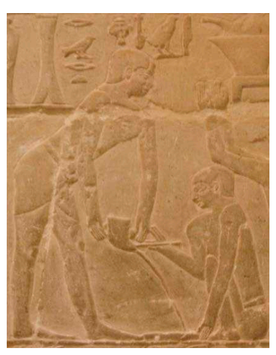
All the artefacts are standardised allowing compatibility, control and management of the bronze casting

Crucibles	Tuyeres	Pot bellows
One of the various kinds, in the shape of a ship carina, is made in a local clay with sand. The hearth shows spherical traces. An average Qantir crucible of 250 cm³ corresponds exactly to the Egyptian measure of 25 dbn (1 dbn = 91 g).	Two distinct parts: the canal and the jet which goes through the outer side of the tuyere proximal part. This drilling was made following a pre-defined angle of 135°. The tuyere heads are greatly damaged by the fire with a diagonal erosion.	Typical of the NE; they are made of two parts: one in terracotta, the other in leather. The leather bag was pulled up with a string and was then compressed by the blower's foot. The blower always activated two bellows at a time.



Previous proposals of interpretation, Qantir, Ramesside period, stratum B3a in E. B. Pusch, *Divergierende Verfahren der Metallverarbeitung in Theben und Qantir?* Ägypten und Levante 4, Wien, 1994, p.153, abb. I.

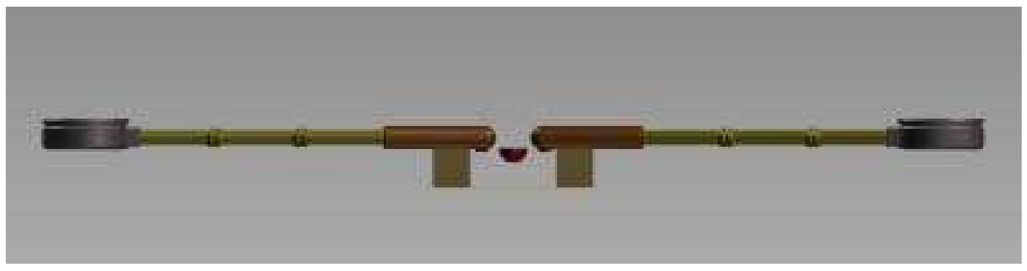




↑ Details of metalworkers during the casting, Mastaba de Mererouka, Saqqara, Old Kingdom.
↑ Casting with O.K. crucibles and potholders, experimentation, G. Verly, 2011.
← New proposal with 20 crucibles and 40 blowers, 3D modelisation, G. Verly, 2011.
← Position of the crucible in Stratum III, 3D modelisation, G. Verly, 2011.

De-waxing ovens, Qantir, Ramesside period, QI-ax/3, stratus B/3

Four cross-shaped ovens



They are geographically connected to the melting ovens. The interpretation of their exact use remains problematic; we suggest they were used for the de-waxing of the moulds

Phase I 80% de-waxing, firing of the clay moulds, during X hours
Phase II Full de-waxing of the residual wax absorbed by the clay, during X hours
Phase III Maintaining the moulds hot before casting

Experimental archaeology

This is not an autonomous discipline, but a scientific research tool that can be described as an hourglass. On the upper part, the various classic disciplines dealing with the historical subjects. In the centre, experimental archaeology working on a precise topic and following a specific objective. In the bottom part, classic disciplines again, but providing new answers to new topics. We also learned that all our articles and theories are only projections of our thought, to be considered with caution.

Like the Egyptians, we appreciate the timing of melting: through the cherry-red colour of the crucible, through the continued breathing of the fire, through the white colour of the charcoal, through the blue-green tin gas, through the vibrations in the degassing stick and through the mirror effect of the bronze.

The Egyptian metallurgy had limited means at its disposal. The bronze workers seemed not to possess metallic tools. They kept the slag with a dry stick or with a pipe bellow. The vertical heat radiation limited the unpleasant effects on the blowers. To manipulate the crucible, they covered themselves with mud which dried when facing heat, but as long as it was humid, protected sufficiently the skin. Their eyes, on the other hand, did not benefit from any protection.

Experimental archaeology also contributed to the understanding of metallurgy iconography in the TT (depending on the interpretation limits and the factual data they can produce). Iconographies that should be read in a loop, highlighting this pre-industrial production, through their cyclic character and through their production type such as the Amon temple's doors. Weisgeber estimates, when considering the mould fragments, that each door dates from 1.6T.

