Casting Rodin's Thinker

Sand mould casting, the case of the Laren Thinker and conservation treatment innovation

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Chapter 1 Historical development of the sand mould casting technique

1.1 Introduction

The technical study of historical bronzes has concentrated, till now, mainly on Renaissance and Baroque bronzes. The bronzes of these periods are almost invariably cast using the lost wax method. In contrast, the casting techniques used in the nineteenth century, when lost wax and casting in sand moulds were used concurrently, have received very little scholarly attention, although in recent years, increasingly, especially in sculptors' monographs, papers appeared detailing technical aspects such as the casting technique of nineteenth sculpture. For example, excellent work has been carried out by Ann Boulton on Matisse and Barye and on Degas bronzes by Anne Pingeot, Arthur Beale, Daphne Barbour and Shelley Sturman.[34]

In order to place the sand mould casting technique within the wider context of foundry technology, an overview of the historical development is required. Literature, giving a thorough chronological historical overview of the use of sand moulds for casting, is non-existent and when sand mould casting is covered, this is very fragmentary and brief. Cyril Stanley Smith in his *A Search for Structure, on the early history of casting, moulds, and the science of solidification*, covers the historical development of casting in sand moulds only briefly and incompletely.[35] Recently, Susan La Niece has given a short historical development of sand mould casting in the Islamic world, which, although outside the scope of this thesis, provides possible origins for sand mould casting in Europe.[36]

This chapter gives for the first time an overview of the historical development of sand mould casting in Europe. This is done by researching the early use of sand as a primary mould material in Europe in a broader context by including metalworking disciplines, other than sculpture founders, who traditionally also made use of sand as a mould material. To determine the place of sand mould casting, in the wider context of the various casting methods, I have compiled a diagram of the historical casting 'family'. (fig. 1.1) In this casting family, only those casting techniques are included, known to be in use before 1900. The discriminating factor in this overview is the status and permanence of the model or pattern and the mould. A pattern is the model used to fabricate the mould for casting the metal into. The way the molten metal is distributed in the mould, is not considered a discriminating factor in this overview.[37]

[34] Matisse: Boulton 2007a, 73-97; Barye: Boulton 2006, 66-72; Degas: Czestochowski and Pingeot 2002
[35] C. Smith 1981, 127-173.
[36] La Niece 2016, 263-276.
[37] For example assisted with a vacuum, steam, centrifugal force or slushed around (slush cating) or the type of gating system used such as ascended or descended casting.

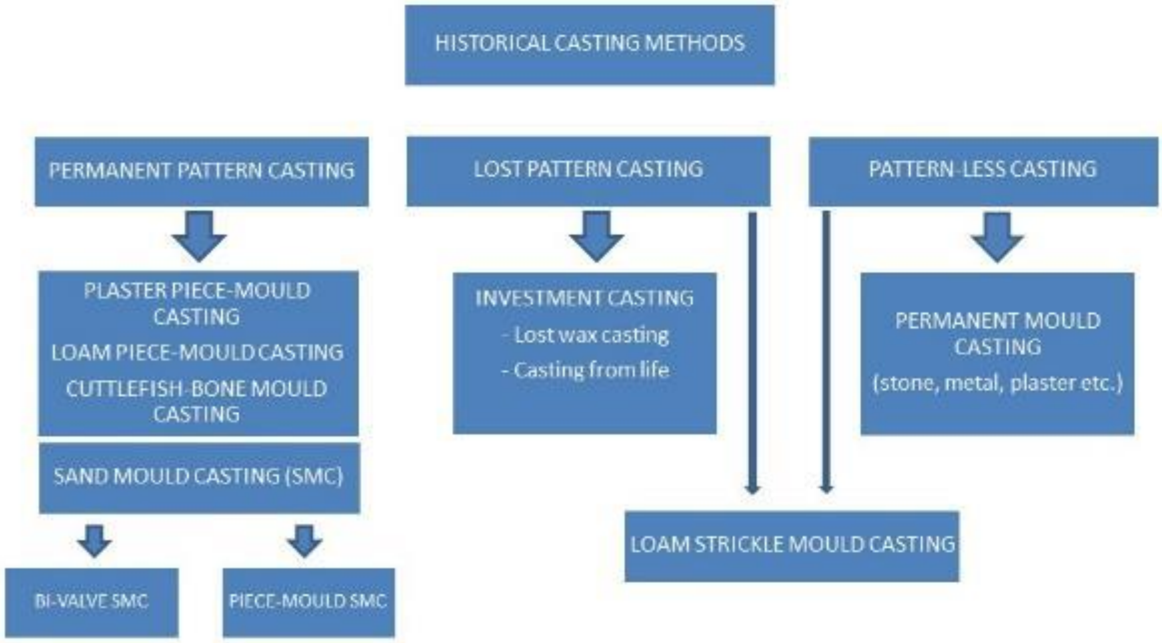

Fig. 1.1. Historical casting 'family tree', arranging the main casting methods in use before 1900.

The initial division is made on the presence and permanence of the pattern. Permanent moulds such as stone or metal moulds can be used repeatedly and do not require the use of a pattern to function as a mould.[38] With direct lost pattern casting, the pattern is destroyed in the process, whereas with indirect lost wax casting, the master model is preserved. With permanent pattern casting, a sturdy rigid pattern, is employed and removed after moulding, making it possible to re-use this pattern. A mould usually does not survive high temperature lost pattern and permanent pattern casting. Of these various different forms of casting, only a few have been used for the casting of bronze sculpture in Europe and the United States, during the nineteenth and early twentieth century.

Before the nineteenth century, when a more intricate object such as a figure sculpture, needed to be reproduced in metal, the object was cast using the lost wax or *cire perdue* method. With the *cire perdue* method, already in use since Classical Antiquity, a wax model made specifically for casting, is the starting point.[39] The wax is often made around a core of refractory material to create a hollow casting. This wax model is embedded in a mould made from refractory material such as plaster, or a clay and loam mixture, with the core held in place by small iron core nails. This combination, wax model enclosed in the mould, is heated to bake the mould and at the same time also, more importantly, to melt and burn out all traces of the wax. Once all the wax has been melted out and thus the negative form of the sculpture model, inside the mould cavity, has been created, the mould is ready to receive the hot molten

[38] Historically western pewterware is cast in metal moulds, which could be in use for generations.
[39] Hunt, L.B. "The Long History of Lost Wax Casting." *Gold Bulletin*, Volume 13, Issue 2, June (1980): 63-79. & Mattusch, C. C. "The preferred Medium: The Many Lives of Classical Bronzes." *The Fire of Hephaistos: Large Classical Bronzes from North American Collections*, Harvard Art Museums (1996): 15-43.

bronze. With lost wax casting, fine clay was usually applied as the first mould layer, to capture all the fine surface details, often backed up and reinforced with loam. The terms loam and clay, as used in earlier written sources, were often used inter-changeable, strictly speaking clay consists of very finely grained (< 2μ) and homogeneous rock particles, whereas loam is a coarser grained mixture which includes clay. The characteristics of clay, sand and loam are discussed further in detail further later in this chapter. Loam was also used directly as a mould material for the production of simple, circular shaped copper alloy hollowware and candlesticks during the late Middle Ages and the early modern period.[40] The production of this type of items did not make use of a pre-fabricated wax model, but a strickle to shape the core as well as the model.[41] This model, made from a more sandy loam, was upon finishing of the outer mantle mould, removed to create the mould cavity. Because of the coarser nature of loam, the as-cast, i.e. unfinished, surface is usually rougher than for example an object cast in a fine clay mould.

Looking at the history of casting in sand moulds it is useful to make a distinction between various sand mould casting techniques. A basic definition of sand mould casting has been given as "a method of casting metal, using a sand mould, which is formed and held within a wooden or metal frame called (casting) flask".[42] To distinguish sand mould casting from lost wax casting it is also important to emphasise the fact that sand moulds are not heated to remove the pattern. The sand mould is warmed to drive off the moisture and to make the mould more rigid but not as hard as with baked loam or clay moulds.[43]

The first part of this chapter looks at the nature of moulding sand. What properties makes this sand so suitable for moulding and casting? To understand this, moulding sand from historical sources, such as core material or sampled in the past in foundries, are analysed. Additional information is gathered from historical textual sources, providing information on the chemical composition. While the second part of this chapter charts the early development of sand mould casting up to 1800, this first part, on the nature of moulding sand, necessarily has to draw on later source material, due to the fact that before 1800 no sources are known giving the chemical composition of moulding sand.

[40] Thomas, N. et al. *L'or des dinandiers: Fondeurs et batteurs mosans au Moyen Age*. Maison du patrimone medieval mosan (2014): 55-60.

[41] A strickle is a board with the shape of the desired profile which can be used as a scraper to form the mould, core or model.

[42] Entry *sand casting* by Beentjes, T. in *Materials & Techniques in the Decorative Arts: an Illustrated Dictionary*, Lucy Trench, et al, John Murray (2000): 425.

[43] 204-260°C, see Hoffman, M. *Heads and Tales*. Charles Scribner's Sons (1936): 100.

1.2 Sand mould casting

The first step in the production of an object, using the sand mould casting method, would be to make a model. This model, in foundry terms called a pattern, was made of wood, metal or another sturdy material, able to withstand the forces applied during the moulding process. Wax models were less suitable because the wax had the tendency to stick to the sand, as well as deform during moulding. An existing object, could also be used as a model for the moulding and casting process, this created a cast copy, commonly referred to as an after-cast or *surmoulage.*[44]

The most commonly practised form of sand mould casting uses a two-part mould, whereby the pattern leaves an impression in the two halves of the mould. This simple form of sand mould casting was mostly used for moulding and casting shapes with no undercuts, such as medals, simple metal utensils or furniture mounts.[45] This limitation was due to the need to remove the pattern from the mould without damaging the mould, as well as the pattern. The pattern was embedded in the lower part of the mould, called the drag or nowel, with approximately half of the pattern still protruding from the sand.[46] Because this special moulding sand contained some clay, it was capable of holding the imprint of the pattern, although it still needed to be contained within a frame, called flask.

The next step was to place the upper half of the flask, called the cope, on top of the drag and fill this with sand, to form the top part of the mould. The cope and drag could then be separated and the, potentially re-useable, pattern removed to create the mould cavity. Runners to channel the liquid bronze to the mould cavity were now carved in the sand. The two mould halves put against each other again and the space in the mould, created by the removal of the pattern, was subsequently filled with molten metal to produce the casting.

With both processes, lost wax and sand mould casting, the mould often becomes damaged in the process and is nearly always destroyed in order to free the casting. The commonly used term, 'cast from the same mould', to describe identical castings by the sand mould casting method, is nearly always incorrect.[47] Even if the mould survives the casting process intact, the mould surface in direct contact with the hot metal chars and is very often cracked and is therefore frequently unsuitable for further use as a mould. The term 'cast from the same model or pattern' is therefore more appropriate when discussing sand mould castings. An

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[44] Bassett, J. and P. Fogelman. *Looking at European Sculpture*: *a guide to technical terms*. The J.Paul Getty Museum (1997): 7.

[45] An undercut, in foundry work, is an overhanging portion of the pattern, preventing easy withdrawal of a mould made from rigid material. Undercuts are sometimes referred to as underworked areas, see Overman, Fred. *The Moulder's and Founder's Pocket Guide*. Hart (1852): 143.

[46] Tate, J.M and M.O. Stone. *Foundry practice: a treatise on molding and casting in their various details.* H.W. Wilson (1904): 74.

[47] When casting in simple bi-valve moulds it is very occasionally possible to remove the casting without damaging the mould making it in theory possible to re-use the mould. The author, with 25 years of experience in casting, has to date, not been able to re-use a sand, loam or plaster mould that had been used to cast copper alloys or precious metals into.

exception is the use of metal moulds for casting low melting alloys such as pewter, lead and later zinc and aluminium. Because these moulds, usually made from iron or copper alloys, have a significantly higher melting point than the metal cast into them, they are not affected by the casting and can be re-used almost indefinitely. Indirect lost wax casting, whereby an inter-model is used, is another exception. This wax inter-model is made by pouring wax in a re-usable plaster piece-mould. The final plaster or clay mould that is used for casting the bronze into is invariably destroyed to remove the bronze cast. It is debatable whether wax pouring constitutes casting, to justify the term cast from the same mould.

The names given historically to the two casting methods, sand casting and lost wax casting, are confusing. Sand casting refers to the mould material cast into and not the material being cast in the process. Since it is not sand that is being cast, the term sand mould casting would be more accurate and will therefore be used throughout this thesis. The term lost wax casting derives from the material from which the model or pattern is made and which is replaced in the process by metal. Lost wax casting is a form of casting whereby the pattern is destroyed in the process, a type of casting one could refer to, more generally, as lost pattern casting. Life casting, using materials from nature such as plants or small animals as patterns, is another example of lost pattern casting.[48]

Sand mould casting is sometimes erroneously referred to as a casting technique with a less detailed result.[49] This is not correct, a well-executed sand mould casting can have the same surface detail as a lost wax casting, including details as fine as fingerprints.[50] Where the two casting methods, lost wax and sand mould casting, really differ is in the use of the pattern and/or model. With sand mould casting the pattern can be re-used which makes it suitable for multiple runs, whereas with lost wax the pattern, as implied by the name, is lost. This means for the founder using the lost wax technique, that he either uses directly the original artist's wax model for casting (direct lost wax casting), or indirectly by making a permanent mould of this original model and uses this to make a wax inter-model or pattern that will be used to make the final cast (indirect lost wax casting).

1.2.1 Types of sand mould casting

Sand mould casting can also be divided into different groups, based on the way the sand grains are bonded together and to what extend the mould is dried (fig. 1.2). There are basically two forms of sand mould casting:

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[48] Smith, P. H. and T. Beentjes. "Nature and art, making and knowing: reconstructing sixteenth century life casting techniques." *Renaissance Quarterly* 63, spring (2010): 128–179; Beentjes, T and P. H. Smith. "Sixteenth Century Life-casting Techniques, a reconstruction. "*The Renaissance workshop*." D. Saunders et al. Archetype Publ. for British Museum (2013): 144-151.

[49] Wenley, R. *French Bronzes in the Wallace Collection*. Wallace Collection (2002): 22; Forrest, M. *Art Bronzes*. Schiffer Publ (1988): 11; Avery, V. and J. Dillon. *Renaissance and Baroque Bronzes from the Fitzwilliam Museum, Cambridge*. Daniel Katz (2002): 225; Elliot, P. "The Nineteenth and Twentieth Centuries", in Ekserdjian et al. (2012): 94.

[50] Boulton 2007a, 81-82.

- addition hardening sand mould casting
- natural sand mould casting

Addition hardening sand mould casting

This type of sand mould casting came only in general use during the twentieth century and has in industrial foundries often replaced natural sand mould casting. The binders such as the polymer resins urea formaldehyde, phenol formaldehyde or water glass (sodium metasilicate),[51] which are used in addition hardening sand mould casting, act as glue and render the sand mould permanently rigid. After casting the moulds are broken up and discarded, the sand cannot be re-used. This type of sand mould casting is also sometimes referred to as hardened mould or chemically bonded casting.[52]

Natural sand mould casting

Natural sand mould casting makes use of unadulterated natural sand from river deposits (alluvial) with a clay content or an artificial mix of sands occasionally with extra non-synthetic binders. Modern founders sometimes use oil as a binder, I have not been able to find any historic references of the use of oil as a binder for sand moulds. The clay or other binders do not harden the moulds permanently and the sand moulds therefore can be broken up after casting for re-use.

Natural sand mould casting can also be divided into two groups:

- green sand mould casting
- dry sand mould casting

Green sand mould casting

Green sand mould casting uses water as binder for argillaceous (clayey or clay-rich) sand.[53] The name green sand derives from the presence of water in the sand, similar to the use of the name green wood in woodworking, when describing the use of fresh wood.[54] The moisture content in natural green sand moulds is usually between 6.5 and 8 % depending on the clay content of the moulding sand.[55] The water, which is present in the sand before moulding or introduced by steaming or sprinkling later during moulding, is absorbed by the clay and binds the sand particles together.[56] The function of the water is to hydrate the clay and should not be

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[51] Cured, using carbon dioxide gas

[52] Beeley, P. *Foundry Technology.* Butterworth-Heinemann (2001): 181.

[53] Fahrenholtz, W. G. "Clays" in *Ceramic and Glass Materials: Structure, Properties and Processing*. Shackelford, James F. and R. H. Doremus, Springer US (2008): 111-133.

[54] Buchanan, J. F. *Foundry Nomenclature*. Spon (1903): 58. See also BROMSGROVE GREENSAND, <http://artisanfoundry.co.uk/product_info.php?products_id=38> [accessed 16-6-2018]

[55] Ammen, C. W. *The complete handbook of sand casting*. Tab Books (1979): 31.

[56] Beeley 2001, 204-205.

present as free water since excess water can cause porosity or when the generated steam cannot escape quickly enough and builds up can cause explosions. The radiant heat of the hot molten metal entering the mould is sufficient to drive off the moisture in the inner surface of the mould. This moisture turns to steam and escapes away from the metal through the pores of the sand. After casting the moulds are broken up and the sand can be re-used. Green sand casting was already described by Cellini in 1568.[57] This type of sand mould casting was and still is mainly used for iron founding.

Dry sand mould casting

Dry sand mould casting is the green sand practice modified by drying the mould at 200-300 C°. The removal of moisture results in a smoother finish on copper alloy castings.[58] Dry sand moulds are usually stronger than green sand moulds and can therefore better withstand handling and therefore used for more complicated moulds. The moulds made from moist sand are dried in large ovens to drive off the excess water, however, they are not baked at high temperatures. After casting the dry sand moulds can also be broken up and the sand re-used. The founding of copper alloy sculpture was mostly performed by dry sand moulding and casting. Dry sand moulding has fallen into disuse in favour of addition hardening moulding which does not require lengthy, expensive drying and a shortage of skilled moulders.[59]

Fig. 1.2. Diagram illustrating the various sand mould casting methods.

[57] Cellini, B. and C.R. Ashbee. *The treatises of Benvenuto Cellini on Goldsmithing and Sculpture*. Dover Publ. (1967): 62-63. (translated by C.R. Ashbee in 1898) See for Cellini's precise text in English as well as Italian; *1.3.1 Goldsmiths and medal founders using sand moulds* in this thesis.

[58] Rama 1988, 346.

[59] American Foundrymen's Society. *Casting copper-base alloys*. American Foundrymen's Society (1984): 28.

1.2.2 The nature of moulding sand

The term sand is used to denote a wide range of granular materials with as basic constituent silica or quartz which is composed largely of silicon dioxide (SiO_2). Sand is the result of the breakdown or erosion of rocks and often contains, in addition to quartz, other components such as feldspar, mica, serpentine or zircon.[60] Sand is used in this thesis as a generic term to denote a finely grained refractory material with grain size between 0.063 mm and 2.0 mm (table I). Sand used for moulding and casting is in the foundry literature referred to as moulding sand.

Table I. Soil particle size fractions. (table from ISO 14688-1)

Soil fractions and sub-fractions		**Particle size mm**
Very coarse soil	Large boulder *LBo*	>630
	Boulder *Bo*	>200 to 600
	Cobble *Co*	>63 to 200
Coarse soil	Gravel *Gr* Coarse gravel *CGr* Medium gravel *MGr* Fine gravel *FGr*	**>2,0 to 63** >20 to 63 >6,3 to 20 >2,0 to 6,3[2)]
	Sand *Sa* Coarse sand *CSa* Medium sand *MSa* Fine sand *FSa*	>0,063 or 0,075[1)] to 2,0 >0,63 to 2,0 >0,2 to 0,63 >0,063 or 0,075[1)]to 0,2
Fine soil	Silt *Si* Coarse silt *CSi* Medium silt *MSi* Fine silt *FSi*	>0,002 to 0,063or 0.075[1)] >0,02 to 0,063 or 0,075[1)] >0,0063 to 0,02 >0,002 to 0,0063
	Clay *Cl*	<0,002

In modern foundry practice, moulding sands often have other main constituents such as chromite or olivine and to distinguish these non-quartz particulate materials from sand they are sometimes called aggregates.[61] Unmodified natural moulding sands have now been largely replaced in the modern foundry industry by aggregates or mixtures of natural sand and aggregates due to the depletion of deposits and inconsistencies in sand characteristics.[62] Historically foundries have used predominantly quarried sands for moulding. The exception to this was the use of artificially produced finely powdered refractory materials by sixteenth and seventeenth century medal founders and goldsmiths to produce fine castings. Alessio Piemontese's (1500-1566) descriptions in his *Book of Secrets,* detail the repeated heating, grinding and sieving of emery, pottery shards, oxidised iron filings, pumice stone, bone,

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[60] Strauss, K. *Applied science in the casting of metals*. Pergamon Press (1970): 314.
[61] Campbell, J. *Castings*. Butterworth-Heinemann (2003): 100.
[62] American Foundrymen's Society 1984, 19.

shells, etc. to produce very fine powders.[63] These powders, sometimes mixed with each other, are subsequently used in combination with a binder, such as sal ammoniac (ammonium chloride), gum Arabic or egg white, as moulding material.[64] Although no sand is used in the description by Piemontese, it uses the same principle as sand mould casting whereby: a finely grained refractory material is bonded together with a binding agent, no baking of the mould takes place and the pattern can be re-used.

Strictly speaking with these artificially produced powders, lacking as basic constituent silica or quartz, one cannot speak of sand and the term moulding powder or aggregate to denote this type of moulding material is therefore more appropriate.[65] The moulding and casting recipes detailing the grinding of various refractory materials to a fine powder were common for the early modern period and the large variety of different mould materials described in these recipes suggest sometimes an experimental element. A good example of this is the French manuscript Bnf. Ms. Fr. 640, preserved at the Bibliothèque Nationale in Paris, which lists more than twenty different finely ground mould materials besides naturally occurring sand.[66] The recipes in this manuscript advise grinding, sifting, and/or calcination of these materials and repetition of these steps until the powder can not be rendered finer by these means. The empirical thinking behind this is that the finer the moulding material is the more detailed the cast will be. This premise is valid up to a certain extent, because the finer the individual grains are, the more the mould surface will be closed and thus less permeable to gases. These gases are developed upon entry of the hot molten metal into the mould and need to be transported quickly from the mould cavity to prevent porosity in the cast. The formation of gases in the mould can have several causes. The three main ones are:

- the solidifying metal which releases absorbed gases such as oxygen, hydrogen or nitrogen upon solidification
- trapped air introduced by turbulence in the melt during pouring
- the reaction of the hot metal with organic impurities or moisture the mould or core which can produce gases

The moulding 'sands' prepared by grinding are therefore almost always found in recipes for small castings such as medals and small life-casts whereby the volume of cast metal is small enough not to cause significant problems created by inadequate escape of mould gases. The second reason one finds these finely powdered mould materials only mentioned in conjunction with the founding of small objects is that the preparation of these powders was very laborious and time consuming. The use of naturally-occurring sand in large quantities

[63] Alessio Piemontese was probably a pseudonym of Girolamo Ruscelli, see Ferguson, J. "The Secrets of Alexis. A sixteenth century Collection of Medical and Technical Receipts." *Proceedings of the Royal Society of Medicine 24* (1930) 225-246. For the original work of Piemontese mentioning the use of powdered refractory materials see Piemontese, A. *De Secreti del reverendo Donno Alessio Piemontese*. Sigismondo Bordogna (1555): 206-217.
[64] Smith, C. S. and M. T. Gnudi. *The Pirotechnia of Vannoccio Biringuccio: The classic Sixteenth-Century Treatise on Metals and Metallurgy*. The American Institute of Mining and Metallurgical Engineers (1959): 325.
[65] Campbell 2003, 100.
[66] Smith and Beentjes 2010, 128–179; Beentjes and Smith 2013, 144-151.

which were directly usable for founding, must have offered a more economically attractive alternative.[67]

Schmidtling describes the typical sand found inside sand moulded bronzes as rounded quartz and feldspar grains, uniform in size, with a mean average of around 0.1 mm and each grain surrounded by a ring of clay and therefore independent of the other.[68] This grain size is relatively small compared to modern moulding sands which generally have grain sizes between 0.1 and 1.0 mm.[69] The round shape of the sand grain has three distinct advantages: firstly, it greatly increases the flowability of the sand during ramming, therefore taking a more detailed impression than angular sand grains. Secondly, the round grains allow for a more evenly distribution of the clay in the sand. As Schmidtling described, the individual sand grains are enclosed in clay and this allows them to move more freely during moulding and aids the finely distributed clay in its bonding properties. The third advantage of the small even round grain size is the ability to be highly compacted, creating a very fine mould surface. This latter is at the same time also a disadvantage because it creates a closed surface, not very permeable to gases formed during casting. This is the reason why most modern commercial moulding sands or aggregates have larger more angular grains, increasing the permeability of the sand. The nineteenth and early twentieth century moulder of bronze sculpture counteracted this reduced permeability of the outer mould by creating other escape routes for the gases. One of these, was to design a clever gating system with sufficient escape routes for the gases, either by building in plenty of risers and/or by using the ascended casting method. The other escape route, for the gases formed during moulding, was to make the core very porous and by using core vents or lanterns.