Assumption of a pre-industrial production

Considering the amounts produced and the number of craftsmen (minimum estimation: 160 blowers, 160 metalworkers + craftsmen from other corporations), we believe we can refer to an organised and structured pre-industrial production. Next to the typical metallurgic installations, there were other workshops, which were exclusively in charge of by-products and subsequent activities. Workshops of charcoal men, potters, tanners, wax sculptors and moulders took care of the by-products. Logistics included masters and their assistants, scribes, weighers and suppliers. Small multifunctional and standardised refining workshops along with finishing casted artefacts workshops took care of the artefacts. In total, this activity must have regrouped ± 600 people working full-time. These "workshops" were attached to important administrative structures (such as temples or palaces).

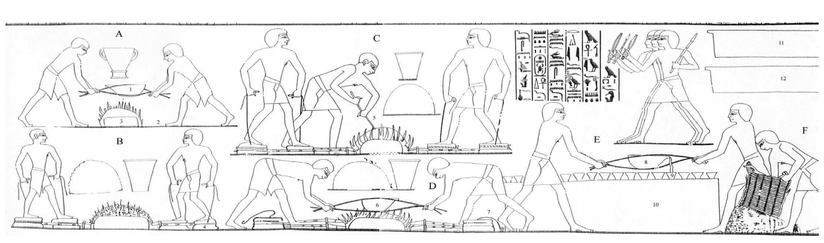
Production: utilitarian typology of an open oven to obtain a first form of "continued casting", estimating that each crucible could provide 1.9kg of bronze every 45 minutes; hence the management of 80 crucibles and multiple casting funnels for each mould. (cfr TT100).

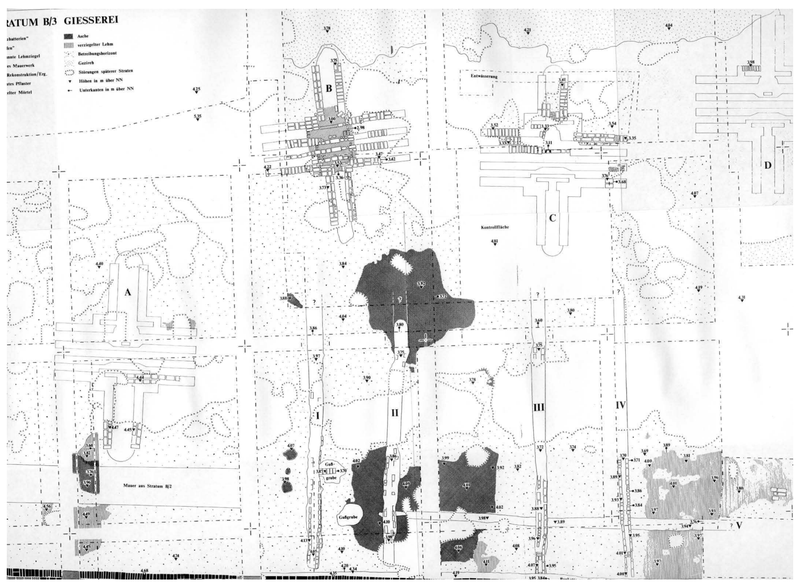
Profitability: simplification of the casting phases, limited number of instruments used, conception of moulds (the layers of matter render the vents useless and the breaking at high temperature, just after the casting, replaced the sawing), standardisation of the ceramics, mechanical and plastic resistance of these ceramics.

In conclusion, Egypt did not innovate in the field of metallurgy but maximised profitability while avoiding additional physical efforts for many workers.

OPEN QUESTIONS

- The cavities in the upper bricks would indicate, with the presence or not of an angle, that the tuyeres were set face to face (two per crucible) or in a cross position (four per crucible)
- Since the production had to be regulated, it seems it would have been two bellows per crucible instead of four bellows per three half-crucible.
- There are no explanations for the circular empty holes in the hearth. The crucible, set in the sand, is a mistaken interpretation. It should be at the same height as stratus III and not necessarily maintained with a support.
- An experiment should be undertaken again to define the charcoal consumption as well as the type of coal (mistake during the first reconstitution on the oven depth)
- Which temperature can we cast in the moulds? Would the size of these moulds be a factor?
- As the moulds cannot be transported, was a mobile wood pontoon set up for the metal workers on the cross-shaped oven? The metal workers flux on the site must be considered: they could not be disturbed but they had to arrive on the spot as fast as possible and they had to use the same casting funnel.
- We do not master the rising of temperature with pot bellows activated by foot.
- Did the foundry workers place two green wood sticks around the crucible (cfr iconography TT100): this seems to us dangerous and hazardable.
- Three main changes in the NE: crucible, pot bellows and handling of the crucibles.





↑ Qantir, Ramesside period, stratum B3a in E. B. Pusch, *Divergierende Verfahren der Metallverarbeitung in Theben und Qantir?* Ägypten und Levante 4, Wien, 1994.

← TT100, Metalworkers in N. De Garis Davies, *The Tomb of Rekh-Mi-Ré at Thebes*, The Metropolitan Museum of Art Egyptian Expedition, New York, 1935, Plate I.

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