The sand moulder would rarely use just one type of sand in the moulding process, the best quality sand would be reserved for the inner surface of the mould. This layer, which would take the impression from the pattern and serve as the contact surface for the molten metal, had to have superior properties. This sand was called facing sand and often new, fresh, and finely sifted sand was used for this. The sand used for the core and non-facing parts of the mould, was usually recycled sand used in previous castings. This explains the often-dark appearance of core sand which contained charred facing sand and additionally usually also contained a carbon-based parting compound.

Several contemporary written sources state the quarry of Fontenay-aux-Roses, in the suburbs of Paris, as the source for the best sand for natural sand mould casting.[70] The type of sand

[67] The only treatment of the sand was usually sifting to rid the sand from larger inclusions such as stones.
[68] Bassett, J. and R.E. Schmidtling II. *Sand casting cores summary Nov 12, 2012*. Unpublished internal report J.P.Getty Museum by J. Bassett and R.E. Schmidtling II, 2012.
[69] Beeley 2001, 200.
[70] The open quarries of Fontenay-aux-Roses gave way to urbanization before disappearing in the 1960s; Descatoire, D. “Les carrières de sable de Fontenay-aux-Roses.” Liens de memoire no.13; *Bulletin des Archives municipales*, Fontenay-aux-Roses, second semestre (2009): 5-8. Rama also states in 1988 that the Fontenay quarry is exhausted; Rama 1988, 346; see also Spon E. Spon. *Spons’ Mechanics’ Own Book*, Spon’s (1889): 25. Partridge mentions the sand as Caen-sand, see Partridge, W. O. *Technique of Sculpture*. Ginn & Company (1895): 88, as does Guettier, A. *De la Fonderie telle qu'elle existe aujourd'hui en France et de ses nombreuses applications à l'industrie.* Lacroix et Baudry (1858): 286.

suitable to produce the piece-moulds for the sand mould casting process is a natural mix of sand and clay, with a typical clay content of between 16 to 20%.[71] This amount of clay gives the sand a greasy feel to the touch and means that the sand, when compressed, holds its shape very well. By pressing a pattern or foundry model into the sand, a perfect impression can be made. A reporter visiting an American foundry around 1900 remarked: "And to look at it you never would imagine it had come all the way from Fontenay-aux-Roses at five dollars a barrel: but put your thumb into it and see how it will retain the impression of very finest line on it."[72]

Mitchell writing in 1916 is equally laudatory about the unique properties of Fontenay sand:

> The sand used for statuary bronze moulding comes from a sand-pit which is situated in a little village on the outskirts of the City of Paris in France. […] Though called "sand" by the foundryman, … it closely resembles a mixture of sand and clay. It can be used just as it comes from the sand-pit although of course it must be finely sieved. No other sand like this has ever been found in the world. You may be sure that many people have looked all over the world for similar sand, … This sand because of its peculiar properties makes it possible to obtain a mould that will reproduce with marvellous fidelity, the finest lines and markings that appear on the sculptor's model.[73]

Although sand moulders manuals also mention sand from other sources, the sand used for high quality sculpture moulding was almost invariably the Fontenay sand.[74] This costly sand possessed superior qualities justifying shipping it as far as the United States.[75] Standard natural moulding sand was costing in Paris in 1890 between 0.85 and 1 franc per cubic metre.[76] Fontenay sand, in contrast, was already in 1882 selling in France for 12 francs per cubic metre and a barrel holding between 360 to 400 kg, 10 francs.[77] This same type of barrel was sold in 1901 to foundries in New York for 5 dollar a barrel.[78]

This sand was particularly favoured by copper-alloy founders and was used to cast small to medium sized objects. Fontenay sand was deemed not so suitable for very large castings and

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[71] Rama, 1988, 346.

[72] Brooks, B. "The genesis of a Bronze Statue", *Boston Evening Transcript*, Nov 27 (1901): 14. <https://news.google.com/newspapers?nid=2249&dat=19011127&id=03o-AAAAIBAJ&sjid=0FkMAAAAIBAJ&pg=3026,3525117&hl=nl> [accessed 22-6-2018]

[73] Mitchell, W. D. *The Art of the Bronze Founder: Especially in its relation to the casting- of bronze statuary and other sculptural work*. Jno Williams (1916): 18.

[74] Courpière (Puy-de-Dôme, La Seine-Inférieure, La Haute-Marne, Les Ardennes, Le Cher (Vierzon), L'Isère (Voreppe), etc. Gillot mentions also the sand from the quarries of Montrouse although they have different, usually inferior, properties and have to be prepared in a different manner, see Gillot, A. and L. Lockert. *Nouveau manuel complet du fondeur de fer et de cuivre ...: Suivi de la fonte des statues et des cloches*. Librairie encyclopédique de Roret (1879): 247.

[75] Buchetti, J. *La fonderie de cuivre actuelle: bronzes, laitons, aluminium, etc. procédés, outils, matériel.* C. Béranger (1898): 83.

[76] Guettier, A. *Le fondeur en métaux*. E. Bernard (1890): 47.

[77] "Le sable de Fontenay, qu'on envoie dans toutes les parties du monde, mème en Angleterre et en Amérique, et qui sert pour les bronziers et les orfèvres, vaut par tonneau de 360 à 400 kilogrammes 10 francs, et par mètre cube mis brut en wagon 12 francs." see Guettier, André. *La Fonderie en France*. E. Bernard (1882): 121.

[78] Brooks 1901, 14.

to cast iron into and was therefore sometimes mixed with sand from other sources as witnessed by the English journalist and author William Blanchard Jerrold (1826-1884), during a visit to the Barbedienne foundry in 1864:

> Hard by a man was mixing in just proportions the new yellow Fontenay sand with the black being that which had already served. He said:" We mix the new sand with the old. The sand is too precious to be used only once, and we find, indeed, that the mixture of the old with the new is a good combination. The sand is to be found only at Fontenay aux Roses. To it we attribute much of the excellence of our French castings. Other sands have too much silex [flint] in them, and this has exactly the proportion necessary for our work.[79]

One source mentions that the Fontenay-aux-Roses quarry produced two different types of sand with different properties. A brown, clay rich, type and a yellow sandier type with the two types mixed to the desired consistency.[80]

No other source mentions a deep brown sand from Fontenay and it is doubtful whether this brown clayey sand, as mentioned in this article from 1869, actually derived from the Fontenay quarry. Other sources mentioning the colour of Fontenay sand describe this invariably of a yellow colour. Moulds made with Fontenay sand gave the best results when dry and this drying was carried out in special drying ovens, prior to casting. The natural sand mould casting, using the Fontenay sand, is therefore usually not green sand mould casting but dry sand mould casting instead.[81] For finer foundry work in copper alloys the Fontenay sand could be used new, although some manuals instruct the reader to mix new sand with some pre-used sand from the same source.[82] This mixing, often together with wetting, is known as tempering.[83] Tempering of foundry sand, prior to moulding, was till the end of the nineteenth century carried out by hand and later with special mixing machines in the larger foundries.[84] The moulding sand, mixed and wetted, is beaten and rolled to the right consistency for moulding.[85] When the high quality sand from Fontenay became difficult to obtain, foundries such as Thinot began to use also sand from other sources such as Carrière de Villejuif and Jesseu.[86] Some foundries such as the Bedi-Makky foundry in Brooklyn, basically still use the sand acquired generations ago from France. The round grain size of this French sand enables

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[79] Jerrold, William Blanchard. *The children of Lutetia. Vol. 2.* Low & Marston, 1864. Various other sources mention the mixing of moulding sand, see for example: Launay 19, Fesquet mentions a mixture used of 2 parts Fontenay-aux-Roses sand, 1 part Richmond sand and 1 part Lumberton sand, see Overman 1881, 264.
[80] "The sand employed is one of two qualities, one being of a deep brown colour, and very loamy; the other a very light yellowish-white, with more yellow particles. Both are obtained at Fontenay-aux-Roses, not far from Paris, to the North-west. The two sorts are mixed, first, by interstratifying them in alternate layers in heaps, the relative thicknesses depending partly on the class of work the sand is being prepared for."; Anonymous. "Bronze Foundries", *The Brooklyn Daily Eagle* (Brooklyn New York) 9 September (1869) Thursday page 4.
[81] Guettier 1858, 285-286.
[82] Guettier 1890, 390 and Buchetti 1898, 84.
[83] Buchanan 1903, 105
[84] Buchetti 1898, 84-87.
[85] The Brooklyn Daily Eagle 1869, 4.
[86] Email correspondence with Jane Bassett, Getty Conservation institute, January 2015. This information was gathered during a visit to the Thinot foundry in 2007.

this continued use, although over time, the sand will deteriorate because of loss of active clay and accumulation of parting compound and is therefore periodically refreshed with new active clay (bentonite).

The suitability of a moulding sand for copper alloys is determined by several factors of which the following three are the most important for dry sand moulding:

- texture
- permeability
- bonding power

These properties are now determined by standardized testing and this is common practice in modern large industrial foundries.[87] The smaller, more artisanal fine art foundries, operating in the nineteenth century and early twentieth century would judge the properties of a sand more empirically. The classic test to judge the moulding properties of a sand is to take a handful of moistened sand and compress this inside the palm of one's hand. If the sand holds well together and takes a fine imprint, it is judged to have the right properties for moulding.[88]

Texture

The historically-used natural moulding sands derived from various geological sources, which were of residual or sedimentary character. Residual sands are formed by the disintegration of the rock in situ, while the sedimentary sands are the result of deposition of sandy or loamy material in water. Residual sand grains are generally of an angular morphology whereas sedimentary sands grains have a tendency to be rounded. These sedimentary sands were deposited by moving water in river beds, floodplains and lake bottoms. The variations in coarseness of the sedimentary sands was caused by the specific velocity of the moving water and resulted in the accumulation of layers of different grain size.[89] These different grain sizes are ordered and named in ISO 14688-1 (table I). Large grains in the moulding sand means also large openings between the grains, allowing the molten metal to penetrate into the mould

[87] See for this, for example: "Formsandprüfung" in Hasse, S. *Giesserei-Lexikon*. Schiele & Schön (2007): 236-243. & Beeley 2001, 182-198.
[88] Georg Altmütter remarks in this respect: "Man erkennt die rechte Beschaffenheit des Formsandes durch ein sehr einfaches praktisches Mittel, indem man nämlich etwas davon, schwach befeuchtet, in der hohlen Hand zu einem Klumpen zusammendrückt, wobei dieser alle Spuren von den kleinen Fältchen der Haut wohl ausgedrückt zeigen muß, ohne sich schlüpsrig anzufühlen, und ihn dann einen Fuß hoch wirft und mit der Handfläche auffängt, wobei er nicht abbröckeln oder zerbrechen darf. Sand, welcher zu fett ist (zu viel Thon enthält), nimmt durch das Befeuchten und Zusammenpressen eine glatte, schlüpsrige Oberfläche an; zu magerer (zu wenig thonhaltiger) bindet nicht genug, d. h. bröckelt leicht aus einander". (translation author) "One recognizes the usability of the molding sand in a very simple way, by pressing some of it, lightly moisted, within the palm of the hand into a lump, whereby all the skin details of the hand are imprinted, without feeling sloppy, and when trown a foot in the air and caught with the palm of the hand it should not crumble or break. Sand, too fat (containing too much clay), acquires through wetting and pressing a smooth, sloppy surface; too lean (too little clay) does not bind enough, meaning easy crumbling apart." Altmütter, Georg. "Messinggiesserei sandabformen." in *Technologische Encyklopädie oder alphabetisches Handbuch der Technologie, der technischen Chemie und des maschinenwesens*. Prechtl, J. J., Ritter von and K. J.G. Karmarsch, J.G. Cotta, vol 9 (1838):590.
[89] Ries, H. and F. L. Gallup. *The clays of Wisconsin and their uses. With a Report on molding sands / by H. Ries and F. L. Gallup*. State (1906): 226-227.

surface, giving a rough surface to the castings. Finely grained sands give better surface rendering but their low permeability, which makes it more difficult for the mould and core gases to escape, could cause surface porosity. Moulding sands used for iron founding have generally larger grain sizes (220-250µ) than those for copper alloy founding.[90] This is because most output of iron foundries is of an industrial nature, and these objects are usually heavily finished by machining. The grain size of nineteenth century moulding sand from Fontenay-aux-Roses was found to be not more than 50µ.[91] By modern standards this would now be classed more a silt than a sand.

Schmidtling's recent analysis of moulding sands for the J. Paul Getty Museum in Los Angeles, found higher values for the grain size of Fontenay sand, with a mean average grain size of 110µ.[92] Schmidtling's sands were collected in Parisian foundries in 2007, from each of the then remaining three Parisian sand mould foundries: Thinot, Godard and Chardon & Petit-Fils. Only one of these, Thinot (which ceased operating in 2009), was still using sand from Fontenay-aux-Roses. This must have been quarried in the late 1960s when the Fontenay sand quarries stopped producing. Comparing the grain size of Fontenay sand, collected in 2007, with that of 1862, it was found that the earlier sand was much finer. (table II)

The size of the sand grains is determined by a standardized sieve test, passing the sand through a series of sieves of decreasing mesh.[93] The morphology of the sand grains in moulding sands is defined in terms of angularity and sphericity. The best moulding sands for fine work have grains which are rounded with medium to high sphericity.[94]

Table II. Comparison between average grain size of sand from Fontenay-aux-Roses.

source of sand	average grain size
Fontenay sand (1960's?, collected in 2007)[95]	110µ
Fontenay sand (1960's?, described in 1979) [96]	75µ[97]
Fontenay sand (1862)	<50µ[98]

[90] Brown, J. R. *Foseco Ferrous Foundryman's Handbook*. Butterworth-Heinemann (2000): 146.
[91] "Körnchen von weniger als 1/60 Millim. Größe, manche bis 1/20 Millim.", see Karmarsch, C. "Über Formsand.", *Mittheilungen des hannoverschen Gewerbevereins* (1862): 210.
Guettier, 1882, 104.
[92] Bassett, J. and R.E. Schmidtling II 2012.
[93] Ries and Gallup 1906, 202.
[94] Brown 2000, 147.
[95] Thinot ochre, see Bassett and Schmidtling II 2012.
[96] Ammen 1979, 31.
[97] Ammen gives a Grain Fineness of 176 (AFS), which roughly converts to 75µ, see Ammen 1976, 31. A direct conversion from AFS (American Foundry Society) grain size number to mm is not possible, see Brown 2000, 16.
[98] "Körnchen von weniger als 1/60 Millim. Größe, manche bis 1/20 Millim."; (grains as small as 1/60th of a millimetre, many till 1/twentieth of a milimeter; transl. author), see Karmarsch 1862, 210.
Guettier 1882, 104.

Sand grains vary from well-rounded to rounded, sub-rounded, sub-angular, angular and very angular and is established by visual examination under magnification.[99] Kampmann (1844) noticed under magnification that the grains of Parisian moulding sand were rounded.[100] Whereas Schmidtling observed some degree of angularity with later sand from Fontenay-aux-Roses.[101] This supports the view that the later Fontenay sand, quarried in the second half of the twentieth century, was of a diminished quality compared to the sand used earlier.

Permeability

Permeability of moulding sand is the ability of a sand, to distribute liquids or gases though it, and is determined by the voids between the sand grains, called pores. This permeability is influenced by the following factors: the degree of compacting, grain size and the amount of binding agents in the sand.[102] The compacting of a moulding sand is done by ramming the sand against the pattern inside the flask. A high degree of compacting creates a dense mould surface, capable of taking a detailed and smooth impression. At the same time a dense mould surface also decreases the amount and size of the pores and thus the permeability of the sand. The compactability of a sand is dependent on the grain size and morphology and the amount and type of binder. Rounded sand grains will move with greater ease and will compact better, especially with the aid of a moist binder such as clays in natural sand. The amount of clay in itself has an impact on the permeability of sand. High amounts of clay will occupy the space between the sand grains, reducing the permeability and thus blocking the pathway for the escaping gases.[103]

Cohesion strength[104]

Moulding sand should have sufficient bonding power to keep the mould impression together and to resist the forces of the molten metal. Pure sand on its own, possesses hardly any bonding power, whereas pure clay in contrast, has a comparatively high bonding power. Pure sand's lack of bonding power makes it unsuitable for moulding. The disadvantage of pure clay as a moulding material is the amount of shrinkage occurring. In order to use clay as a mould material it needs to be mixed with water. The absorption of water by the clay makes it swell and when the mould is dried to make it suitable for casting, the escaping water causes it to shrink. This shrinkage changes the dimensions of the mould and results often in a cracked mould. Despite this shrinkage, clay has often been used as a first layer in lost wax moulds. To counteract shrinkage problems, the clay for these moulds is applied in thin layers and allowed to dry between the application of successive layers. Sand with a certain percentage of clay, however, is very suitable as a moulding material. Clays are mineral substances of extremely fine grain size, less than 2µ. (table 1) They consist of mainly oxides of aluminium and silicon,

[99] Guettier 1882, 147.
[100] Elsner, L. "Über die Zusammensezung der besten Formsande." *Journal für praktische Chemie*, Nr. 7 and 8, 1844.
[101] Bassett and Schmidtling II 2012.
[102] Ries and Gallup 1906, 210.
[103] Ries and Gallup 1906, 212.
[104] Foundry literature also uses the term bonding power.

forming of platelets of aluminium silicates. It is these plate-like particles, which give clays their unique properties.

The absorption of water in clay takes place between these platelets, transforming the clay into a plastic material with adhesive properties capable of bonding individual sand grain together.[105] When the sand dries, the escaping water produces shrinkage of the lattice which enhances the strength of the bond, making clay binders effective for both green and dry sand moulding.[106] This hydration of the clay is reversible with temperatures well above the normal drying range for sand moulds, enabling the recycling of moulding sand.[107] Sand moulds can be dried, cast into and regenerated by adding moisture after each cycle. Heating to higher temperatures, drives off the chemically bound water and can affect permanently the bonding.

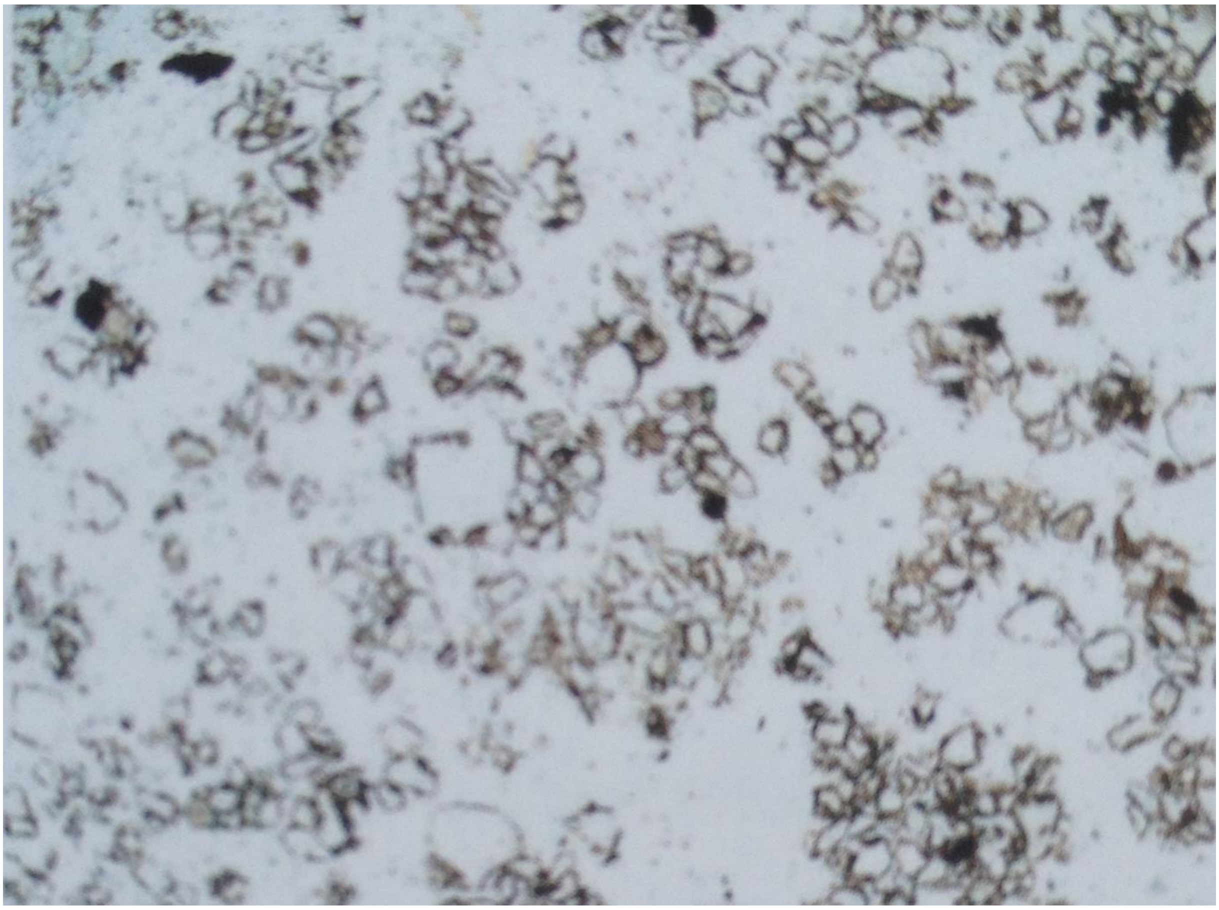

Fig. 1.3. Petrographic sample illustrating core material with loose sand grains of roughly equal size, each outlined by a thin layer of dark clay. The clay shows up as a dark line around each individual sand grain. Core sample from *Hercules, Nessus, and Deianeira* (Rijksmuseum Amsterdam, inv.no. BK-1957-2), cast attributed to Crozatier, design after Adriaen de Vries, sand mould casting, probably Paris c.1845-1850. (from Bassett and Schmidtling II 2012, 38)

[105] American Foundrymen's Society 1984, 22.
[106] Beeley 2001, 203.
[107] Temperatures up to 200 °C.

This loss in the ability of the clay to regenerate with water, begins around 400°C and is complete at 700°C.[108] In foundry terms this overheated clay is now called dead clay, as opposed to active clay that still possesses bonding capacity.[109] The ideal distribution of clay as a binder in moulding sand is as a thin film around each grain. When compacted the clay forms lens shaped masses at the contact points of the grains.[110] This is exactly what can be observed with Parisian moulding sand under magnification (fig. 1.3).

The percentage of clay in natural moulding sand varies greatly, producing sand with different properties. The following classification of clay-based sand is used in current foundry practice:[111]

< 8 % lean
> 8 % till 14 % middle fat
> 14 % till 20 % fat
> 20 % extremely fat

These variations are a result of the geological origin of a sand. Sand deposits frequently show variations both horizontally and vertically.[112] These variations affect specific properties of a natural occurring sand, which could mean that a vein of good sand could become exhausted over time. This happened to some well-known historic quarries such as Fontenay-aux-Roses near Paris and Highgate near London, rendering these sands unavailable for modern testing or analysis.[113] Even if these quarries would still produce today, it would be questionable whether the modern sand would have the same quality as the sand used in previous centuries, due to the geological variations. I have tried therefore to find nineteenth century analyses of moulding sands and in particular, sands used for moulding bronze sculpture. Most of this nineteenth century information regarding the composition of moulding sand, covers the sands used for iron founding because the iron founding industry was economically of greater importance. The main issue with using analytical data of this early period is the fact that the means whereby these data are collected are rarely specified. This makes it very difficult to compare, verify or reproduce these compositional data.

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[108] Beeley 2001, 203.
[109] American Foundrymen's Society 1984, 25.
[110] Beeley 2001, 202.
[111] Bundesverband der Deutschen Giesserei-industrie. *Das traditionelle Lehmformverfahren zum Herstellen von Läuteglocken*, BDG, 2, 2015, <http://www.bdguss.de/fileadmin/content_bdguss/Der_BDG/Richtlinien/F_01.pdf> [accessed 22 June 2018]
[112] See for example Ries and Gallup 1906, 226-227.
[113] Highgate and Hampstead Heath sand quarries have been operating at least since the late Middle ages and ceased working in the 1940's, see Baker, T.F.T. et al. "Hampstead: Hampstead Heath", *A History of the County of Middlesex*, Volume 9, C. R. Elrington (ed.) (1989): 75-81, http://www.british-history.ac.uk/vch/middx/vol9/pp75-81, [accessed 22 June 2018]

1.2.3 Compositional data of moulding sand

As mentioned earlier, published compositional data on moulding sand before the nineteenth century is non-existent. However, most of the moulding sands, used in the nineteenth century, derived from quarries already in use long before 1800.

One of the earliest analysis of moulding sand, which included a sand for copper alloys, was by Kampmann published in 1844.[114] Kampmann analysed moulding sand from various foundries in Western Europe including sand from Paris for bronzes.[115] This sand from Paris is almost certainly from Fontenay-aux-Roses because French literature, covering the sand mould casting of bronze sculpture, mentions only this source.[116] In 1862, Carl Karmarsch published another analysis of various moulding sands, mostly for iron founding but he also covers some moulding sands for non-ferrous founding, including sand from the Fontenay-aux-Roses quarry.[117] The only French source I have been able to find giving a compositional analysis of Parisian moulding sand, is from Guettier (1882).[118] The data given by Kampmann and Guettier are very similar whereas Karmarsch data stands out with a very high iron oxide content. (table III)

Table III. Comparison between published nineteenth century compositional data on moulding sand from Paris.

source of sand	Silica	Clay[119]	Iron oxide	Chalk[120]	Source
Paris sand	91.907	5.683	2.177	0.415	Kampmann (1844)
Fontenay-aux-Roses	82	7	11	trace	Karmarsch (1862)
Fontenay-aux-Roses	92	5.50	2.50	trace	Guettier (1890)

Whereas nineteenth century compositional analyses give silica values between 82-92%, the recent data produced by Schmidtling found values for silica content between 39-48%.[121] The values for clay also show great differences between nineteenth century literature (5.5-7%) and the results of Schmidtling (47-60%). Even if the iron oxide and chalk are regarded as part of

[114] Elsner 1844, Nr. 7 and 8.
[115] "Pariser Sand, vorzüglich zu Bronze-Guß geeignet, see Elsner 1844, Nr.7 and 8.
[116] See for example Launay, Jean-Baptiste. *Manuel du fondeur sur tous métaux ou traité de toutes les operations de la fonderie*. Librairie encyclopédique de Roret (1827): 19. And also Guettier 1858, 286.
[117] Karmarsch 1862, 210.
[118] Guettier, 1858 104.
[119] English and French publications using this data, usually translate *Thonerde* (literally clay earth) as alumina, see Percy, J. *Metallurgy, the art of extracting metals form their ores, and adapting them to various purposes of manufacture*. Murray (1861): 239. Also see Guettier 1858, 104.
[120] *Kalk* is in older English literature translated as lime: an antiquated term to denote chalk, a form of limestone composed of the mineral calcite. Calcite is calcium carbonate or CaCO3.
[121] Schmidtling separates sand into quarts and feldspar and other minor minerals such as muscovite and lamprobolite. Bassett 2008, 240.

the clay component, making the nineteenth century clay values of 7.86-18%, there is still a wide gap between the two data sets. As mentioned earlier, no information regarding the method of analysis is given for the nineteenth values, making it very difficult to compare with modern analysis. Schmidtling used X-ray diffraction (XRD) in combination with Polarised Light Microscopy (PLM) for his quantification.[122]

Table IV. Comparison between published twentieth century compositional data on moulding sand from Paris.

Source of sand	Silica	Clay	Feldspar	Muscovite
Crozatier? (core)[123]	41	52	6.5	0.5
Crozatier? (core)[124]	31	60	8	trace
Paris sand (acq. 1950's)[125]	47	47	-	-
Fontenay sand (collected in 2007)[126]	-	42	-	-
Fontenay sand (1970's?)[127]	-	17.2	-	-

It is interesting to compare the Schmidtling clay values with the only other relatively recent published analysis of Fontenay sand, by Ammen (table IV).[128] Ammen does not mention when this sand was collected or analysed but this cannot be later than 1979, the year of publication of his book. Descatoire, however, mentions that the Fontenay-aux-Roses quarries ceased operating already in the 1960s.[129] Ammen's analyses are an average of ten samples.[130] Ammen gives a clay value of 17.2 %, almost 2.5 times less than Schmidtling and much closer to the nineteenth century values. Interestingly Ammen also mentions that during World War I, when Fontenay sand was unavailable to US foundries, the French sand was replaced with sand from Albany, N.Y. with an average clay content of 19.2 %.[131]

[122] Bassett 2008, 35-44.
[123] *Hercules, Nessus, and Deianeira* (Nelson-Atkins Museum of Art, Kansas City. inv.no. 44-53) attributed to Crozatier, after Adriaen de Vries, sand mould casting probably Paris c.1845-1850, see Bassett 2008, 240.
[124] *Hercules, Nessus, and Deianeira* (Rijksmuseum Amsterdam inv. no. BK-1957-2) attributed to Crozatier, after Adriaen de Vries, sand mould casting, probably Paris c.1845-1850, see Bassett 2008, 252.
[125] Sample from Petterson Art Foundry, located outside of Stockholm. Foundry purchased this sand in France in the 1950's, see Bassett 2008, 240 note 2.
[126] Thinot ochre, see Bassett and Schmidtling II 2012.
[127] Ammen 1976, 31.
[128] Ammen 1976, 31
[129] Descatoire 2009, 5-8.
[130] Ammen does not give his method of analysis. This was probably a standard foundry analysis such as a sieve test.
[131] Ammen 1976, 31.

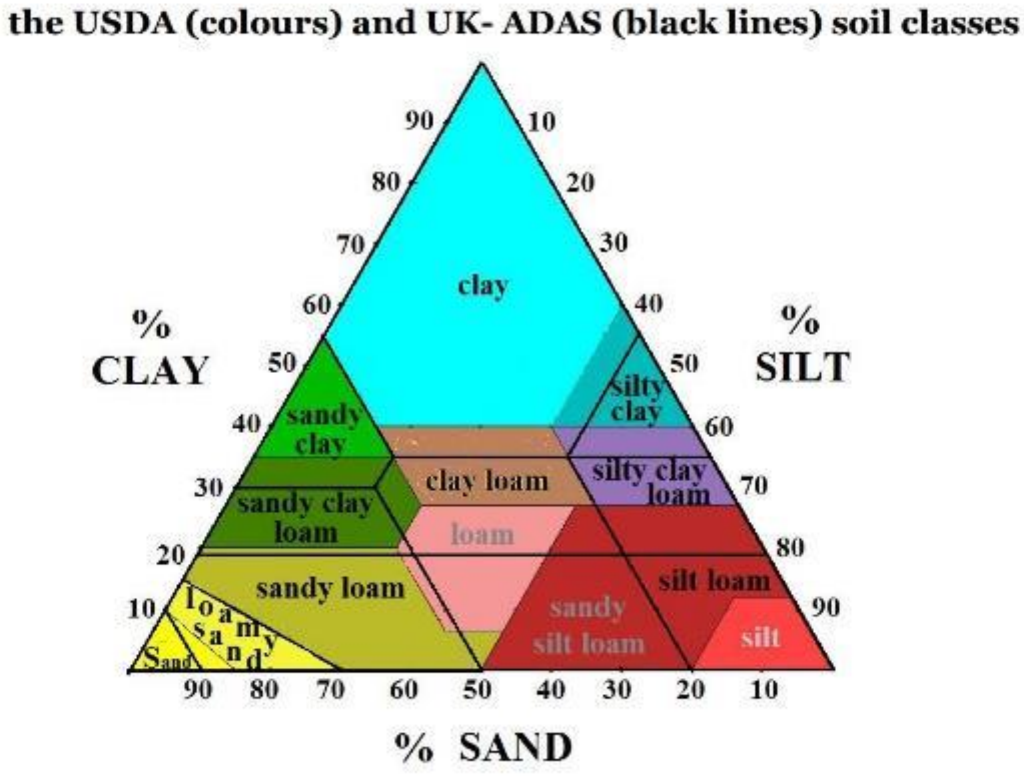


Fig.1.4: Soil textural triangle showing both the USDA and the UK-ADAS soil classes. (image Wiki commons)

The large discrepancy of Schmidtling's silica and clay values from the results of other analyses is remarkable. These results are discussed further in this and the following section, also in comparison to newly-undertaken analyses for this thesis. One could argue that cores, usually made from recycled moulding sand, have a slightly different composition compared to outer mould material but there is no distinct difference discernable between Schmidtling's clay values for cores and outer mould material.[132] Rama gives a typical clay content of fine art moulding sand of between 16 to 20%.[133] I have only found one reference of a clay value over 20% for moulding sand, which mentions it is unsuitable and should therefore be mixed with a less clayey sand.[134] Moulding sands with a clay content between 16-20% are classified by USDA (United States Department of Agriculture) and UK-ADAS as sandy loams (fig. 1.4).

The above-mentioned inconsistencies in clay and silica content of moulding sands required clarification and it was therefore decided to initiate more research by analysing various moulding sand samples.

[132] Bassett and Schmidtling II 2012.

[133] Rama 1988, 346.

[134] 35.52% ."Nr. 12. Sehr fetter Sand von Neudörfel bei Wiener-Neustadt, als Formsand zu fett.", see Karmarsch 1862, 210.

1.2.4 Grain-size distribution of moulding sand

The determination of the clay content of sand is established by measuring the grain-size distribution of this natural sediment. This can be determined by various methods. Traditionally the clay content in moulding sand was established by chemically or mechanically separating the clay from the sand and comparing the difference between the original weight of the clayey sand and the now clay free sand. Another way to establish the clay content of sand is by point counting, or qualitative analysis of a thin section under magnification, using crosshairs.[135] This point counting, the method used by Schmidtling,[136] is considered the least accurate of the above-mentioned methods mainly because the ratio clay is based on visual observation.[137]

Recently a more accurate method to determine the grain-size distribution of a sand has been applied, called laser diffraction.[138] Laser diffraction measures particles in a laser beam scatter laser light at angles inversely proportional to the size of the particles. Large particles scatter light at small forward angles whereas small particles scatter light at wider angles. Using Fourier and reverse Fourier optics, the scattering is imaged to an array of detectors at the focal plane of the optics. The distribution of the scattered light energy on the detectors can be directly related to the particle size distribution of the sediment in the laser beam.[139] Apart from being very accurate for measuring small particle sizes, laser diffraction is especially suited for historic sand core samples because it requires only a very small sample size, in the region of 0.5 g. or less.[140] The following samples were submitted for laser diffraction analysis:[141]

1) moulding sand from Jesseu sampled in the Thinot foundry in Paris in 2007
2) moulding sand from Fontenay-aux-Roses sampled in the Thinot foundry in 2007
3) moulding sand sample collected during visit at the Bedi-Makky foundry in May 2015 reputed to be imported from France around 1900
4) core sample removed from bronze cast by the Gruet Jeune foundry in 1880[142]
5) core sample removed from bronze cast in 1885 by the Pierre Bingen foundry[143]

[135] Hutchison, C. S. *Laboratory handbook of petrographic techniques*. Wiley (1974): 51-53.
[136] Bassett 2008, 39.
[137] Personal communication with Dirk Goossens on 10 November 2015. See also Goossens, D. "Techniques to measure grain-size distributions of loamy sediments: a comparative study of ten instruments for wet analysis." *Sedimentology* (2008): 65-96.
[138] McCave, I. N. et al. "Evaluation of a Laser-Diffraction-Size Analyzer For Use With Natural Sediments." *Journal of Sedimentary Research* 56 (4), July (1986): 561–564.
[139] Goossens 2008, 68.
[140] Goossens 2008, 68-69.
[141] Performed by Dr. Dirk Goossens: Laboratory for Experimental Geomorphology , Catholic University of Leuven, Belgium.
[142] Core sample removed on 2-4-2012 by author from inside Rodin's *Bust of St. John the Baptist* (RMP S.6670) cast in 1880 by the Gruet Jeune foundry in Paris.
[143] Core sample removed on 2-4-2012 by author from inside Rodin's *Bust of Victor Hugo* (RMP S.497) cast in 1885 in Paris by Pierre Bingen.

6) core sample removed from bronze cast in 1896 by the E. Groult foundry[144]
7) core sample from bronze cast by the A. Rudier foundry between c.1931 and 1937[145]
8) core sample from a bronze by cast by the Petermann foundry in Brussels in 1909[146]
9) core sand from Fontainebleau removed from inside a sand mould cast bronze from Chardon & Petit-Fils foundry in Paris in 2007

The samples of this group can be divided into two groups: sand that was collected directly in the foundry and sand that was sampled from cores of existing bronzes. The sand, collected in the foundry, was sand ready to use for moulding, the outer mould as well as the inner core. The data in table V indicates that the clay values, as detected by laser diffraction, do not differ greatly from the values given in the nineteenth & twentieth century foundry literature. They are somewhat lower in clay than the 16-20% range, with only the Fontenay sand falling in this range. This could be due to more to the more accurate analysis by laser diffraction but also caused by the relative small sample size (1 gram), used for laser diffraction compared to the larger samples (50 grams) standardly used for analysis in foundries.

Another explanation could be that the sand used by the Thinot foundry in 2007, was already of diminished quality and not of the earlier standard. The low quality of the Bedi-Makky moulding sand can possibly be explained by the repeated re-use of the sand since 1900, which decreases the clay content. The laser diffraction analysis confirms the discrepancy between the Getty data and the values given in the foundry literature.

Table V. Comparison between the clay percentages of Paris moulding sand.

Source of sand: foundry	**Clay %** Laser diffraction[147]	Point counting[148]
Jesseu[149]	15%	40.5 %
Fontenay-aux-Roses[150]	16%	42%
Bedi-Makky Brooklyn	10%	--

[144] Core sample removed on 2-4-2012 by author from inside Rodin's *La Terre* (RMP S.623), cast in 1896 by the E. Groult foundry in Paris in 1896.
[145] Core sample removed during restoration work in 2010 from the inside of the *Thinker* (Singer Laren inv.no. 56-1-412), cast by the A. Rudier foundry in Paris between probably 1931 and 1937.
[146] Core sample collected during examination on 2-12-2015 from a bronze by Rik Wouters in Kröller-Müller Museum, Otterlo, Netherlands cast in 1909 by the J. Petermann foundry of Brussels. (inv.no.KM 125.377)
[147] Carried out by Dr. Dirk Goossens in Leuven in December 2015.
[148] Carried out by Ronald Schmidtling II in 2012 for the decorative arts conservation department at the J.P.Getty museum in Los Angeles.
[149] Thinot brown. See Bassett and Schmidtling II. Collected by the Getty in the Thinot foundry in 2007.
[150] Thinot ochre. See Bassett and Schmidtling II. Collected by the Getty in the Thinot foundry in 2007.

Table VI gives data for clay values in core material sampled from inside historic bronzes, showing great variations in clay content, with values as low as 2 % and as high as 12.5 %. A possible explanation for this can be the proximity of the sand to the metal.

Table. VI. Comparison between the clay percentages of historic core material as analysed with laser diffraction.

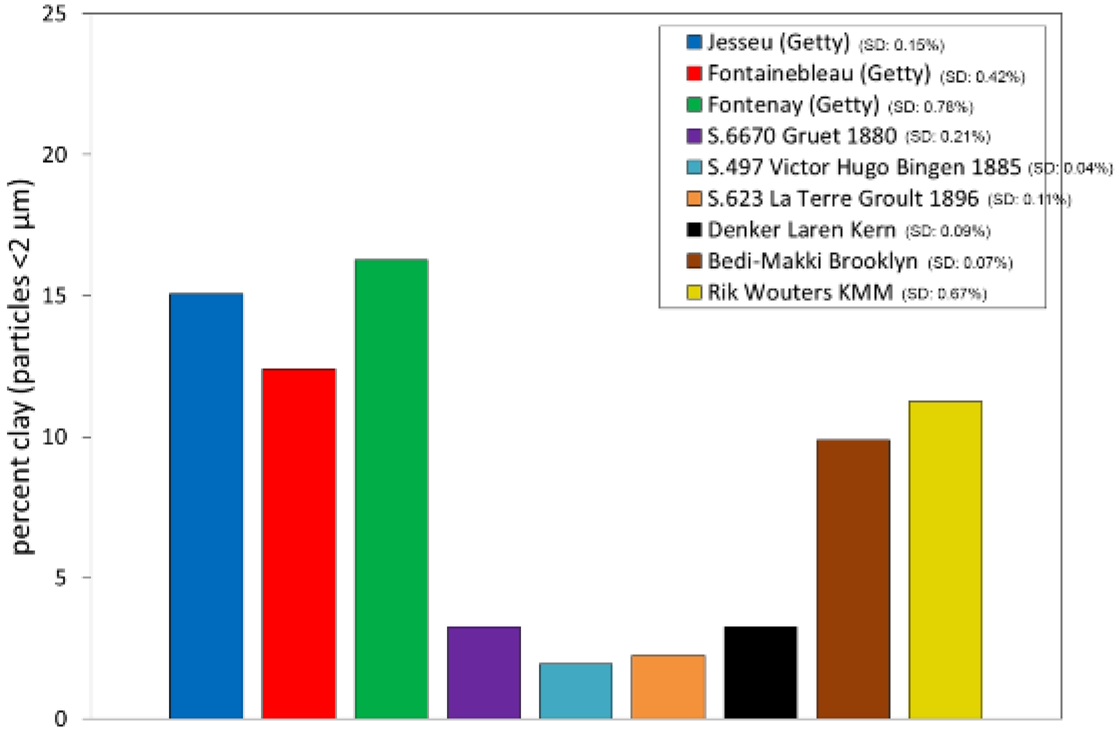
Source of sand: core	**Clay %** Laser diffraction[151]
Gruet Jeune (1880)[152]	3%
Pierre Bingen (1885)[153]	2%
E. Groult (1896)[154]	2.2%
Rudier (1930's)[155]	3%
Petermann 1909	11.5%
Fontainebleau (2007)	12.5%

Some bronzes which were sampled for core material, for example the bronzes from the Rodin Museum Paris, had very little core material remaining. The sand that could be removed was very close to the metal and therefore blackened by the heat. This may have had an effect on the clay content.[156] Only the bronzes from the Petermann and the Chardon & Petit-Fils foundry had sufficient core material remaining, to take a sample well away from the metal.

When put together in one table (table VII), the differences between sand collected in the foundry and core sand, are even more prominent.

[151] Carried out by Dr. Dirk Goossens in Leuven in December 2015.
[152] Core sample removed on 2-4-2012 by author from inside Rodin's *Bust of St. John the Baptist* (RMP S.6670) cast in 1880 by the Gruet Jeune foundry in Paris.
[153] Core sample removed on 2-4-2012 by author from inside Rodin's *Bust of Victor Hugo* (RMP S.497) cast in 1885 in Paris by Pierre Bingen.
[154] Core sample removed on 2-4-2012 by author from inside Rodin's *La Terre* (RMP S.623) cast in 1896 by the E. Groult foundry in Paris.
[155] Core sample removed during restoration work in 2010 from the inside of the *Thinker* (Singer Laren 56-1-412) cast by the A. Rudier foundry between probably 1931 and 1937.
[156] For more on the effect of heat on the clay content see further this chapter.

Table VII. Clay content of various moulding sands collected in foundries and sampled from cores. (image D. Goossens)



Laser diffraction determines not only the clay content of a sample but also the complete grain-size distribution of the entire sample. This makes it possible to determine the average grain size in a sample which is given in tables VIII and IX.

Table VIII. Median diameter of particles in moulding sands collected in foundries and sampled from cores. (image D. Goossens)

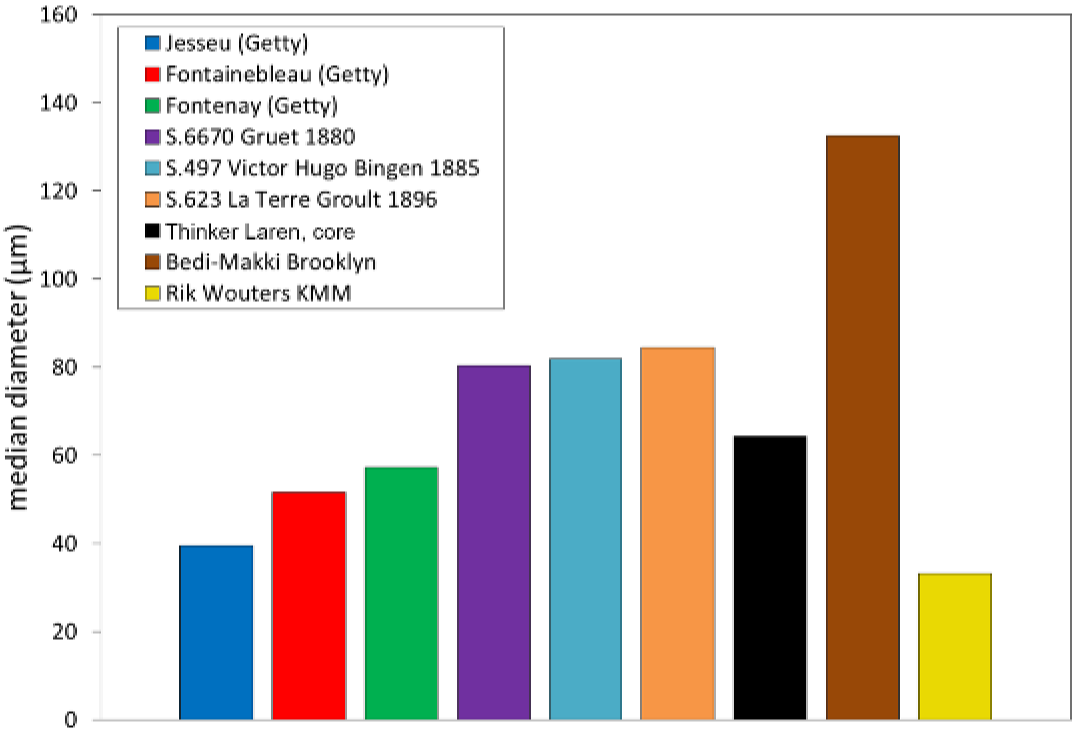
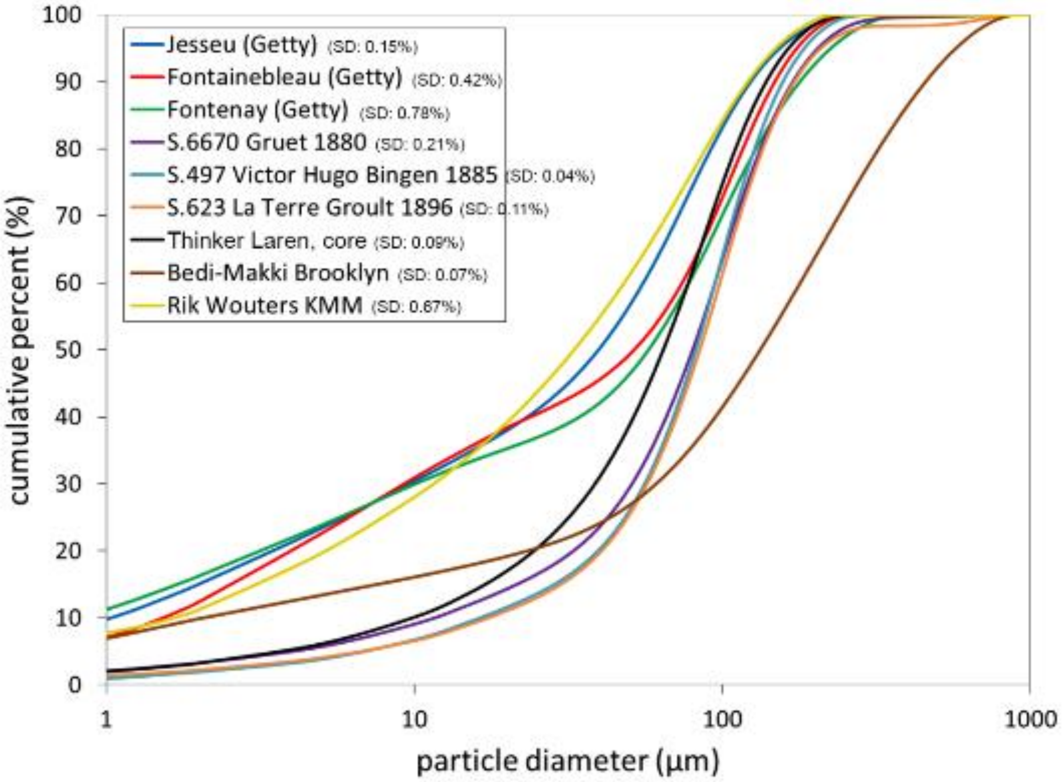


Table IX. Cumulative percentage of particles in moulding sands collected in foundries and sampled from cores. (image D. Goossens)



Several trends can be observed from the above data. The average grain size of core material is larger than that of the moulding sand from the foundry. An explanation could be that coarser sand was used for the core, as a result of less working by mulling and sifting. Another explanation could be that the heat of the molten metal altered the grain-size distribution of the sand by 'sintering' the grains together. The average grain size of 40-60µ of the moulding sand collected by the Getty in the Parisian foundries in 2007, is consistent with values of sand from the nineteenth century and even later (table II), indicating that the grain-size distribution of the sand did not alter much.

Again, the values that Schmidtling produced are not consistent with values in the foundry literature and values produced with laser diffraction. Tables XIII and IX give for the moulding sand of the Bedi-Makky foundry a relative large average grain size which could be explained by the prolonged use of their sand. The above data generated by the laser diffraction analysis indicates that the heat of the molten bronze influences the grain-size distribution of moulding sand and therefore it was decided to carry out new analysis, to determine the effect of heat on the clay content and grain size of moulding sand.

1.2.5 The effect of heat on the grain-size distribution of moulding sand

The research in the previous section indicated a possible effect of heat on the grain-size distribution of moulding sand. To gain a better understanding of this, a reconstruction cast was carried out using argillaceous moulding sand.[157] After the mould was cooled down completely, the outer mould sections, the false cores, were removed carefully to keep them intact. The usual pattern of heat discolouration could be observed whereby the sand closest to the metal was charred black (fig. 1.5).

Fig. 1.5. Cross section of a reproduction outer mould section of Brussels earth, showing the visible effect of the heat of the molten metal.

Moulding sand further away from the inner mould surface displayed a gradual colour change, ranging from dark brown to the unchanged colour of the Brussels earth. Based on colour, five zones could be observed and sand was sampled from each of these zones (fig. 1.6). This was done from several false cores to get an average and create sufficient sample material (>20 grams) for thorough analysis. The following five zones were identified:

Zone 1: completely black charred sand
Zone 2: dark brown sand
Zone 3: brown sand
Zone 4: light brown sand
Zone 5: unchanged natural colour of the sand

Samples of the five zones were submitted for analysis together with a sample of un-used sand. The analysis was performed again using laser diffraction.[158]

[157] Brusselse aarde (Brussels earth) obtained from sculpture supplies the Hazelaar in Soest. The supplier of the sand, Sibelco in Maastricht was contacted and the sand was quarried in Aldenhoven in Germany. This is close to the Dutch/Belgian border and the sand derives from the same geological sand layer as Brussels earth layer near Brussels.
[158] Dirk Goossens performed this analysis by laser diffraction.

Fig. 1.6. Close up of the cross section of the heat affected mould surface with the five zones indicated.

This produced again results for clay content and average grain size. A much greater quantity of sample material was now available for analysis, compared to the previous analysis of the various core samples and foundry-acquired moulding sand. This made it possible to investigate whether the dispersion of sample material influenced the results. One group of samples was dispersed ultrasonically and one not. If one looks at the final results of the analysis, as summarised in tables X to XIII, some trends can be observed. The first one is that the clay content decreases with the proximity of the zone to the metal, zone 1 containing less clay particles than zone 2 etc. This was observed in dispersed as well as non-dispersed samples. In relation this, one can observe an increase in average grain size (median particle diameter) the closer the sample material is positioned to the hot metal. Again, this was visible in dispersed as well as non-dispersed samples. Although both trends could be observed in dispersed and non-dispersed samples, the absolute figures for dispersed and non-dispersed were different. The dispersion doubled the amount of clay that went into solution, thereby reducing the average grain size diameter by a factor two or more.

The justification for this second sand analysis, was to find the causal effect of heat on the clay content of moulding sand. This second analysis observed a trend whereby sand closest to the hot metal showed the greatest decrease in clay content. A possible explanation for this can be the sintering of the clay particles. Clay particles in pottery clays start to cement together at temperatures above 900 C when fired, although this so-called sintering has also been observed as low as 600 C.[159] The temperature of the molten bronze is around 1200 C when it enters the mould, this is probably sufficient to cause sintering in the upper surface layer of the inside of the mould.

[159] Monteiro, S. N., and C.M.F. Vieira. “Solid state sintering of red ceramics at lower temperatures.” *Ceramics International*, *30*(3) (2004): 381-387.

Table X. Clay content of heated and non-heated Brussels moulding sand samples (non-dispersed) (image Dirk Goossens)

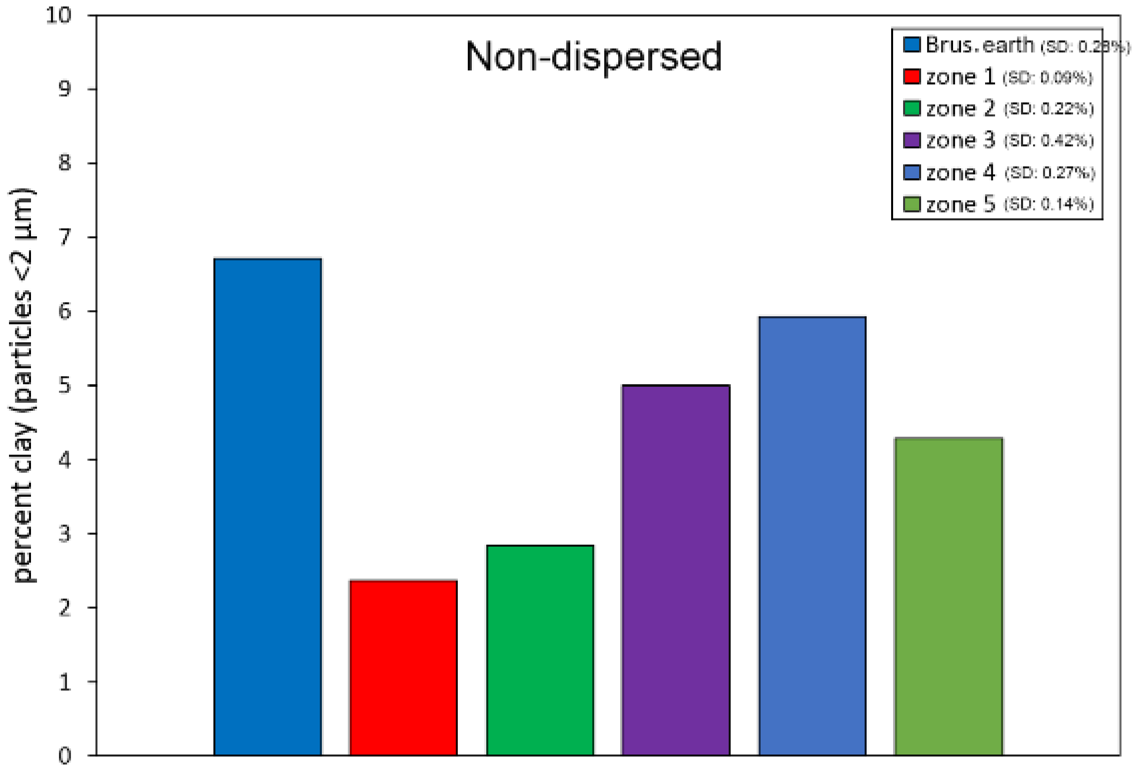


Table XI. Clay content of heated and non-heated Brussels moulding sand samples. (fully dispersed) (image Dirk Goossens)

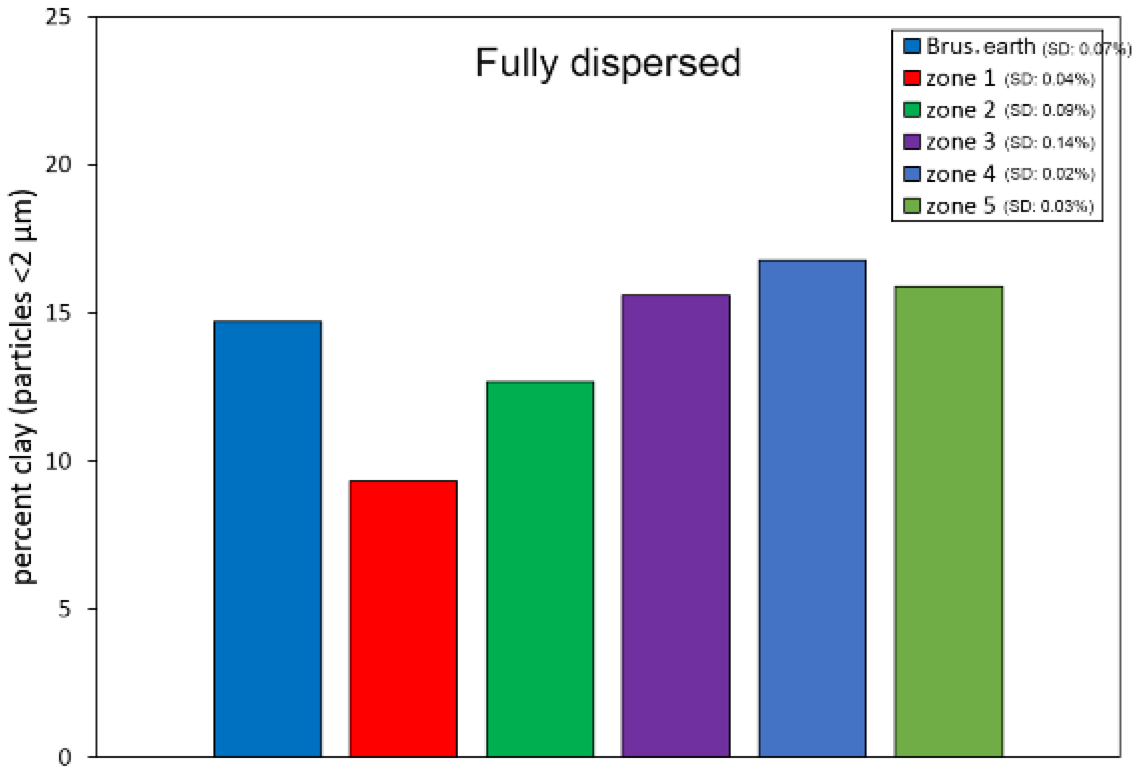


Table XII. Average grain size of heated and non-heated Brussels moulding sand samples. (non-dispersed) (image Dirk Goossens)

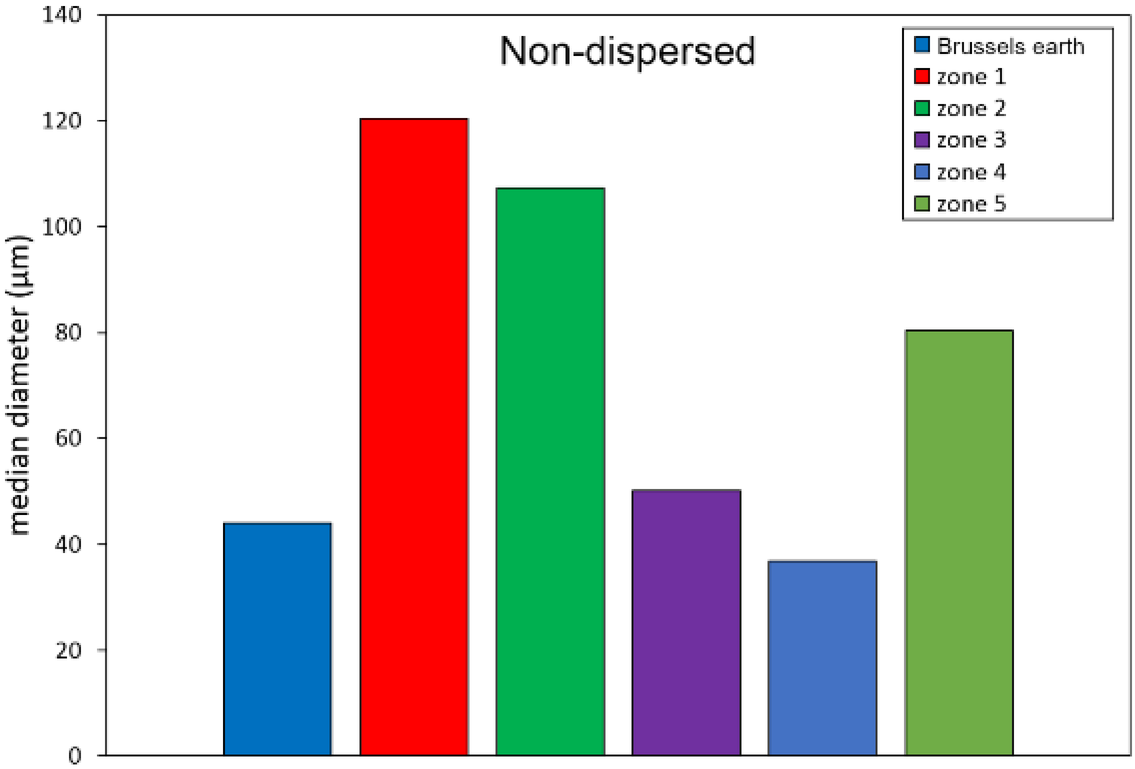
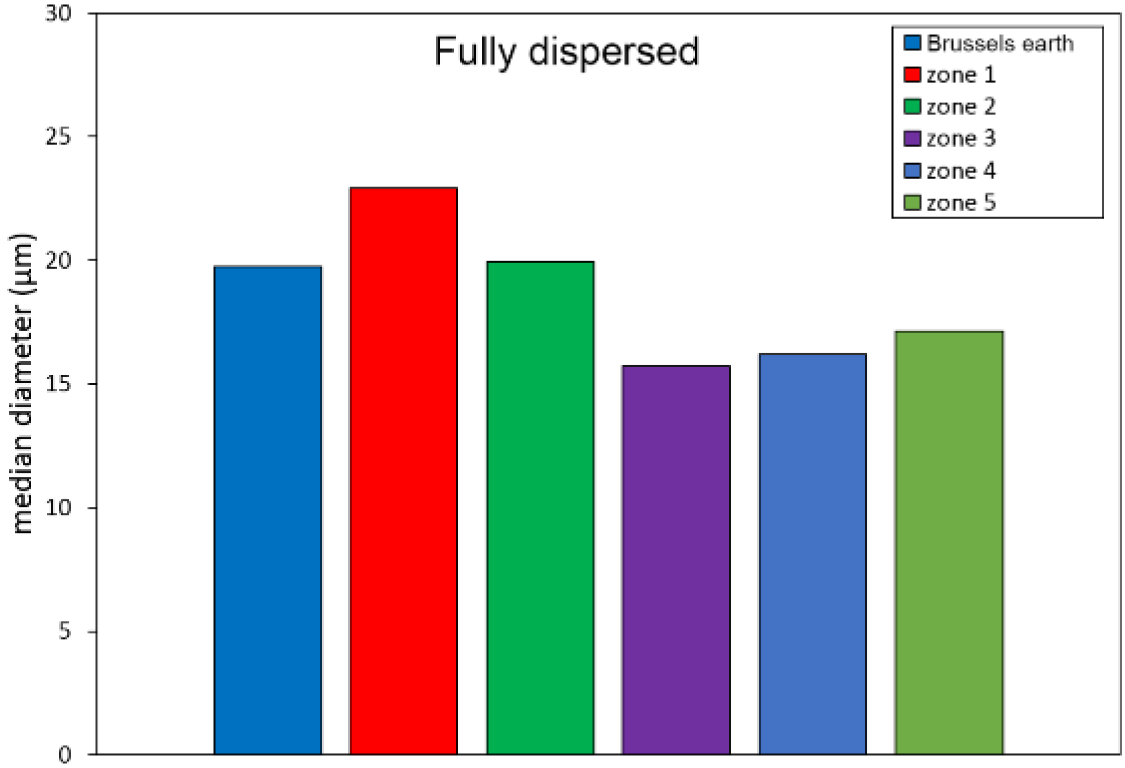


Table XIII. Average grain size of heated and non-heated Brussels moulding sand samples. (fully dispersed) (image Dirk Goossens)



1.3 The use of sand mould casting before the nineteenth century

Although there are references of early use of sand mould casting in Mesopotamia, ancient China and the Middle East and possibly pre-historic Europe, this chapter will concentrate on the development of sand mould casting in historic Western Europe.[160]
Tracing the history of sand mould casting is not straightforward: the lack of archaeological evidence due to the ephemeral nature of sand moulds limits the manner in which the method can be studied.[161] Early descriptions occasionally refer to the use of sand in connection to casting although one has to be careful interpreting this since sand was frequently added to loam or clay moulds.

The first use of sand as a mould material in Western Europe probably dates from the late fourteenth century when sand mould casting began to be used for the creation of simple castings such as cast iron fire backs. These were cast into open or basic bi-valve moulds.[162]
Aitchison suggests the introduction of sand as a mould material in the late fourteenth century may well be as ingot moulds for the production of pig-iron.[163] This suggestion is quite plausible because sand as a moulding material is not only inexpensive, and economical in use because it can be re-used and is fast to work with, yet above all it is resistant to the high temperatures (c.1200 ºC) of molten iron. This pouring of pig-iron was likely carried out by making the negative mould impressions into the foundry floor which is traditionally a sand floor (fig. 1.7).

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160 Müller-Karpe, M. "Der Guss in der verlorenen Sandform in Mesopotamien." *Mitteilungen der Deutschen Orient-Gesellschaft* 122 (1990): 173-192; Derui, T. and L. Haiping. "The ancient Chinese casting techniques." *China foundry*, vol. 8 nº 1 (2001): 131; Al-Jazari (Ismail ibn al Razzaz). "*The book of Ingenious Devices* (1206)", translated from the Arabic by Donald R. Hill, Kluwer Academic Publishers (1973): 190-195 & 274. Hill suggest a possible transfer of the skill of sand mould casting from China to the Arabic world. For more information on sand mould casting in the Islamic world, see La Niece, 2016 and Allan, J. W. *Persian Metal Technology 700-1300 AD*. Ithaca Press (1979): 62-63; Goldmann, K. "Guß in verlorener Sandform – Das Hauptverfahren alteuropäischer Bronzegießer?" *Archäologisches Korrespondenzblatt* 11 (1981): 109 –116. & Goldmann, K. "Bronzegußtechniken im prähistorischen Mitteleuropa." *Archäologische Bronzen, antike Kunst, moderne Technik*. Hermann Born (Ed.), Museum für Vor- und Frühgeschichte, Staatliche Museen Preußischer Kulturbesitz (1985): 52-58.

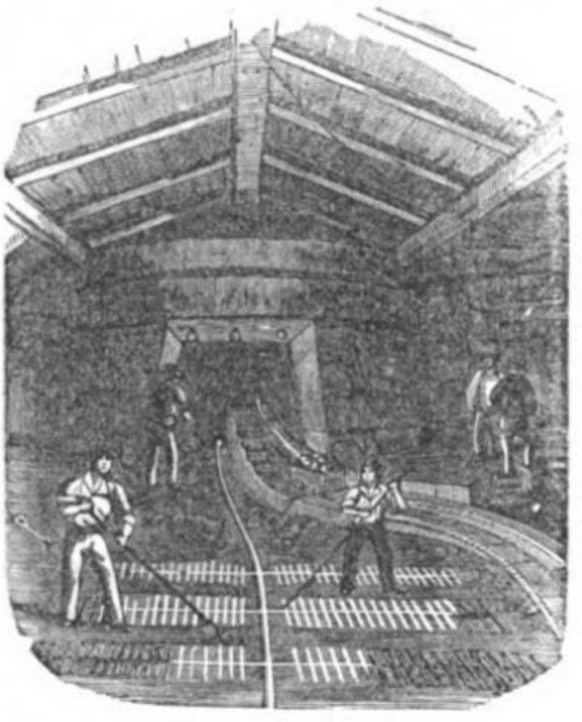
161 The excavations, between 2005 and 2008, of the post-medieval foundry (1545-1667) in the historic centre of Dubrovnik, gave evidence of sand mould casting. Moulding sand was found here in an area dedicated to sand moulding and casting, see Peković, Željko, and Nikolina Topić. "A late-medieval and post-medieval foundry in the historic centre of Dubrovnik"*Post-medieval archaeology* 45.2 (2011): 266-290.
Casting flasks have rarely been found in an archeological context. One exception is the early seventeenth century iron flask found in historic Jamestown see *Sand Casting Mold* <https://historicjamestowne.org/selected-artifacts/sand-casting-mold-2/> [accessed 22 June 2018]

162 Aitchison, L. *A History of Metals*. Interscience Publishers (1960): 348.

163 An ingot is a rough casting in a basic form, rendering it suitable for further processing. Pig iron is the initial product, in the form of ingots, of smelting iron ore with a high-carbon fuel. The name derives from the branched structure in sand bed acting as mould, with numerous individual ingots aligned at right angles to main runner, similar in appearance to a litter of piglets suckling on a sow, see Aitchison 1960, 407.

Fig. 1.7. Herri met de Bles, *Landscape with a Foundry* (detail), between 1525 and 1550. Oil on panel, 88 × 115 cm. National Gallery in Prague. (image Wiki commons)

A practice that was still in use during the nineteenth century (fig. 1.8).



CASTING PIG-IRON.

Fig. 1.8. The casting of pig iron in the Robert Wood's Ornamental Ironworks in Philadelphia in 1853. (from Hinckley 1853.)

For lack of archaeological evidence our knowledge of the early-modern use of sand mould casting must rely heavily on textual evidence such as art technological written sources and contemporary depictions of workshop practices.

The following section gives a chronological overview (ca 1400-1800) based on various documentary sources from a wide geographical area including Italy, the German lands, the Low Countries, France and England. The aim is to provide a critical development of sand mould casting in the early modern to modern periods. This is done by charting the main developments and establishing the first use of certain tools and techniques. Textual evidence providing detailed technical information, akin to trade secrets, has occasionally been published in the past, albeit not in abundance. Evidence for the use of certain moulding techniques can only be found described in early written sources. A substantial variance in written source material between various countries and periods can however be observed.

For example, enlightened France provides today's art-technological researcher with very detailed and profusely illustrated sources in the form of the publications by the l'Académie royale des sciences, the *Encyclopédie* by Diderot and d'Alembert and their followers. Material from countries like Britain and the Low Countries on the other hand, is less often encountered. This might give a distorted historical perspective. A place of publication is not necessarily of importance as casting centre and first evidence in a publication does not imply this innovation occurred in the city or country of publication. In addition, guild restrictions sometimes preventing members to publish craft knowledge, should also be taken in consideration. An example is the oath for new members of the Worshipful Company of Goldsmiths in London which contained the following: "…And you shall not disclose the secrets and skills (pryvitees) of the said craft but always behave as a good and true man towards your wardens and your Company…"[164] Although there is no proof that this oath was enforced, it can provide an explanation for the fact that the first English goldsmithing manual was only published in 1877.[165] By taking these above-mentioned arguments in consideration, I believe a valid historical perspective regarding the development of sand mould casting, can still be given.

This exploration of the subject uses examples from different branches of metalworking which have historically made use of sand moulds for casting. These include goldsmiths, casting gold and silver, and copper alloy and iron founders.[166]

[164] *Privity*: a thing that is kept hidden and secret; private business; personal affairs (Oxford English Dictionary). In the Ordinances of the Worshipful Company of Goldsmiths in London the word privity is also used with special reference to the skills and methods of the craft, see Reddaway, T.F. and L.E.M. Walker. *The early history of the Goldsmiths Company 1327-1509: the book of ordinances 1478-83*. (fo.11v.), Edward Arnold (1975): 213. I am grateful to David Beasley, former librarian of the Worshipful Company of Goldsmiths in London, for this reference.

[165] Gee, G. E. *The Practical Gold – Worker - or the Goldsmiths and Jeweller's Instructor.* Crosby Lockwood & Co, 1877.

[166] The distinction between goldsmiths, working mainly in gold and silversmiths, working mainly in silver, is a fairly recent one. In the Post-modern era a goldsmith refers usually to a generalist working in precious metals which can include jewellery, medals and hollowware, cast as well as wrought.

Although it is tempting to make a division between these type of founders, this is not easy because of the many overlaps between these professions. Goldsmiths, especially in the Renaissance, were often also sculptors working in bronze, for example Benvenuto Cellini.[167] In converse bronze foundries were sometimes asked to cast sculptures in silver.[168] Foundries operating in the nineteenth century were known to cast the same model in iron as well as bronze and even zinc using similar techniques to cast these different metals.

In the course of this analysis, three main groups using sand moulds could be discerned:

- the first group of fine founders, were the goldsmiths and medal founders, specialised in the founding of small detailed castings. Most of the earliest written sources describing the use of sand moulds are by this group
- the second group, were the copper alloy and iron founders, casting utilitarian objects such as pots, candlesticks and furniture mounts but also more industrial objects such as pulleys, wheels, machine parts and ordnance
- the third group, were the sculpture founders, casting in complex sand piece-moulds. This group forms the core of my research and will be discussed in the next chapter

The three groups are listed in chronological order. The majority of published descriptions of sand mould casting by the first group fall within the Renaissance 'how-to' literature.[169] The sand moulding technique used by goldsmiths and medal founders, consisting of simple bi-valve moulds, showed little innovation. To trace the innovations, leading to the use of complex sand moulds for the founding of sculpture, it is important to look at the technical development in the casting of utilitarian, industrial objects and cannon during the seventeenth and eighteenth centuries. This second group falls broadly within the age of encyclopaedias whereas the third group fits, on the whole, into the group of specialised manuals typical of the nineteenth century.[170]

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[167] Often Itialian Renaissance sculptors received a formal training as goldsmiths, for example Ghiberti, Pollaiuolo and Verrocchio, see Collareta, M. "The Historian and the Technique: On the role of Goldsmithery in Vasari's *Lives*." *Sixteenth-Century Italian Art*. Cole, Michael W.(ed.), Blackwell (2006): 291.

[168] Charles Crozatier casting a 3 foot high silver Maria; Fol 17 verso, Letter Dinger to Beuth, 1.1.1828, GStA PK I.HA Rep. 76 Vb Sekt.4, Tit. XII, Nr. 1, Bd. 2, 1827-1829.

[169] Long, P. O. *Openness, secrecy, authorship: technical arts and the culture of knowledge from antiquity to the Renaissance*. Johns Hopkins university press, 2001 & Smith, P. H. *The Body of the Artisan: Art and Experience in the Scientific Revolution.* The University of Chicago Press, 2004.

[170] Delon, M. *Encyclopedia of the Enlightenment*. Taylor and Francis, 2013.

1.3.1 Goldsmiths and medal founders using sand moulds

Most of the early textual references to sand mould casting are covering the casting of small, low relief objects such as precious and base metal seals, medals and plaquettes.[171] The first documentary evidence of the use of true sand mould casting can be found at the beginning of the sixteenth century when Leonardo da Vinci's (1452-1519) notes the following: "If you wish to make casts rapidly and simply, make them with a box of river sand moistened with vinegar".[172] Leonardo's note can be found on a folio, dedicated to the moulding process of the Sforza monument.[173] MacCurdy dates this folio from before 1518, perhaps between 1480-1500, when Da Vinci was working on the Sforza monument.[174] Unfortunately, Da Vinci does not specify the river from which he obtained this sand. Although this is the earliest reference to date of sand mould casting in Europe it is likely that this casting technique was already in use for some time. Da Vinci does not mention this type of casting as something new or special.

If one looks at earlier textual sources covering metal casting, no description or depiction of sand mould casting can be found. There is for example no description of sand mould casting in the important medieval metalworking source *Schedula diversarium artium* (before-1100).[175] Also close examination of the depictions of the various metalworking professions in the *Hausbücher der Nürnberger Zwölfbrüderstiftung*, dating from 1425 till 1806, did not yield one image of a sand mould or flask.[176] Cennino d'Andrea Cennini (c. 1370-c. 1440), in his painters handbook *Il libro dell'arte*, mentions the use of powdered ashes bonded with salt water as a mould material to make a mould of a seal or coin.[177] The use of these ashes however, is not as a form of sand but is akin to the use of plaster whereby the mould material is poured in a liquid form. The scarcity of textual art technical source material on casting from the middle ages means that one cannot draw any solid conclusions. It is conceivable that sand mould casting was in use in Europe in the centuries before Da Vinci and the knowledge for this was transferred from the Islamic world. La Niece gives several examples of casting flasks from the Islamic world, some with secure archeological provenance and dating from the fourteenth century or earlier.[178] The court inventor Al-Jazari, writing around 1200, described the process of sand mould casting in his *Book of Knowledge of Ingenious Mechanical*

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[171] Tuttle, P. "An Investigation of the Renaissance Casting Techniques of Incuse-Reverse and Double-sided Medals" *Italian Medals*, Pollard, J. Graham. (ed.), National Gallery of Art. Studies in the History of Art, Volume 21 (1987): 205-212.

[172] "Se volli fare presti gietti semplici, fagli chon una cassa di sabion di fiume inumidito chon acieto"; Translation by MacCurdy, see MacCurdy, E. *The Notebooks of Leonardo da Vinci*. George Braziller (1955): 1031.

[173] Windsor drawing 12350. I would like to thank Dr. Andrea Bernardoni, senior researcher at the Galileo Museum. Institute and Museum for the History of Science, Florence for communicating this information and providing the original Italian text.

[174] MacCurdy 1955, 1031.

[175] Brepohl. E. *Theophilus Presbyter und die mittelalterliche Goldschmiedekunst*. Edition Leipzig, 1987. & Clarke, M. "Reworking Theophilus: Adaptation and Use in Workshop Texts." *Zwischen Kunsthandwerk und Kunst: Die ‚Schedula diversarum artium'*. Speer, A. et. Al, Walter de Gruyter (2014): 72-89.

[176] Online http://www.nuernberger-hausbuecher.de/index.php?do=page&mo=2>[accessed 22 June 2018]

[177] Cennini, C. and D. V. Thompson. *The craftsman's handbook*. *("Il Libro dell' Arte" ,* c. 1400). Dover Publications (1954): 130-131.

[178] La Niece, Susan. "Medieval Islamic Metal Technology." *Scientific Research in the Field of Asian Art: Proceedings of the First Forbes Symposium at the Freer Gallery of Art*. P. Jett (ed.) Archetype (2003): 92

Devices.[179] Italy with its close ties with the Islamic world is a likely candidate to have imported the Islamic sand moulding skill, or possibly medieval Spain with parts of the Iberian peninsula still under Muslim control till the late fifteenth century.

Vannoccio Biringuccio (1480-1539?) in his *Pirotechnia* of 1540 devotes a whole chapter to the use of sand and powders as a mould material.[180] This chapter describes the use of binders, such as flour and water, urine or wine to hold the previously heated sand together and to give it the right consistency in order for the sand take good impressions, akin to the modern way of addition hardening sand mould casting.[181] Biringuccio describes this as part of the small art of casting although he also mentions he had seen the same methods used for large castings up to three hundred pound a piece.[182] Typifying this casting method as truly a quick and easy method.[183] The excavations between 2005 and 2008 of the foundry (1545-1667) in the historic centre of Dubrovnik seems confirm the foundry practice of sand mould casting during this period. Moulding sand was found here in an area dedicated to sand moulding and casting.[184] In contrast the excavations of a foundry in Chinzica, Pisa, active between the early thirteenth century and 1406, gave only evidence for casting in fired clay/loam moulds. This foundry specialised in the mass production of simple copper alloy clothing accessories such as clasps.[185] A type of object that would be usually produced from the sixteenth century by sand mould casting.

These early descriptions are all examples of dry sand mould casting. It is only later in the sixteenth century, when Benvenuto Cellini (1500-1571) described using a moist argillaceous sand from the river Seine in Paris, in his treatise on goldsmithing and sculpture, that one can speak of green sand mould casting:

> ... as I write I am minded of a very rare kind of this tufa earth which is found in the bed of the river Seine in Paris.[186] While there I used to take what I wanted from hard [close] by the Sainte Chapelle, which stands on an island in Paris in the middle of the Seine. It is very soft, and has the property, quite different from **other clays** used for the moulding process, of not needing to be dried, but when you have made from it the shape you want, you can pour into it while it is still moist, your gold, silver, brass, or any other metal. This is a very rare thing, and I have never heard of it occurring anywhere else in the world.[187]

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[179] Al-Jazari and Hill 1973, 192-194.
[180] "Modo di far la poluere da tragittare ogni metallo in fresco, e modi di formare." see Biringuccio, V. *De la Pirotechnia Libri X*. V. Rossinello (1540): 253-254.
[181] Smith and Gnudi 1959, 324-328.
[182] *"Arte piccola del gitto"* see Biringuccio 1540, 251. Muskets(*moschete*), large candelabra(*candelieri grandi*), andirons (*capi fuochi*) and works of great importance (*lavori d' assai importantia*). He also illustrates a sand mould for a small bell, ibid 253-254.
[183] "veramente è modo presto, & facile" see ibid 253.
[184] Peković and Topić 2011, 266-290.
[185] Carrera. F. "The "ex laboratori Gentili" workshops in Chinzica, Pisa." paper presented at the international symposium; *Medieval copper, bronze and brass*, Dinant-Namur, Patrimone Wallonie, 2014.
[186] "Areno di tufo" see Cellini and Ashbee 1898, 62.
[187] Cellini and Ashbee 1898, 62.

This description by Cellini is very interesting but even more interesting when looking at Cellini's own words in the original language:

> … mentre che io scrivo, e' mi sovviene una di queste arene rarissima, la qual si è nel fiume della Senna di Parigi ; questa in mentre che io vi stetti presi di quella che era intorno alla Santa Cappella, la qual cappella è in mezzo della Senna, che è in isola in Parigi; questa è sottilissima da per sè, et ha una proprietà diversa dall' altra, che adoperandola in nel modo che si fa alle altre **terre con le staffe**, e' non accade rasciugarla come alle altre **terre** si fa quando l' uomo ha formato quel che e' vuole ; ma subito format che tu hai l' opera tua così umidiccia, come promette il modo di acconciarla universalmente, così umidiccia dico, vi si può gettar drento oro, argento et ottone, e tutti quei metalli che ti vengono in preposito. Questa è cosa raris sima, che mai l'ho sentito dire che tal cosa sia in altra parte del mondo.[188]

Cellini uses the word *terra* which is usually translated as earth and not clay (It. *Argilla*). He makes no distinction here between clay and sand (It. *sabbia*). Although Ashbee uses first the word tufa earth, further on he still ranks it as a form of clay.[189] When Cellini discusses the use of clay for making lost wax moulds, he also uses the word *terra.*[190] The *terra* for lost wax moulds require distinctly different properties than the *terra* for flasks. (It. *terre con le staffe*) Natural moulding sand, used for sand moulding, gets its special properties from the presence of a substantial amount of clay between its sand grains. The properties and appearance of moulding sand is therefore more reminiscent of clay than of ordinary loose sand and explains why Cellini ranks it amongst clays. This indiscriminate use of terms has also been observed by for example Lebon that in French texts of the eighteenth and nineteenth centuries the terms *terre* and *sable* are often inter-changeable.[191]

Cellini's description of using moist sand is by my knowledge the first mention of green sand mould casting. Cellini describes very specifically earth from the Seine river bed which later in the nineteenth century was going to provide the most sought-after sand for the sand mould casting process. The role of Parisian moulding sand in the history of the French cast metalwork is somewhat under-acknowledged. The very high quality of sand mould castings achieved in France from the late seventeenth century onwards in silverware, bronzes and ormolu can possibly for a part be attributed to the use of this sand.[192] Especially sand from the Fontenay-aux-Roses quarry in Paris was to acquire, in the course of the nineteenth century, international fame as one of the best moulding sand with Réaumur already mentioning in

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[188] Cellini, B. and C. Milanesi. *I Trattati Dell'oreficeria E Della Scultura*. Felice Le Monnier (1857): 102.
[189] Cellini and Ashbee 1898, 62.
[190] Cellini and Milanesi 1857, 163.
[191] Lebon, É. "*Sable ou terre ?*" *Le fondeur et le sculpteur*, Collections électroniques de l'INHA (2012) <http://inha.revues.org/3468> [accessed 6 June 2018]
[192] Amalgam gilt copper alloy castings, often furniture mounts but also objects such as candlesticks, wall sconces or chandeliers. The name derives from the French *or moulu* meaning ground gold. For further reading see Ottomeyer, H. and P. Pröschel. *Vergoldete Bronzen: Die Bronzearbeiten des Spätbarock und Klassizismus*. Klinkhardt & Biermann, 1986.

1722 the well-established practice of Parisian founders using Fontenay sand: "Le fer qui avoit été entouré de sable, tel que celui de Fontenay-aux-Roses, fort estimé des fondeurs de Paris…"[193]

Apart from descriptions in manuals one can also find more tangible evidence of sand mould casting in early depictions of goldsmith's workshops. A relative large number of goldsmith's workshop interiors on paintings, engravings and drawings exists, likely because engravers, painters and draughtsmen before 1700 were often initially trained as goldsmiths.[194] Close study of depictions of gold and silversmiths' workshops demonstrates the use of casting boxes or flasks from at least the middle of the sixteenth century onwards. Of the twenty images known to me depicting goldsmiths in their workshops, dating from before the middle of the sixteenth century, none of these show flasks. When carrying out the moulding process using sand, one always needs to contain the sand within a frame called flask. Originally, the open frame was bottle-shaped (fig. 1.9) and made from iron and occasionally from wood.[195]

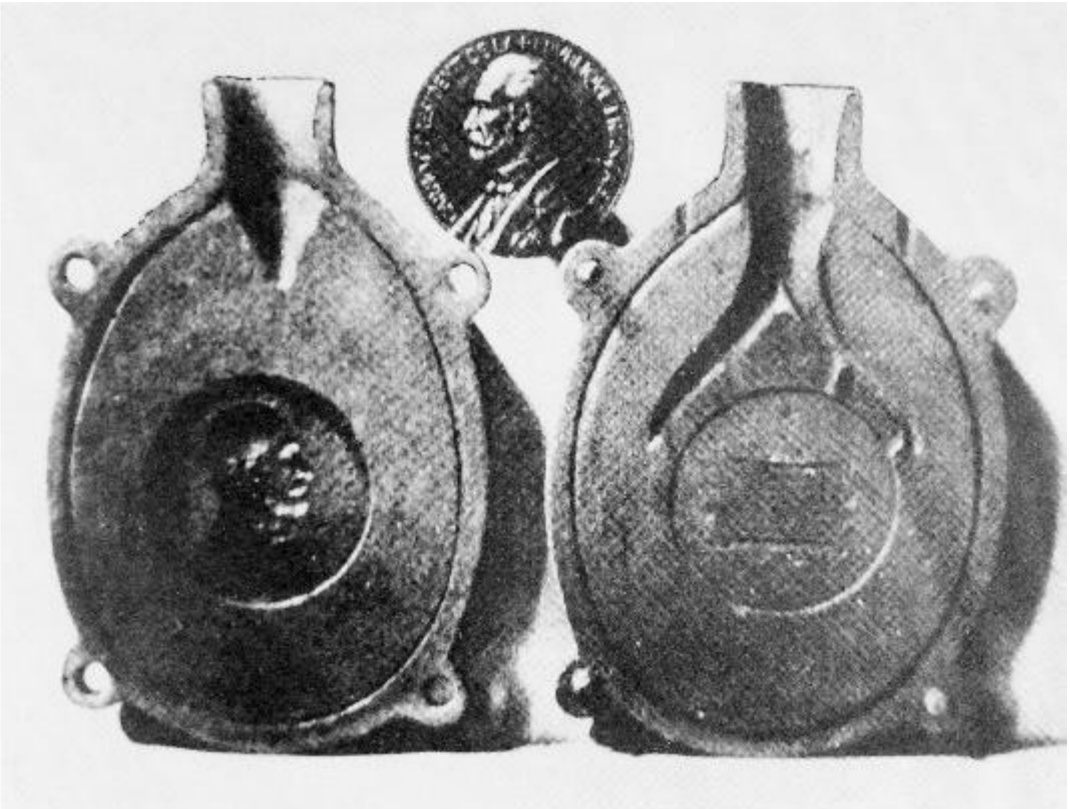

Fig. 1.9. A finished sand mould inside a flask ready for casting. The medal used as pattern has been removed and the gating system has been carved in the surface of the sand. (from Richter, Ernst-Ludwig. *Altes Silber*, Keyser, 1983, fig. 201)

[193] "The iron which is enclosed by sand, such as that of Fontenay-aux-Roses, which is held in great esteem by the foundry men of Paris" (translation author). Réaumur, R. F. de. *L' Art de convertir le fer forgé en acier et l'art d'adoucir le fer fondu, ou de faire des ouvrages de fer fondu aussi finis que de fer forge*. M. Brunet (1722): 19.
[194] For example Albrecht Durer and Theodore de Bry, see Landau, D. and Peter W. Parshall. *The Renaissance print, 1470-1550*. Yale University Press (1994): 1.
[195] Réaumur, 1722, 434-435.

This flask is then held together in a clamp and ready to pour the molten metal into (fig. 1.10). The drawing by Jan Luyken (1649-1712) is a study for an emblem book he published together with his son Casper (1672-1708) in 1694, and is the earliest depiction of process of pouring metal in a sand mould found to date.[196] This is not the earliest image giving proof of casting in sand moulds, an earlier one illustrating only flasks, will be discussed next (fig. 1.11) but I have placed this image here as to illustrate the process of casting metal in sand moulds.

Fig. 1.10. Jan Luyken, *De silversmit*, Amsterdam, 1694. Drawing. Amsterdam Museum (inv.no. TA13444). A silversmith pours metal into a bottle shaped sand mould, held between a clamp. (image Amsterdam Museum)

This earlier image, a woodcut print by the Sienese artist Domenico Beccafumi (1486-1551) and dated to 1540-1550 depicts a fine metal worker, probably a goldsmith, at work in his workshop (fig. 1.11). This print forms part of a series of ten prints: *The various operations of alchemy*.[197] There is no consensus yet on whether this series of prints was intended to illustrations an alchemical text or to be part of Biringuccio's *Pirotechnia*. Gabriele links these woodcuts to Biringuccio's Pirotechnia and comes up with two hypotheses: one that the woodcuts were inspired by Biringuccio's Pirotechnia, which would give the woodcuts a post 1540 date.[198] The other hypothesis is that these woodcuts were a first draft for the Pirotechnia but were never included, which would date the woodcuts earlier, probably around 1530. The print would then have been intended for Book 8: *Concerning the Small Art of Casting.* Karpinsky, argued already in 1960 against these theories and remarked: "It therefore seems

[196] Luyken, J. and C. Luyken. *Spiegel van het Menselyk Bedryf*. Kornelis van der Sys, 1694.
[197] Mino, G. *Le incisioni alchemico-metallurgiche di Domenico Beccafumi*. Giulio Giannini & Figlio, 1988.
[198] Mino, np. I would like to thank Stefania Lorenzotti for help with the translation and interpretation of this text.

impossible that a book of practical instruction by an author who repudiates alchemy should be illustrated with Beccafumi's prints, which are suffused with alchemical thought."[199]

Modern scholars such as Bernardoni argue that Biringuccio's position on alchemy is more discerning:

> …[Biringuccio] taking a negative stance towards the 'false and sophistic' alchemists who hide their art behind esotericism, magic, alchemical authority and those who practice chemical process without ratio and empirical control, and taking a positive stance towards "true alchemy" as a philosophical and technological activity grounded on reason and empirical experimentation.[200]

While alchemy is still often associated with futile attempts to trans mutate base metals into gold, many historians of science now consider alchemy in the early modern period as one of the precursors of modern metallurgy and chemistry.[201] Despite this changed perspective on alchemy, Kaplinsky still has a point.

Fig. 1.11. Domenico Beccafumi, c.1540-1550. Woodcut illustration of a silversmith in his workshop. From a series of ten prints: *The various operations of alchemy*. Empty casting flasks are seen hanging on the right wall, on the work bench on the right and filled flasks are visible in a clamp on the foreground. (image British Museum)

[199] Karpinski, C. "The Alchemist's Illustrator." *The Metropolitan Museum of Art Bulletin*, Summer (1960): 9-14.
[200] Bernardoni, A. "Artisanal Processes and Epistemological Debate in the Works of Leonardo da Vinci and Vannoccio Biringuccio."*Laboratories of Art: Alchemy and Art Technology from Antiquity to the Eighteenth Century*. Sven Dupré (ed.), Springer (2014): 69.
[201] P. H. Smith 2004, 16

Compared with Beccafumi's images the prints in the Pirotechnia are purely functional, supporting the text and not cluttered with tools, other objects or people not directly related to process being illustrated. Beccafumi's illustration is the earliest depiction of casting flasks I have found and provides visual proof of the practise of bi-valve sand mould casting during this period. The empty casting flasks can be seen hanging on the right wall, on the work bench on the right and filled flasks are visible in a clamp on the foreground (fig. 1.11). Although the flasks are easily discernible, it is clear from their detail and also the details of the other tools depicted, that Beccafumi was not a founder or metalworker himself. The flask lying on the worktop could not work in practice: it lacks the registration pins and holes and it is depicted curved whereas it should be perfectly flat to function properly.

The same type of flask can also be seen on two later engravings by Etienne Delaune (1519-1583) from 1576 (fig. 1.12). Delaune is recorded working as a goldsmith in Paris in 1546 and briefly in the royal mint six years later. His first dated prints were made when he was 42 years old. As a Calvinist, he left Paris at the time of the St Bartholomew's Eve massacre in 1572, and moved first to Strasbourg and later, according to the inscription on this print, to Augsburg.[202] More detailed than the previous illustrations, both depict a number of metal flasks hanging from pegs against the wall of the workshop, (fig. 1.13). They have the typical bottle or flask shape with the 'neck' part, the entry point for the metal, pointing downwards. Also visible are the registration pins (keys) halfway the sides, which are to position the flask halves perfectly against each other. Visible, next to the flasks, is also fixed to the wall the screw clamp used for clamping one or more flasks together for casting. Although theses engravings were published in Augsburg, these could also have been made when Delaune was working as a master goldsmith in Paris from 1546 till 1572.

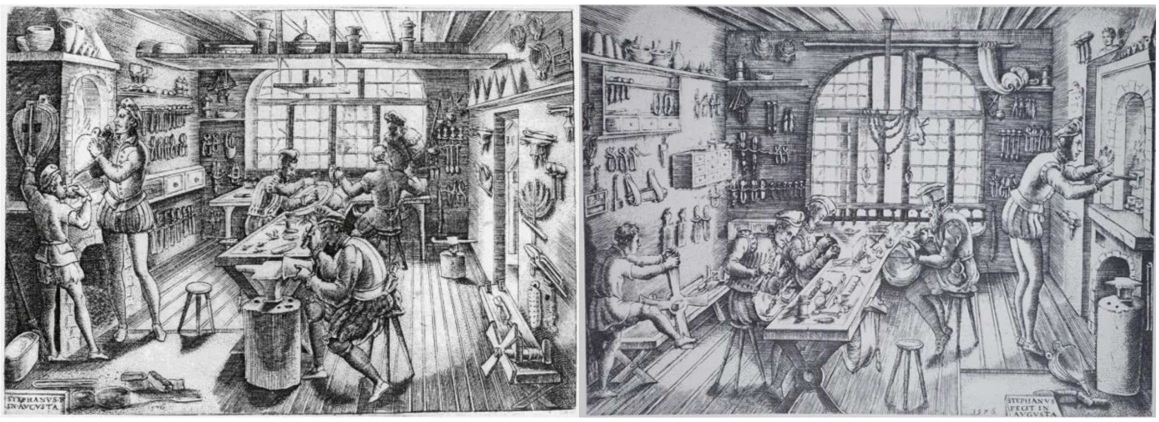

Fig. 1.12. Etienne Delaune, Augsburg, 1576. Two engravings of an interior of a goldsmith's workshop. (image British museum)

[202] See Livings, G.E. A. Techniques for the Manufacturing of Aiglets during the Late Middle Ages, with a Comparison of Medieval, Post Medieval and Modern Methods.(2015): 25 note 27 <http://www.livingstonjewelers.com/library/AigletsSCA20150425.pdf > [accessed 12 november 2018] See for this print online: <http://www.britishmuseum.org/research/collection_online/collection_object_details.aspx?objectId=1419428&partId=1 > [accessed 6 June 2018]

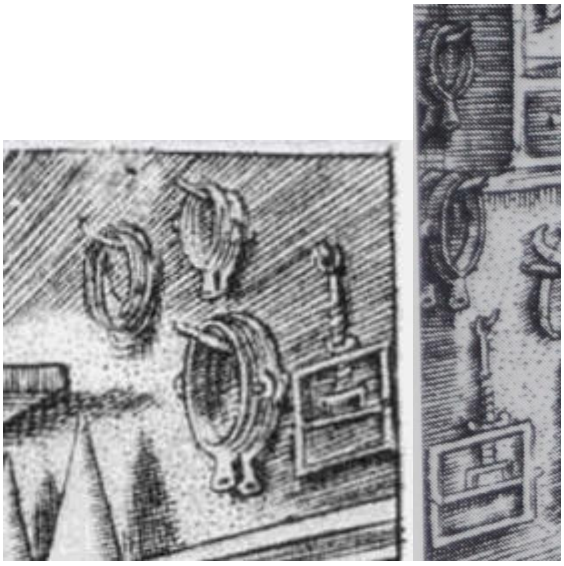

Fig. 1.13. Etienne Delaune, Augsburg, 1576. On the left a detail of the above left engraving and on the right a detail of the right engraving showing the casting flasks together with their clamp suspending from hooks on the wall.

Based on the previously mentioned sources, the knowledge and skill of sand mould casting could have been transferred from the Middle East to Renaissance Italy, followed by Italian artisans, for example Cellini or Leonardo da Vinci, introducing sand moulding in France (both working at the court of Francis 1). French craftsmen, such as Delaune, subsequently introduced sand moulding in Southern Germany. However, the knowledge exchange over the Alps was not one way. While some Italian artisans travelled North, one also sees artists and artisans from North and Western Europe travelling to Italy. South German bronze founders rivalled and sometimes surpassed their colleagues South of the Alps in the founding of sculptures.[203] These founders, however, were using the lost wax technique to produce their bronzes.

I have not been able to find evidence for the use of sand moulds North of the Alps from before the middle of the sixteenth century. Proof that sand moulding was already practised in the German lands before Delaune's arrival in Augsburg is given in a print by Jost Amman (1539-1591), published in Frankfurt am Main in 1568 depicting flasks for bi-valve sand moulding (fig. 1.16).[204] This print will be discussed in detail further in this chapter. The first evidence I have found for the use of sand moulding in the Low Countries can be seen on the painting *Allegory of Fire*, by Jan Brueghel the elder, preserved in the Pinacoteca Ambrosiana in Milan. This oil panel painted in Antwerp around 1608, formed part of a series of allegories of the four elements, and depicts Vulcan's forge with in the foreground a display of tools and products of precious metal working, arms and armour making and alchemy (fig. 1.14).

[203] van Langh, R. "Innovations in the casting technology of sixteenth century European bronze sculptures" *Technical Studies of Renaissance Bronzes*, Rijksmuseum (2012): 77-103.

[204] Sachs, H. *Panoplia omnium liberalium mechanicarum et sedentariarum artium genera continens*, Sigmund Feierabend, 1568. (German title: *Eygentliche Beschreibung aller Stände auff Erden, hoher und nidriger, geistlicher und weltlicher, aller Künsten, Handwercken und Händeln*.)

Fig. 1.14. Jan Brueghel the elder, *Allegory of Fire*, 1608. Oil on panel, 44 x 66 cm. Pinacoteca Ambrosiana, Milan, (inv.no. 68). (image Wikipedia commons)

This painting, of which many copies are extant in collections worldwide, is of great significance for the study of early modern metalworking.[205] One has to be, of course, careful with the interpretation of paintings,[206] however the accuracy of the metalworking tools, depicted on the original painting, is remarkable and suggests an intimate knowledge of metalworking.[207] Heirman's analysis of this painting focussed on the depiction of the water wheel and showed that this water wheel in many later versions of this painting by copyists, was incorrectly copied and could not properly function. To date no study has been made of the array of goldsmithing tools depicted on the painting. Amongst these goldsmithing tools depicted in the foreground on the left, a closed sand mould is visible on the floor (fig. 1.15).

[205] Heirman lists 43 copies, see Heirman, J. *Jan II Brueghel en Het Vuur: een studie van de metallurgie in de zeventiende eeuw*. Kunstacademie Hamme (2002): 70-71. The painting, for example, illustrates for the first time a sheet rolling mill in the context of a goldsmiths workshop.

[206] Fock, W. C. "Werkelijkheid of schijn. Het beeld van het Hollandse interieur in de zeventiende-eeuwse genreschilderkunst**."** *Oud Holland*. Vol.112(4) (1998): 187-246.

[207] The paintings in Lyon (1606 Musée des Beaux-Arts inv.no. A-75), and Milan (1608, Pinacoteca Ambrosiana inv.no 68) are considered to be the originals; Heirman 2002, 60.

Fig. 1.15. Jan Brueghel the elder, *Allegory of Fire*, 1608. Detail showing a flask filled with sand lying on the workshop floor.

Interestingly, the mould is depicted with the brown casting sand inside the flask. It shows a flask filled with sand, ready for casting. This is clear from the fact that the entrance funnel of the flask is empty and not filled with the casting head of the casting. The grey colour of the flask is identical to, for example, the iron bench vise lying close by and it can be safely assumed that the flask is also made of iron. The colour of the sand is very typical of a type of casting sand used in the Low Countries called *Brusselse aarde*.[208] It was quarried in an area between Louvain and Sint-Truiden near Brussels and had a clay content between 10-15%.[209] One can find for example an early detailed description of the use of this sand in a Dutch treatise donated to Constantijn Huygens (1596-1687) in 1629.[210] Huygens was given this treatise by his old study pal and friend Johan Brosterhuisen (1596-1650): who, like him, was experimenting with various forms of casting, life-casting as well as medal casting in sand.[211] Brosterhuisen in turn got it from the lawyer Willem Dedel who extracted it from the memoirs'

[208] English translation of *Brusselse aarde* would be Brussels earth or sand.
[209] Gullentops, F. and L. Wouters. *Delfstoffen in Vlaanderen*. Brussel: Ministerie van de Vlaamse Gemeenschap (1996): 39.
[210] Although the distinguished Dutch poet, diplomat, composer and scientist Huygens did not receive a formal training as goldsmith, he was introduced into the basics of medal making by the Hague goldsmith Adriaen Rottermont (1579-1652) who's uncle was the famous sculptor Adriaen de Vries (c.1556–1626); De Heer, A.R.E. "Constantijn Huygens en de penningkunst." *Jaarboek voor munt en penningkunde.* V. 80 (1993): 275.
This treatise is part of a large collection of personal papers once belonging to Constantijn Huygens now preserved in the Royal Library in the Hague.(inv.no. KA XLVII, Fol. 185ff. Personally collected and bound by Huygens it carries the following title: *"Musica, medica, phijsica, odofera, perfumatoria, fusoria, coquinaria, philosophiaca, mathematica, artificialia, Constantini Huginii, Ars Formandorum et poliendorum votorum ad usum astronomicum"*. The treatise, largely unpublished, covers fabricating modelling wax, the assay and refining of gold and silver, the casting of medals, casting flowers and small animals from life and making plaster models and moulds. The part of the treatise on the casting of medals is published in De Heer 1993, 271-288.
[211] Johan Brosterhuisen (1596-1650): Study pal of Huygens', botanist, practised etching and painting, wrote poetry, in contact with Muiderkring and translated for Jacob van Campen Vitruvius and other architectural treatises. From 1646 he held a chair at the Illustre School of Breda.

of a 'great' founder.[212] It gives a step by step account of using this sand, in the treatise referred to as 'Brussels sand (or sant)', to cast medals using a flask.[213]
The two-page description of sand mould casting in the treatise mentions the use of a parting compound to prevent the mould halves sticking together.[214]

In this respect it is interesting to look at a slightly later Dutch source, a treatise by the Dutch silversmith Willem van Laer (1674-1722?). Published for the first time in Amsterdam in 1721 and titled *Weg-Wyzer Voor Aankoomende Goud en Zilversmeeden*, it offers a manual for the apprentice gold- and silversmith.[215] Amongst descriptions of assaying and the production of jewellery and silver wares there are two interesting chapters on the use of sand mould casting. One chapter, with the title 'Van 't gieten zo van Zilver als Goud' (Of the casting of silver as well as gold), gives many intricate details of casting in sand of precious metal parts.[216] Van Laer mentions for example the fact that the Brussels sand improves with use. He recommends to heat the new sand in a glowing charcoal fire to rid the sand of flammable [organic] matter. This is followed by grinding or pounding the sand and rinsing it in water. After drying, this sand will be ready for use as moulding or form sand.[217] The next thing Van Laer touches upon is the use of a parting compound, *stofzand.* The author recommends, although charcoal powder is commonly used, instead to use very finely ground and dried Brussels sand, or *tripoli*,[218] or pumice or any fine powder that does not burn as long as it is used minimally, van Laer calls this amaril.[219] He also mentions the preparation of the sand by mixing in other components such as soot, tripoli or finely powdered roof tiles, and discusses binders such as sal ammoniac (ammonium chloride), gum (natural) or glue, beer, salt, syrup and even urine.[220]

The sand moulding described by van Laer is very similar to the sand moulding descriptions by Biringuccio and Piemontese, almost two centuries earlier. Van Laer's example demonstrates that bi-valve sand moulding, as practised by goldsmiths, was subjected to very little change. The mould ingredients, such as the natural sands or powdered refractory material, show some variation depending on the local geology as do some of the binding agents but basically the goldsmiths and medal founders were using small iron flasks creating simple bi-valve sand

[212] Willem Dedel (1600-1650): Lawyer, brother of Huygens' personal tutor Johan Dedel. Brosterhuisen wrote: "….de me la communiqué de ma part par Mr Dedel, l' advocat, l' art de getter; c' est un livret escrit à la main, tiré des memoires d'un grand fondeur"; from a letter (no.420) written to Huygens by Brosterhuisen on January 9th 1629 University library Leiden Cod. Hug. 37 (Brosterhuizen) 12 <http://resources.huygens.knaw.nl/briefwisselingconstantijnhuygens/brief/nr/420 > [accessed 22 June 2018]
[213] In the treatise called *fles* or *flesch*
[214] Dry finely powdered Brussels sand (*Drooch fyn gewreven Brussels sant*); De Heer 1993, 283.
[215] Other editions Middelburg 1730 and Amsterdam 1768, both with no alterations to the text.
[216] Van Laer, W. *Weg-Wyzer Voor Aankoomende Goud en Zilversmeeden*. Frederik Helm (1721): 130-140.
[217] Van Laer 1721, 134.
[218] Decomposed siliceous rock, or diatomaceous earth, (old name is rotten stone) which is still used even today as a polishing compound.
[219] Van Laer 1721, 135-136. This should not be confused with today's Amaril, which is an type of natural occurring corundum (aluminium oxide), magnetite, a magnetic oxide, hematite and quartz used for making abrasives, more commonly known as emery.
[220] Van Laer 1721, 136 and 140.

moulds. Even today goldsmiths still make use of this system although the sand is nowadays bonded with oil instead of water.

1.3.2 The early use of sand mould casting for the production of domestic wares[221]De

Published in the same year as Cellini's treatise, one can find another early depiction of flasks for sand mould casting, although this time not in connection with goldsmithing or medal casting. This publication is the *Panoplia omnium liberalium mechanicarum et sedentariarum artium genera continens*, published in Frankfurt am Main, Germany, in 1568, with text by Hans Sachs (1494-1576) and illustrations by Jost Amman. The entry for *Rotschmidt* illustrates a founder finishing a candlestick surrounded in his workshop by a display of his products (fig. 1.12).[222] These products can be roughly divided into hollow wares, such as jugs, ewers and dishes traditionally made by hammering and cast wares, such as candlesticks, spigots, chandeliers and horse statuettes.[223] The German and Latin text of Sach's book gives somewhat contradictory terms. The Latin text uses the term *conflator orichalceus* which can be safely translated as brass founder. The German title *Rotschmidt* is not so easy to translate. A *Rotschmidt* (or *Rothgiesser)*, literary red smith, is according to Johann Georg Krünitz (1728-1796) in his *Oekonomische Encyklopädie*, a craftsman who casts in loam whereas a *Gelb-Giesser* (yellow or brass founder) uses sand moulds for casting.[224] Perhaps the workshop illustrated by Amman was practising both crafts or maybe in the sixteenth century there was no clear distinction yet between the two terms. In the left corner of Amman's print are a number of metal flasks piled on the floor. These flasks were probably used to cast small parts, such as the spigot handle, candlestick and chandelier parts or the handles of ewers. The lack of detail of depicted tools, Amman omits for example the registration pins, suggests that Amman had no intimate knowledge of this type of metal working.

A few decades later, in 1632, a patent was awarded to the Dutchman Jacob Schot of Vianen (near Utrecht) for the casting of thimbles in sand moulds made from the earlier mentioned *Brussels sand.*[225] The Dutch know-how in using sand moulds for casting was 'exported' to England when John Lofting, running a thimble factory in Islington (near London) and known to employ Dutch workmen around 1693, was actively trying to recruit a Dutch founder the

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[221] Parts of this sub-chapter have been used for the following paper: Beentjes, Tonny. "Breaking the mould: A history of sand mould casting in Western Europe based on early written sources. " *Sources on art technology : back to basics : proceedings of the sixth symposium of the ICOM-CC Working Group for Art Technological Source Research,* Sigrid Eyb-Green, Joyce H. Townsend, Kathrin Pilz, Stefanos Kroustallis and Idelette van Leeuwen (Eds.). London: Archetype Publications (2016): 79-87.

[222] With the illustration comes the following text: '*Bildwerck / Wappen / ich gossen hab /, Auff mannig köstlich Fürsten Grab /, Artlich Leuchter / so stehn vnd hangn /, In Kirchen vnd auff dem Sal brangn /, Räuchfesser vnd die Messing Sprützn /, Die man thut in den Brünsten nützen /, Mörser / Leimtigl vnd Schüssel Ring /, Pippen / Laßköff / vnd ander ding.'* see Sachs 1568, np.

[223] It is unlikely, though not impossible, that the horse statuette was cast in a sand mould. Because *Rotschmiede* are traditionally associated with casting in loam it is more likely the horse statuette was lost wax cast using loam moulds

[224] Krünitz, J. G. *Oekonomische Encyklopädie.* J. Pauli [etc.] volume 16 (1773-1858) 737.

[225] Boon, H.F. and C.H. Langedijk. *Vingerhoedmakers en hun bedrijven in de tijd van de Republiek,* Diss. University of Amsterdam (2008): 68-69. <http://dare.uva.nl/record/274014,> [accessed 22 June 2018]

following year to work for his factory to produce cast brass thimbles.[226] This export of crafts knowledge, by Dutch workers working abroad, was a frequent occurrence in the Dutch Republic at the end of the seventeenth century.[227] The Islington factory sourced their casting

Fig. 1.16. Jost Amman, *Der Rotschmidt*, 1568. A woodcut illustration of a brass founder. From Hans Sachs, *Panoplia omnium liberalium mechanicarum et sedentariarum artium genera continens*, Sigmund Feierabend, 1568. On the right a detail of the metal flasks used for sand mould casting.

sand from nearby Highgate and this sand was first mixed, before use, with red ochre to improve its properties.[228]Boon & Langedijk mention that even the addition of the red ochre still did not produce sand of the quality used in Holland and the casting process of the brass thimbles had to be slightly adapted.[229]

Although the addition of iron oxide does improve the moulding and casting properties of the sand, it decreases the cracking of the mould, the moulders of the Islington factory should actually have added, in my opinion, clay or clay water instead to improve the bonding properties of the sand.[230] Because the sand from Highgate did not stick well enough, a brass

[226] Boon and Langedijk 2008, 73-74.
[227] Boon and Langedijk 2008, 73.
[228] Holmes, E. "A forgotten Buckinghamshire Industry: Thimble Making at Marlow." *Records of Buckinghamshire* 35 (for 1993), June (1995): 2. Highgate sand must have been the main source for moulding sand at the time because William Salmon advocates its use (mixed with some bole) for sand mould casting in 1672, see Salmon, William. *Polygraphice : or the art of drawing…*, Jones (1672): 256. Salmon gives in his Polygraphice a comprehensive account of bi-valve sand mould casting, detailing the sands, tools and moulding.
[229] Boon and Langedijk 2008, 76.
[230] The addition of iron filings or iron oxide to refractory moulds is quite common with both Biringuccio and Piemontese advocating its use. Iron oxide is still in use in modern foundry work as an additive to prevent cracking of the mould, see Baker, S.G. and J.M. Werling, J.M. "Expansion Control Method for Sand Cores." *AFS Transactions*. 2003.

nail was inserted in this core as reinforcement, to prevent the part of the mould that would form the inside of the thimble from breaking off.[231] In addition to this, I think the nail head acted also as a spacer (chaplet) to keep the core at the right distance from the outer mould. With the better qualities of the *Brusselse aarde* there was no need in the Dutch production process to reinforce the mould with nails although there are references of *Brusselse aarde* being mixed with other sands such as yellow French sand supplied from Rouen to improve its properties.[232] This mixing of two different kinds of moulding sands was often done to manipulate the clay content of the sand.[233]

The use of sand mould casting changed the thimble industry during the course of the seventeenth century. Previously thimbles were made from sheet and soldered together which was a more labour-intensive method making them more expensive to produce than cast thimbles.[234] By moulding and casting the thimbles in a bi-valve sand mould more thimbles could be produced in less time with less people. This enabled the thimble producers that used sand mould casting to produce thimbles in very large quantities: Lofting had a yearly production of up two million cast thimbles![235]

At the end of the seventeenth century sand moulds were starting to be used for the production of other domestic products such as copper alloy cauldrons and skillets.[236] Previously these cooking vessels were made using baked loam moulds or with lost wax casting.[237]
In 1703, Abraham Darby (1678-1717) set up a foundry in Cheese lane in Bristol to produce cast-iron pots, though without success. The next year he travelled to Germany, probably to Stolberg in the Rhineland, where he observed the industrial techniques of coal fired furnaces and the production of large brass pots.[238] He persuaded a number of brass workers to come over to Bristol to work for him in another of his enterprises, the Baptist Mill Bristol Brass Works.[239] These new German workers were skilled in hammering brass hollow ware using trip hammers, these hammered wares are called battery ware. Though they might have had knowledge of casting brass pots in sand they proved unable to help Darby to cast iron pots in

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[231] "every core having a nail with a broad head in it, which head keeps it from the mould, and makes the hollow to cast it in." see Holmes, E. F. "Sewing thimbles" *The journal of the tool and trade history society, Tools and Trades* 4, September (1987): 59-72. Holmes quotes from Houghton, John. *A Collection, of Letters for Improvement of Husbandry and Trade*, Bradly, 1727-28.
[232] Boon and Langedijk 2008, 69.
[233] The Barbedienne foundry in Paris would keep two kinds of sand from Fontenay-aux-Roses: one being of a deep brown colour, and very loamy; the other a very light yellowish-white, with more yellow particles and these would be mixed for specific types of work, see Anonymous. "Bronze Foundries" *The Brooklyn Daily Eagle* (Brooklyn New York) 9 September (1869) Thursday page 4.
[234] Boon and Langedijk 2008, 70.
[235] Boon and Langedijk 2008, 77.
[236] Butler, R. and C. Green. *English Bronze Cooking Vessels & their Founders 1350-1830*. Roderick and Valentine Butler (2003): 27-28.
[237] For a detailed description of the loam moulding and casting process, see Butler and Green 22-27.
[238] Stephens, R. "A Short History of Baptist Mills Brass Works Part One: The Early Years, 1700 – 1720" *Living Easton Web Site*, nd, <http://www.cems.uwe.ac.uk/~rstephen/livingeaston/local_history/brass1.html> [accessed 26 November 2016]
[239] Darby is partner in this together with fellow Quakers Edward Lloyd, John Andrews and Arthur Thomas, see Cox, N. "Imagination and Innovation of an Industrial Pioneer: the First Abraham Darby." *Industrial Archaeology Review*, XII, 2, Spring (1990): 128.

the same way. Darby continued to experiment himself and, together with fellow English founder Roger Downes and his own apprentice John Thomas. If we may believe the English sources, it was by perseverance, that they and not the German workers finally managed to cast iron pots successfully in sand.[240] They used for this a mould of fine moist sand consisting of a two-part flask, with air holes for the escape of steam generated by the hot metal coming in contact with the moist sand.[241]

Whether this historic account is accurate is debatable; time might have added a chauvinistic twist to the tale. However, from the description it can be concluded that green sand moulding in a two-part mould must have been practised. Darby's method must have worked, because he became a very successful iron founder (*iron master*) from then onwards and is credited with laying the foundations of Britain's cast iron industry.
As a reward for his trials, a patent was granted on the eighteenth of April 1707 to Darby for the casting of cast iron bellied pots in sand. This patent, no. 380, contains the following description:

> … a new way of casting iron bellied pots, and other iron bellied ware in sand only, without loam or clay, by which iron pots, and other ware may be cast fine and with more ease and expedition than they can be by the way commonly used[in loam or clay moulds], and in regards to their cheapness may be of great advantage to the poor of this our kingdome, who for the most part use such ware, and in all probability will prevent the merchants off England going to foreign markets for such ware, from whence great quantities are imported...[242]

Unfortunately, the patent does not provide us with images of the founding of iron bellied pots in sand. Even Réaumur (1683-1757), who wrote extensively on iron founding in 1722, does not illustrate the casting of pots.[243] In fact he does not cover the technique of casting pots at all, probably because iron founding in France during the first half of the eighteenth century was not so well advanced as in Britain. Despite the fact that the sand mould casting of iron was first introduced by Darby in England in the early eighteenth century, Abraham Rees(1743-1825) still described the casting of iron cauldrons in loam moulds in 1806.[244]
Réaumur's major work on iron and steel, *L' Art de convertir le fer forgé en acier et l'art d'adoucir le fer fondu*, does however, contain an interesting illustration of iron casting in progress (fig. 1.17). This illustration is the earliest depiction of iron founding in flasks containing sand moulds.[245] In addition to this, one can find on this plate in the lower right

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[240] Cox 1990, 129.
[241] Knight, E. H. *Knight's Mechanical Dictionary*. Hurd and Houghton (1877): 499.
[242] Tyler, J. D. "Technological Development: agent of change in style and form of domestic iron castings." *Technological Innovation and the Decorative Arts*, Ian M.G. Quimby and Polly Anne Earl (Ed), Winterthur Conference Report 1973, The Henry Francis du Pont Winterthur Museum (1974): 145.
[243] Réaumur, 1722.
[244] See the entry *casting* in Rees, Abraham. *The Cyclopædia; or, Universal Dictionary of Arts, Sciences, and Literature*. Longman. (1802-1820) The entry *casting* dates from 1806.
[245] The original French term used here and in general, *chassis,* is translated into flask. Although Anneliese Grünhaldt Sisco uses the term frame, the correct foundry term, flask, is preferred and generally used in English

corner a very early depiction of an unfinished casting with the gating system still attached. The runners show a branched configuration from a main sprue diverging into smaller runners, hence the name "casting tree" for this type of casting.

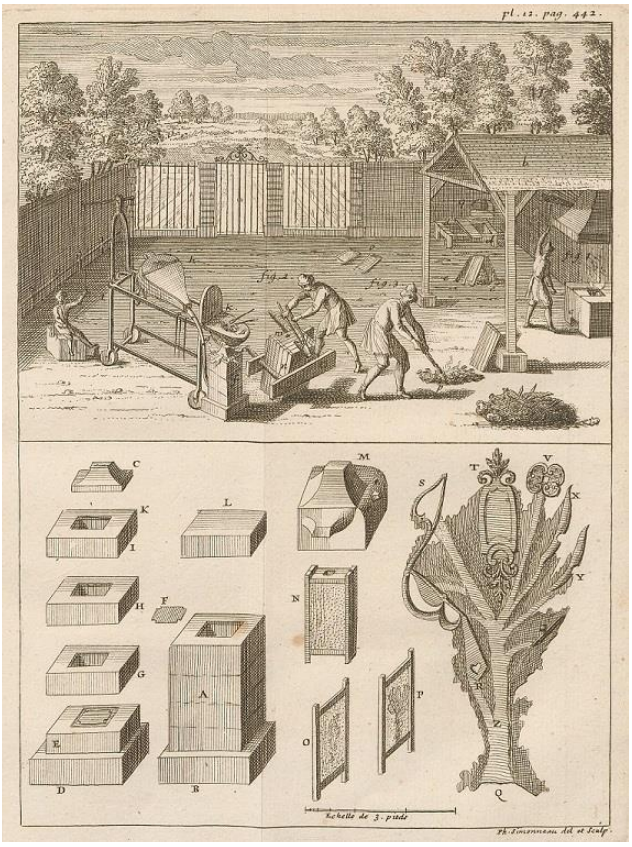

Fig. 1.17. René-Antoine Ferchault de Réaumur, Paris, 1722. Engraving illustrating iron casting in simple bi-valve sand moulds. The moulding sand is held in flasks clamped in a press. Plate 12 from Réaumur, René-Antoine Ferchault de, *L' Art de convertir le fer forgé en acier et l'art d'adoucir le fer fondu, ou de faire des ouvrages de fer fondu aussi finis que de fer forge*, 1722, 442.

Réaumur recommends to heat the entire sand mould, firstly to render the mould very dry and secondly to improve the fluidity of the molten iron poured inside the mould and thus improving the casting. Because Réaumur's foundry men use wooden flasks, they are forced to keep heating to a minimum and he therefore recommends replacing the wooden flasks by iron flasks to enable to heat the moulds at higher temperatures.[246]

Réaumur was a strong believer in the versatility of cast iron and he had good foresight when he predicted that:

> In the future it will be possible to make cast-iron stoves good enough to heat those apartments… The large urns which beautify the flower beds in our gardens will be

technical foundry literature, see Réaumur, R. A. F. de, C. S. Smith, and A. Grunhaldt Sisco. *Réaumur's Memoirs on steel and iron: a translation from the original printed in 1722*. Chicago university press, 1956.

[246] Réaumur 1722, 434-435.

made of cast iron and will have the same graceful shapes as those made of bronze… Finally we shall be able to cast in iron an endless number of statues and busts.[247]

Although Réaumur's prediction was correct, it probably took longer than he initially might have envisaged. The cast-iron stoves were indeed, soon after Réaumur's publication of 1722, produced in large numbers. These stoves were built from flat cast iron plates, which could be cast in simple two-part moulds or even open moulds. The more three-dimensional objects, such as the garden urns and statuary, required more complex moulds and were therefore only produced in large quantities in the nineteenth century. Having said this, Réaumur gives a tantalising description of a cast-iron horse statuette in Louis XV's cabinet at Versailles and foresees this statuette will: "soon no longer be one of the objects, which owe their rarity to the material of which they are made."[248] Again, as with the horse statuette illustrated by Amman in 1568 (fig. 1.16) it is unlikely though not impossible that the horse statuette was cast in a sand mould. It is more likely the cast iron statuette was a lost wax casting in loam since plaster moulds cannot withstand the high temperature of around 1450°C at which cast iron is poured into the mould.[249]

Moving on further in the eighteenth century, the first depiction appeared of the founding of iron pots in sand moulds in the Diderot *Encyclopédie*'s chapter on iron founding, *Forges ou art du fer* (3rd section).[250] The casting of bellied iron pots was in the Diderot *Encyclopédie* still carried out with loam. Conical iron pots, however, are cast now with the use of sand moulds.[251] These conical pots were easier to cast than bellied pots because of the absence of undercuts and therefore did not necessitate the use of a pre-shaped core. To achieve this, the moulder made use of a clever system of three wooden flasks (fig. 1.18). The moulding of

[247] "On pourra avec le fer fondu faire à l'avenir des poeles…. Les grands vases à fleurs , don't on pare les Parterres , auront en fer , les forms les plus gracieuses, comme en bronze , & pourront être aussi bien reparés. Enfin on pourra mouler en fer une infinite de statues, de bustes." ; Réaumur 1722, 550-551. Translation Réaumur 1956, 354.

[248] "Le petit cheval de fer fondu qui est dans le cabinet Sa Majesté à Versailles, ne sera plus au nombre des ouvrages rares par leur matiere." see Réaumur 1722, 551. Hassenfratz mentions, in 1812, that this small cast iron horse was collected during the seventeenth century, "On voyait, du temps de Réaumur, dans le cabinet du Roi, a Versailles, un petit cheval de fer fondu que l'ont plaçait au rang des objects rares, conserves dans le dix-septième siècle." see Hassenfratz. *La sidérotechnie, ou l'art de traiter les minérais de fer pour en obtenir de la fonte, du fer, ou de l'acier*, Volume II, Firmin-Didot (1812): 251. This iron horse does not longer exists. Personal communication with Genevieve Bresc-Bautier, former head curator of sculpture at the Louvre.

[249] For a description of the lost wax moulding and casting in loam of cast iron statues see the chapter; *Vom Gießen der Statuen* in Tiemann, W. A. *Abhandlung über die Förmerei und Giesserei auf Eisenhütten : ein Beitrag zur Eisenhüttenkunde*, Raspesche Buchhandlung (1803): 78-85.

[250] Forges ou art du Fer. Troisieme section. *Encyclopédie ou Dictionnaire raisonné des sciences, des arts et des métiers,* edited by Denis Diderot and till 1759, co-edited by Jean le Rond d'Alembert. Vol. 4, plates, 1765, author of this entry is probably Étienne Jean Bouchu (1714-1773). For convenience, references to this work will be henceforth abbreviated to Diderot *Encyclopédie*. The text accompanying these plates can be found online: http://portail.atilf.fr/cgi-bin/getobject_?a.139:33./var/artfla/encyclopedie/textdata/image/ > [acc. 22-6-2018]

[251] Eight years later the l'Académie royale des sciences in Paris published another description of the casting of iron pots in loam and sand, by Étienne Jean Bouchu (1714-1773). Although more detailed, it still described a process not much different from the Diderot descriptions which accounts for the attribution of the Diderot section on iron to Bouchy. See De Courtivron, le Marquis and É. J. Bouchu. "Des fontes moulées [quatrieme partie]," Tome II. Les quatre premières sections sur les fers, *Descriptions des arts et métiers*, ed. Bertrand, J. et al, 1774. An online version can be found at: http://cnum.cnam.fr/CGI/redir.cgi?4KY58.2 > [acc. 22 June 2018]

these larger household items was distinctly different from the bi-valve flask system as used by silversmiths, medal casters and founders of other low relief items such as furniture mounts. The smaller patterns mould with the bi-valve flask system could be simply pressed in the sand, this was not possible with more voluminous items such as hollowware. To mould these bulkier items the sand was applied and compacted against the pattern instead.[252]

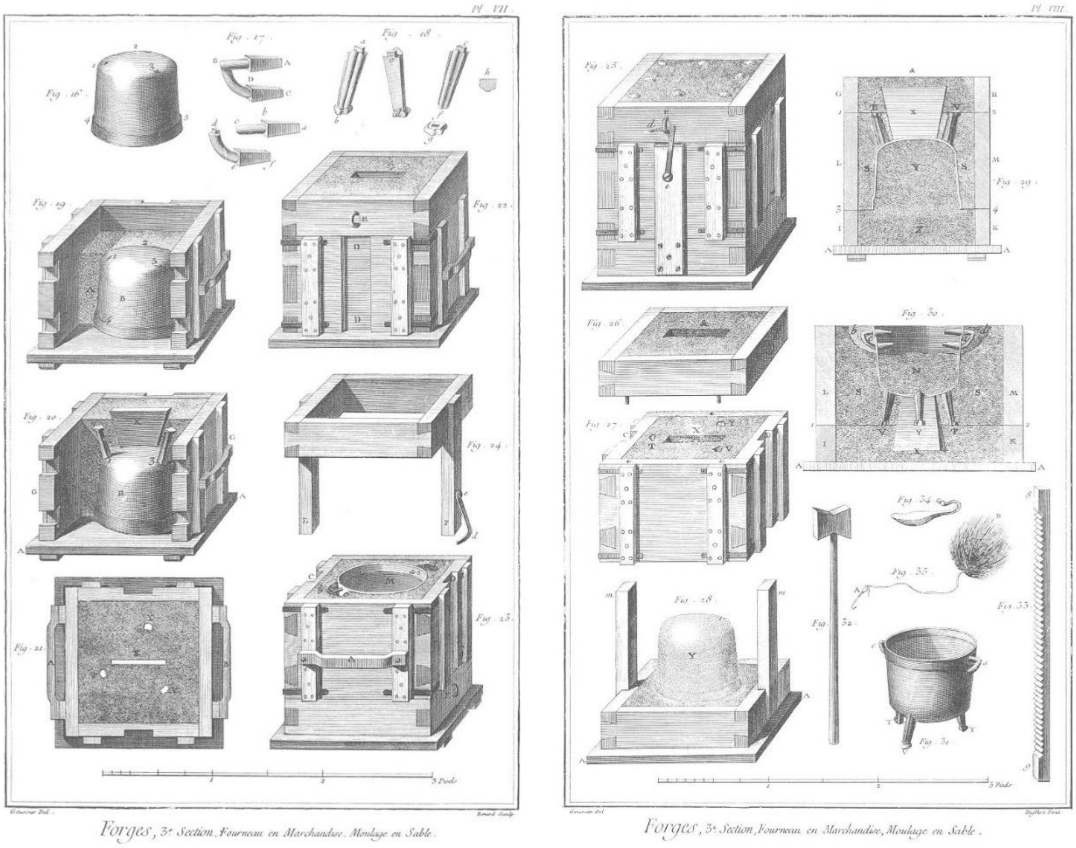

Fig. 1.18. Engraved plates VII & VIII from *Moulage en sable*. Forges ou art du Fer. Troisieme section; Denis Diderot, *Encyclopédie ou Dictionnaire raisonné des sciences, des arts et des métiers,* Vol. 4, plates, 1765

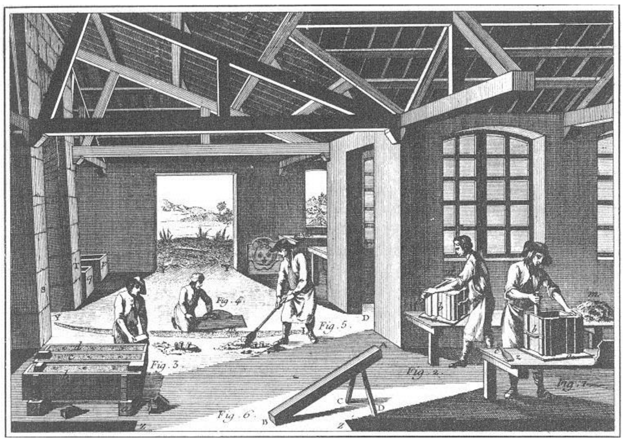

Fig. 1.19. Detail of plate V, Moulage *en sable*. Forges ou art du Fer. Troisieme section; Denis Diderot; *Encyclopédie ou Dictionnaire raisonné des sciences, des arts et des métiers,* Vol. 4, plates, 1765

[252] The larger items with high relief such as certain furniture mounts, larger medals and plaquettes and fire-backs were already moulded by pressing sand against the pattern and not by pressing the pattern in the sand.

Figure 1.19 illustrates the interior of an iron foundry with on the right two moulders filling the box or flask with sand, with the worker on the extreme right (fig. 1.19 plate V, fig.1) compacting sand with a rammer. In the background another moulder is pressing a wooden pattern in the sand of the foundry floor (fig. 1.19 plate V, fig.4). Although the description of the plate does not give us much information about this object, the contours of a fire back are discernible, the type of object that more or less started sand mould casting three hundred years earlier.[253]

1.3.3 First evidence for piece-moulding in sand[254]

The use of more than two flasks to build up the sand mould shows that the sand mould founders were by the middle of the eighteenth century developing more complex forms of sand mould casting to make it possible to mould and cast intricately shaped objects. Because sand moulds are rigid, patterns with an overhanging detail, so-called undercuts, are problematic to mould. This is because the pattern with sand mould casting, in contrary to lost wax casting, needs to be removed from the mould intact and also without damaging the sand mould. To solve this problem the moulders working in sand in the eighteenth century had basically two options: to divide the pattern in sections so this could be removed in parts or to make up a mould in sections also removable in parts, a so-called piece mould.
The sub-chapter *Fondeur en Sable* from the chapter "*Fonte de l'or, de l'argent et du cuivre*", from Diderot's *Encyclopédie* from 1767, illustrates and describes both approaches when it covers the casting of a pulley wheel (fig. 1.20).[255]

The outer rim of the pulley wheel has a half round groove to guide a rope and when the pulley wheel would be mould in the standard two-part sand mould this overhanging groove would be impossible to reproduce. The moulder, in his attempt to mould the pulley wheel, would also pack the sand into the groove. When removing the pattern, he would tear away the overhanging sand inside the groove from the rest of the mould and thus damage the carefully crafted mould. By using a pattern that was split, lengthwise in the middle (fig. 1.20 pl. V: no. 40.) and using not two but four flasks (fig. 1.20 pl. V: no..51), the moulder could avoid the undercut problems. When using more than two flasks, the intermediate flasks positioned between the cope and drag, are called cheeks.[256]

[253] For the complete chapter and other chapters from the Diderot *Encyclopédie* online: http://portail.atilf.fr/cgi-bin/getobject_?a.139:33./var/artfla/encyclopedie/textdata/image/ > [acc. 22-6-2018]
[254] Parts of this sub-chapter have been used for the following paper: Beentjes 2016, 79-87.
[255] *Encyclopédie ou Dictionnaire raisonné des sciences, des arts et des métiers,* edited by Denis Diderot and till 1759, co-edited by Jean le Rond d'Alembert. Vol. 5, plates , 1767, the author of this entry is not known.
[256] Tate and Stone 1904, 74.

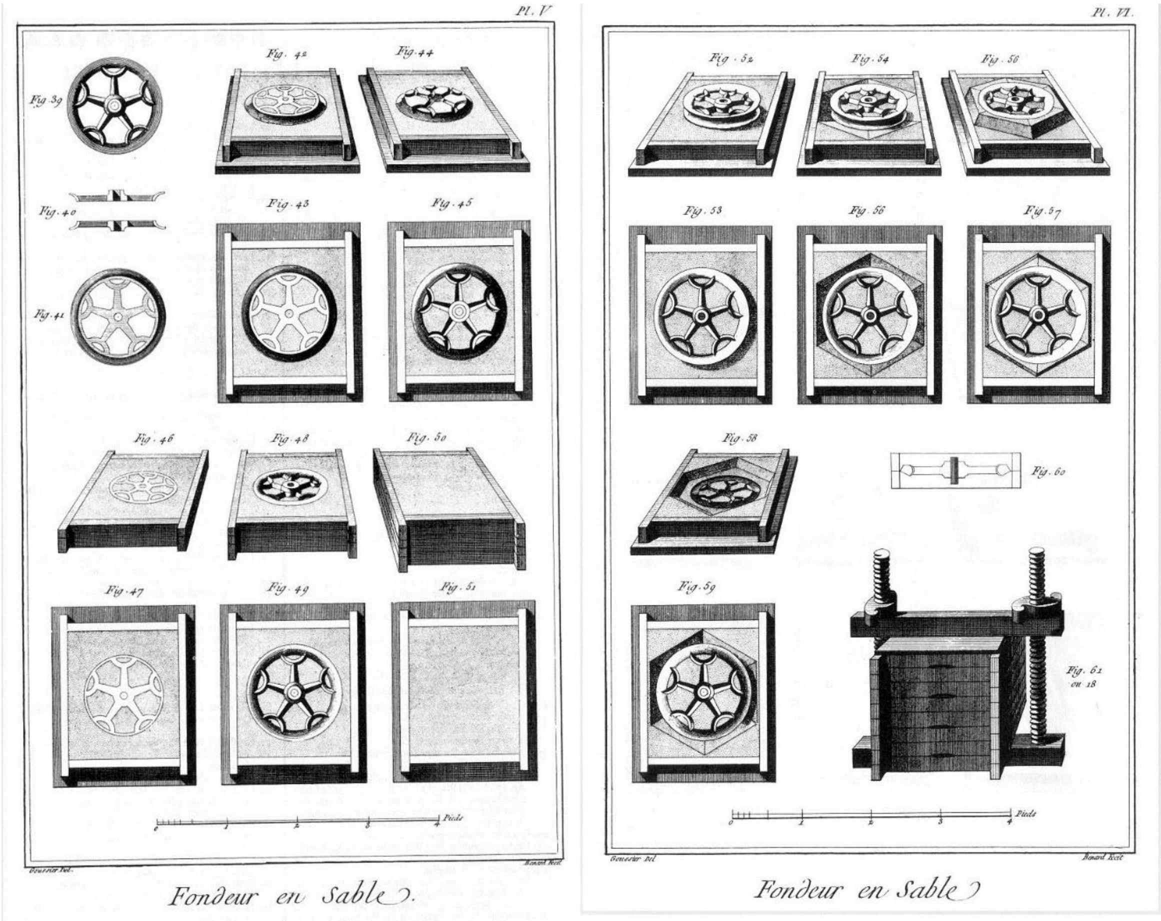

Fig. 1.20. Engraved plates V & VI, Fondeur en Sable, from “Fonte de l'or, de l'argent et du cuivre"; Denis Diderot; *Encyclopédie ou Dictionnaire raisonné des sciences, des arts et des métiers,* vol. 5, plates, 1767

A more sophisticated, though more difficult, solution to the moulding in sand of an undercut pattern is illustrated in fig. 1.20 plate VI. This moulding technique avoids using a split pattern by using extra mould pieces called *false cores* which can be removed separately. According to Byrne the brass founders called every loose piece of the mould, not intended for holes, a *false core.* Iron founders used often the term *drawback* instead of false core.[257] The term *false* was used to distinguish these external mould pieces from the internal core used to create a cavity inside the casting, sometimes referred to as the true or real core.[258] False cores are made from the same sand as the rest of the mould. These mould pieces are created by compacting locally sand around the pattern using tools called rammers (fig. 1.17).[259]

The sides of these false cores not facing the pattern are smoothly and geometrically shaped, without undercuts, to facilitate removal from the pattern and re-assembly to form the piece mould. The Diderot *Encyclopédie* does not mention a parting compound in the accompanying text. The use of a parting compound, such as graphite or charcoal powder, is essential to prevent false cores from sticking to the rest of the mould.

[257] Byrne, O. *Practical Metal-Worker’s Assistant*, Henry Carey Baird (1851): 150.
[258] See Overman 1881, 266-267.
[259] Sub-chapter 4.2.3 *False-cores* in this thesis will go deeper into the making of false cores.

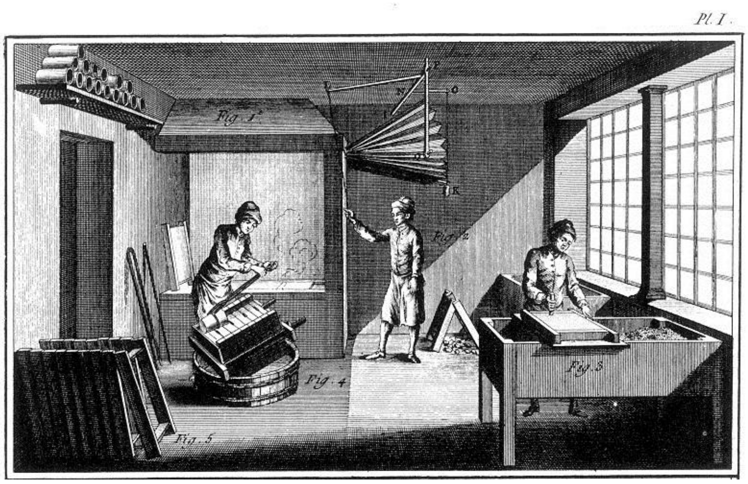

Fig. 1.21. Detail of plate I, Fondeur en Sable from "Fonte de l'or, de l'argent et du cuivre"; Denis Diderot, *Encyclopédie ou Dictionnaire raisonné des sciences, des arts et des métiers,* vol. 5, plates, Paris, 1767

The illustration and description of false cores in the Diderot *Encyclopédie* is a pivotal moment in the history of sand mould casting. It is the earliest documented evidence of the use of sand piece-moulding I was able to find and this thesis is the first time it is presented as such. The Diderot *Encyclopédie* section on the casting of bronze sculpture does not describe the use of piece-moulding in sand and there is no evidence yet that sculpture was cast using the sand piece-moulding technique during the time of the Diderot *Encyclopédie.*[260]

At some point, a moulder working in sand, must have discovered how to make pieces of compacted moulding sand against the pattern without the support of a flask. Because this has, up till now, never been seen as an 'invention', nothing is known of who first developed this and where. France is an option, because of the description by Diderot, although it could also have been Britain with its large sand mould founding industry. There is no textual evidence for the use of false-cores in Britain in the eighteenth century although this does not imply false-cores were not used. The wealth of information given in Réaumur's publications, the Diderot *Encyclopédie* and their successors could give the impression that France was more advanced in foundry work. This is not necessarily correct; the lack of technological source material from England in the eighteenth century does not rule out that foundry work in Britain was equal if not more advanced than in France. No English equivalent of Diderot or Réaumur was published during the eighteenth century and therefore one has to look at other documentary sources such as patents. Darby's patent of 1707 discussed earlier is an early example of this and later in the eighteenth century another patent detailing sand moulding was awarded to Isaac Wilkinson.
This patent (No.723) was granted on April 21st 1758 to Isaac Wilkinson of Bersham Furnace, in the Parish of Wrexham, in the County of Denbigh for;

> A new method or invention for casting of Guns or Cannon, Fire Engines Cylinders, Pipes, and Sugar Rolls, and other such like Instruments in dry sand in Iron Boxes

[260] For more detailed information on the piece-mould casting of sculpture see also chapters 2 and 4 in this thesis.

> made for that purpose; whereby the said Guns or Cannon, Fire Engines Cylinders etc., will be made and cast in a much more neat, complete, exact and useful, as well as cheap and expeditious manner than any method hitherto known and made use of.[261]

Wilkinson's patent for an improved way of casting in sand moulds hollow cylindrical castings proved later in combination with his son John's (1728-1808) invention of an accurate boring machine, around 1775, to be instrumental in the success of Watt and Boulton's steam engine.[262] The other product that could be cast with his new method were cannon and interestingly the marquis of Montalembert also claims in the same year, 1758, to have invented the casting of iron cannon in sand in his foundry in the Perigord in France.[263] Whether the simultaneous 'invention' of the casting of cannon in sand was merely a serendipitous event remains to be researched. The founding of cannon is important to mention here because innovations in gun founding by using sand moulds were to be instrumental in the development of the founding of sculpture in sand moulds.

Advances in military technology often find their way into manufacture of non-military goods and the advancement of sand mould casting is such an example. In 1794, a few years into the French Revolution, foundries were ordered to help to re-arm the weakened defence forces of the fragile new republic.[264] Neighbouring forces were amassing to invade France in order to reinstate the old regime and there was a real shortage of good cannon to defend France. Using the conventional methods for casting cannon with loam moulds would have taken too long and would have been too costly. A group of foundry engineers under the direction of Gaspard Monge (1746-1818) had already been working on perfecting the sand mould casting technique for the casting of cannon and were asked to develop a cost effective and fast way of doing so.[265] Then, in the second year of the new revolutionary calendar (1793/'94), Monge published his treatise on the casting of cannon with a chapter on the use of sand moulds.[266] In this treatise Monge introduces his innovative technique of segmented flasks.

Although the casting of cannon in sand moulds was already mentioned in 1758 both by Wilkinson and Montalembert, it is however, not clear from Wilkinson's patent description whether he also used a segmented flask system. Wilkinson's patent mentions only the use of iron flasks whereas Montalembert does not mention flasks at all. Monge advocates using iron flasks, open from the sides where sand is rammed very tight into the space between the pattern and the flask. The thickness of the layer of sand is about two pouches (c. 54 mm).[267] Soot is recommended as a parting compound, between the pattern and the sand and between the false cores, similar to the previously described treatises. The patterns are then removed

[261] Davis, R. *John Wilkinson - Ironmaster Extraordinary*. The Dulston Press (1987): 9.
[262] Wickam Roe, J. *English and American Tool Builders*, McGraw-Hill (1926): 3. Boring is the process of enlarging, and making more precise, an existing hole such as drill or casting hole.
[263] Montalembert, M. de. *Mémoire historique sur la fonte des canons de fer*, de Grange (1758): 94.
[264] Lebon 2012, 15-19
[265] Lebon 2012, 15-19.
[266] Monge. G. *Description de l'art de fabriquer les canons*. L'Imprimerie du Comité de Salut Public (1793-94): 67-78 (*Du moulage en sable*)
[267] A *pouche* is a twelfth part of a foot, approximately 27.07 mm

and all the flasks, containing the sand moulds, are bolted together to make up the complete cannon mould (figs. 1.22 & 1.23).[268]

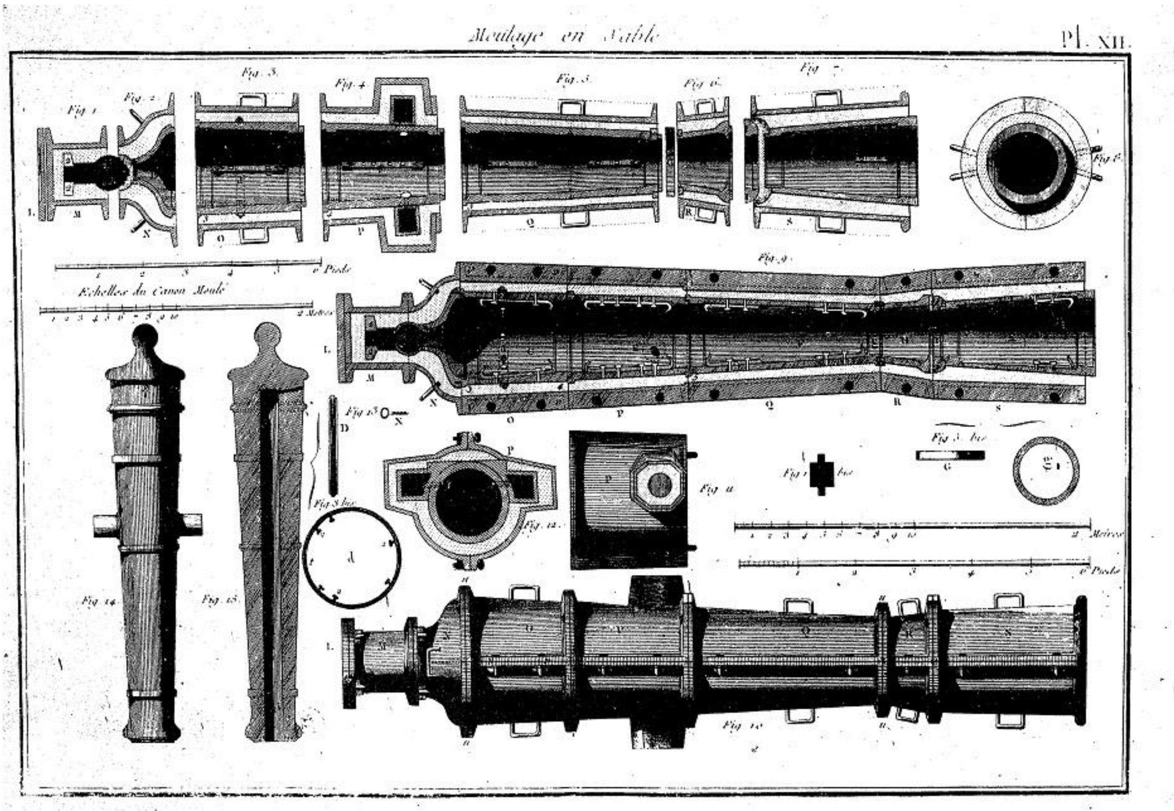

Fig. 1.22. Engraved plate XIII from Monge's treatise on gun founding. Illustrating the assembly of flasks to form the complete cannon mould from Gaspar Monge; *Description de l'art de fabriquer les canons*. Paris: L'Imprimerie du Comité de Salut Public, 1793-94

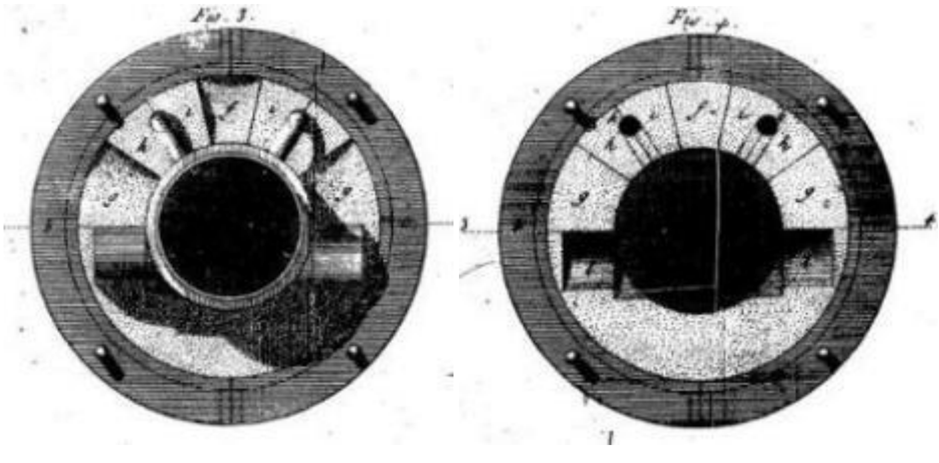

Fig. 1.23. Detail from plate XIII *Moulage en Sable* from Monge's treatise on gun founding, illustrating a cross section of cannon mould showing the use of piece-moulding with false cores. This enabled the moulding of the handles and trunnions of the cannon using sand moulds: Monge 1793-94.

[268] Patterns made of iron or copper alloys (*cuivre*), Monge prefers the latter because they give a smoother result according to the author. See Monge 1793, 67. This could have had several reasons: the iron patterns were perhaps from cast iron which is often porous and the iron pattern had probably a light surface corrosion or a coating.

Monge discusses the requirements of the sand in somewhat more in detail than Diderot. The treatise mentions the fact that nature rarely provides the perfect sand for moulding, nevertheless after recognizing the qualities the moulding sand must have, the author mentions is not difficult to compose one that satisfies.[269] Monge points out that it is important to choose a sand that does not melt when exposed to the high temperatures of cast iron, this to avoid vitrification of the sand surface causing porosity in the casting and would thus spoil the cannon.[270] The sand should also not be too earthy and pure with quite rough and angular sand grains because if too rounded this would not bind and compact well. Monge recommends using quartz sand, angular, with big grains, moistened with clay water. To test the right amount of clay in the mixture, the following test is recommended; "when one takes a handful of mixed sand when it is still wet [moist], and squeezes this in one's hand, and then opens the hand, the sand mass does not lose its shape given by the compression."[271]

The author also mentions that the sand can be used many times as long as it is moistened with the clay water again and in the absence of sand, one could use sieved grog, provided that it can withstand the heat of the metal and it is mixed with the clay water.[272] Monge was subsequently asked in 1794 by the revolutionary committee to set up an emergency programme for travelling instructors, to train foundry men in the new technique of casting cannon in sand.[273] This programme turned out to be very effective and huge amounts of cannon were cast in bronze in a time span previously deemed impossible.

Although Monge's new system of casting cannon in sand was adapted successfully and made it possible to produce large numbers of cannon in a short period of time, it did produce often porosity in the cast cannon. Omer Constant Joseph Dussaussoy (1778-1846), *chef de Bataillon*, in the Royal Artillerie, blames this on compacting the sand too much and the non-permeability of the flasks. In 1817 he published an improved system using perforated flasks and advocates to compact the sand only partially.[274]

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[269] Monge 1793, 72.
[270] Ibid 73.
[271] Ibid 73. (translation author)
[272] Monge uses the term *ciment* which in this context can be best translated as grog or chamotte, a high fired and roughly ground ceramic filler with a high percentage of silica and alumina. ibid 73.
[273] Lebon 2012, 16.
[274] Dussaussoy, O.C.J. "Du Résultat des Expériences faites sur les Alliages de cuivre, d'étain, de zinc et de fer considérés sous le rapport de la fabrication des bouches à feu et autres objets semblables." *Annales de chimie et de physique*, Volume 5, Crochard (1817) 225-234.

1.4 The role of sand mould casting in the technical revolution of early modern Europe

After this overview of the historical development of the use of sand as a moulding material, an attempt can be made now to place sand mould casting in the wider context of historical technological developments. Casting as an historical art-technological technique is by its very nature, requiring a pattern and/or mould, a means of reproduction and not a way to create original works of art. Its role could therefore be labelled as secondary which seems also to reflect its place in the technical revolution of the early modern period. The early use of sand moulds for the casting of pig iron played a minor, albeit still essential, role in the development of the early cast iron industry of the late middle ages. It was really the innovation in the design of furnaces during this period that made it possible to produce cast iron in large quantities.[275] This first liquid iron was cast into pig iron, a half-product that was subsequently converted into wrought iron. Its second use, sometime later, was for the production of cast iron wares. Both these two products could of course be cast in another refractory material acting as a mould, for example stone or clay/loam. These materials, however, had some distinct disadvantages over sand: stone was very labour intensive to work and had the risk of cracking. Loam too, required a great deal more time to work and dry than sand.

Sand as a moulding material offered a cheap alternative, as a readily available material and in its use and ability to be re-used. These economic factors were most likely also instrumental in the choice for the use of sand by Renaissance founders. Both Leonardo da Vinci and Biringuccio praise sand mould casting for its speed and simplicity and devote relatively little attention and space to this technique in their writings compared to other forms of casting such as lost wax casting. Apart from making certain cast wares more affordable, sand mould casting did not contribute a great deal to the technical innovation of the Renaissance. Although Biringuccio mentions the casting of small bells and muskets in sand moulds, the majority of bell and guns cast in the sixteenth, seventeenth and eighteenth century, were made using alternative casting techniques. Founding has been, till the middle nineteenth century, a labour intensive, low tech, process, almost devoid of any machinery so typical of the Renaissance technical revolution.[276] The moulding process, whether in sand, plaster of loam, was performed by hand till the invention of sand moulding machines in the nineteenth century. The cranes used for manipulation were already in use in the middle ages. The only other piece of complicated equipment in the Renaissance foundry was the furnace which had its major developments, as the reverberatory furnace, also in the late middle ages.[277]

The role of sand mould casting in Renaissance art is more substantial. Cast metal as a medium for art, especially bronze, came to unprecedented heights during the Renaissance period. Monumental statuary, equestrian as well as funeral, statuettes, life-castings and medals were executed with great virtuosity. Of these, only the medals were regularly cast with sand moulds, the alternative technique being lost wax casting. There were several advantages for

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[275] Aitchison 1960, 342-343 & Tylecote, R.F. *A history of metallurgy*. Inst. of Materials (2002): 77
[276] Sawday. J. *Engines of the Imagination: Renaissance Culture and the Rise of the Machine*. Routledge, 2007.
[277] Tylecote 2002, 82-87.

using sand moulds for medal casting: first of all, it was fast and simple and therefore less expensive. Secondly the pattern could be re-used and this made it possible to change the reverse and obverse by using different patterns. Thirdly sand mould castings tend to distort much less then lost wax casts and stay therefore nicely flat. Lastly, sand mould casting made it possible to cast incuse-reverse medals, a type of medal whereby the reverse follows the relief of the obverse perfectly resulting in a negative image of the obverse relief on the reverse side of the medal (Fig. 1.24).[278]

Fig. 1.24. Adriaen Symonsz. Rottermont, Amsterdam or the Hague, 1622. Incuse-reverse cast silver medal of Maurits, prince of Oranje-Nassau. Ø 102,8 mm, Teylers Museum Haarlem, inv.no. TMNK 00411. (image Teylers Museum)

For the production of cast household wares, the seventeenth century witnessed a gradual shift from casting in baked loam moulds towards the use of sand moulds. Items as candlesticks, skillets and cauldrons could be produced much faster and more efficient in sand moulds. The skill of finely detailed sand mould casting, already demonstrated by the medal founders began now also to be applied increasingly for silverware and ormolu. French founders around 1700 especially, produced very high-quality casting most likely because of the availability of very good moulding sand from the Seine river beds such as the Fontenay-aux-Roses quarries. One can argue that these objects, silverware and ormolu, could all be reproduced with lost wax casting. Sand mould casting, in this period still basis bi-valve moulding, had however, some distinct advantages over lost wax casting. Some of these were discussed earlier such as less distortion when casting large flat items and fast and cost-effective production.

The other advantage of sand mould casting was the ease of use, availability and interchangeability of the patterns. The process of sand moulding required a sturdy pattern in a tough durable material that could withstand the forces applied to them during moulding. A pattern was therefore by its very nature an item that could be exchanged and transported with ease. The original models of these patterns were usually made in easy to carve finely grained materials, such as boxwood or soft stone, often the work of specialist pattern carvers

[278] Tuttle 1987, 205-212. Rozemarijn Landsman and Jonah Rowen wrote an excellent paper on the production of these incuse-reverse medals for the Making and Knowing project at Columbia University, NYC: *Concerning the Production of "One-sided Hollow" Cast Medals*, forthcoming; http://www.makingandknowing.org/

(*Bildschnitzers* or *Formschneider*). This unique master model was now used by pattern-casters (*Patronengießer*) to reproduce multiples in cast metal such as copper alloys, pewter or lead, turning it in a commodity that could be traded and exchanged.[279] These patterns, usually in the latest fashion, were often acquired by journeyman during their travelling years (*Wanderjahre*) and brought home to be used. Although other media, such as prints and wax models, were also used to transfer the latest style ornaments, these where not as durable and ready to use as these cast metal patterns. Even though sand mould casting made it possible to produce cast silverware and ormolu faster and thus cheaper, the intrinsic high value of silver or gilded copper-alloy meant that these items, during the seventeenth and eighteenth century, remained exclusive and were never produced in very large quantities. However, with more mundane items such as brass thimbles and bellied cast iron pots, sand mould casting did enable mass production of these sort of products. The mass production of these bellied iron pots in turn stimulated the production of coke iron in Britain.

In the eighteenth century there were basically two methods to produce pig iron, with charcoal as fuel and with coal (in the form of coke) as fuel. The charcoal pig iron was cheaper to produce till 1750 than coke pig iron. Charcoal pig iron however was less suitable than coke pig iron for thin walled castings. The higher temperatures at which coke pig iron was produced gave a higher silicon content than charcoal produced pig iron, making the coke pig iron more fluid during casting.[280] Abraham Darby of Coalbrookdale began to use, around 1707, this coke pig iron for the founding of his bellied cast iron pots in sand moulds. This more fluid coke pig iron in combination with sand as a moulding material, reduced the amount of possible casting defects, enabling Darby to produce much thinner pots, half the weight of iron pots of charcoal pig iron. Darby's cast iron pots were an economical success and allowed him to perfect the smelting and production of coke pig iron.[281] From 1750 onwards coke pig iron, in part due to Darby's innovations, became cheaper to produce than charcoal pig iron enabling Britain to produce iron much more economically. This cheaper coke iron (pig as well as bar iron) was instrumental for the industrial revolution in eighteenth century Britain.

The impact of sand mould casting on production of the more industrial items was considerably greater. Iron casting in sand especially was to be instrumental in the development of certain technological advancements. The iron founders in Britain, with their roots in the founding of iron cooking ware, developed means to cast accurately and economically large cylindrically shaped objects such as steam engine cylinders, guns and pipes. These products were going to change industry, warfare, water and sewage management. Other innovative cast iron products, all produced using sand moulds, such as stoves for heating and beams for construction were going to change the way people would build bridges and buildings.

[279] Hayward., J.F. *Virtuoso goldsmiths and the triumph of mannerism, 1540-1620*. Rizzoli International (1976): 60-61 & Seelig, L., et al. *Modell und Ausführung in der Metallkunst.* Bayerisches Nationalmuseum, 1989.
[280] Hyde, C. K. *Technological change and the British iron industry, 1700-1870*. Princeton University Press (1977): 40.
[281] Hyde 1977, 40-41.

1.5 Conclusion

Historical use of the sand mould casting technique has rarely been the focus of serious comprehensive study. This is partly due to the association of the technique with industrial casting processes and partly with the unfamiliarity with this technique. Considered an inferior technique only used for producing decorative and household items, sand mould casting played second fiddle to lost wax casting in appreciation and historical research. This chapter answers several questions why, where and when, the casting in sand moulds originated. The result of this research, is the first comprehensive overview of the historical technical development of sand moulding and casting.

The first part of this chapter looked at the nature of moulding sand. The special properties of this sand, small uniform rounded grain with a clay content of around 16-19%, gave this natural occurring sand superior moulding properties. Comparison between the grain-size distribution of nineteenth century moulding sand and sand from the last half of the twentieth century indicates a decline in moulding properties.

The effect of heat on the grain-size distribution was also investigated and demonstrated a change in the grain-size distribution as a result of the heat of the molten metal. A form of sintering could be observed in the sand in close proximity of the bronze, altering the clay content. This has implications for the interpretation of core analyses carried out in the past. The choice of analytical method also determines to a large extent the accuracy of the analysis of the grain-size distribution as was demonstrated by the comparison between the Getty Schmidtling clay and silica values from 2008 and the recent laser diffraction, carried out as part of this thesis.

Research into the earliest use of sand mould casting is hampered by the ephemeral nature of sand moulds which do not survive well in archaeological context or are not being recognised and identified as remnants of the sand mould casting method. The lack of archaeological evidence shifted the focus of this research to early descriptions or depictions of sand mould casting. The earliest firm evidence for sand mould casting in Western Europe dates from the late fifteenth century. Most of the early written references to sand mould casting are describing the casting of small, low relief objects such as precious and base metal seals, medals and plaquettes by goldsmiths and medal founders. Evidence prior to the middle of the sixteenth century is exclusively Italian including well known early written sources as Da Vinci, Piemontese and Cellini. The ‘sand’ in these descriptions is frequently powdered refractory material held together with organic binders although Da Vinci mentions real river sand and Cellini provides the first description of the use of moist clayey alluvial sand. From the middle of the sixteenth century depictions of goldsmith’s workshops illustrated casting flasks, an essential tool in the sand mould casting process. The use of sand moulds for casting is a general accepted practice amongst goldsmiths and medal founders in Europe, with evidence from Italy, France, Germany and the Low Countries.

Apart from goldsmiths and medal founders, other professions were also making use of sand as a moulding material. From the end of the seventeenth century sand moulds were beginning to be used for the production of other more domestic products such as copper alloy cauldrons and skillets. Previously these cooking vessels were made using loam moulds or with lost wax casting. Some of the foundry knowledge was transferred from the Low Countries and Germany to Britain where sand moulding was also applied to cast iron wares. The founding of hollowware required more complex moulding techniques than the simple two-part moulding as practised by goldsmiths and medal founders. The complex shapes of hollowware and other undercut objects such as pulleys could only be moulded by making moulds made up of more than two mould parts. The first pictorial evidence for the use of these so-called piece-moulds can be found in the eighteenth-century Diderot Encyclopédie in the section on the founding of pulleys. The sand used for sand piece-moulding came from the Parisian suburb Fontenay-aux Roses and had unique properties. These properties were its uniform grain size and shape, with each spherical sand grain covered with a thin layer of clay. Benvenuto Cellini described using a moist argillaceous sand from the river Seine in Paris and Réaumur already mentioned in 1722 the well-established practice of Parisian founders using Fontenay sand. France has a long tradition of high quality cast metalwork. Whereas similar objects in other countries were often wrought, in France these were usually cast. Other artisans making use of sand moulds were the cannon founders. Although sand moulds for gun founding had seen some limited use in England and France around the middle of the eighteenth century, the aftermath of the French revolution brought the sand moulding of cannon to full development. Complex piece-moulds were developed and applied by a new generation of sand moulders who were going to be instrumental in the development of the sand moulding of sculpture.