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Master thesis

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Chapter 1: Introduction

In 1985, divers first discovered the ship now known as the Burgzand Noord 2 (BZN2), near the island Texel. They brought up multiple bronze cannons from the 16th century with texts indicating a Polish origin. The ship is therefore not only known as the BZN2, but also as the Polish cannon wreck (Vos, 2012, p. 111). In the years 2000 and 2001, official archaeological research of the wreck took place and more artefacts of the ship were brought to the surface. Currently, the ship is still in the same location in the Waddenzee under physical protection. However, many of its artefacts are being housed in the maritime depot of Museum Batavialand in Lelystad. This thesis will discuss literary research and will further expand on the ceramic artefacts, specifically their blue pigmented glazes, using results of X-ray fluorescence (XRF) testing.

1.1. Research questions

For this thesis, the main research question is as follows:

‘What does the production and maritime trade look like for the blue glazed objects found on the BZN2 shipwreck?’

With this research question, the aim is to focus on blue glazed ceramics, using the circumstances of a shipwreck to further see what this can mean for answering any questions surrounding these ceramics. In order to help answer the main research question, multiple sub-questions were formulated:

- What is already known about the BZN2, regarding its history, build, artefacts and its cargo?
- How typical is the BZN2 shipwreck in material content opposed to contemporary vessels?
- How heterogenous are cargo loads with ceramics?
- What is the composition of the blue pigments on the ceramic artefacts of the BZN2?
- What is the extent of blue glazed ceramic producers for the BZN2?
- What effect can the post-depositional environment have had on the ceramics?
- To what extent can the provenance of these pigments be established, comparing the XRF results to literature?
- How applicable is XRF analysis in the study of materials found on historic ships?

1.2. The BZN2

The BZN2 is part of a larger archaeological assessment project, searching for shipwrecks in an area called Burgzand, east of Texel. Often, divers would report a shipwreck only after taking many of the artefacts onboard, thus the decision was made by archaeologists to actively search for shipwrecks to be able to get to the wrecks and document them before they were empty (Vos, 2012, p. 29). The entire project lasted from 1998 to 2005, finding twelve locations with wreckage remains (Vos, 2012, p. 34). The location of the ships is shown in figure 1.

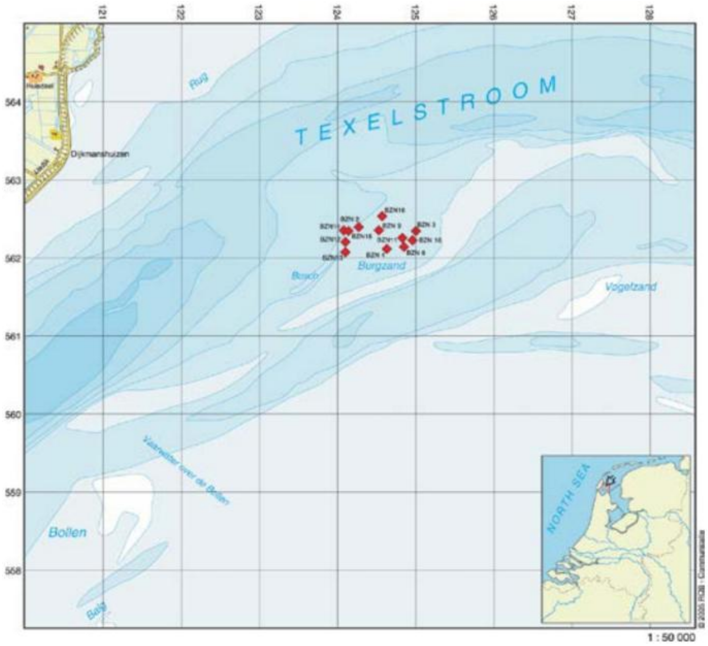

Figure 1. Location of the twelve wreckage sites from the Burgzand project (Vos, 2012, p. 106, Figure 6.1).

The ship BZN2 was built between 1662 and 1665, and its sinking is estimated to have been between 1670 and 1675 (Vos, 2012, p.109). The dating of the ship could not be earlier than 1662, due to a sherd of a large storage jar with Portuguese Latin text stating that the jar was created on the 17th of October 1662 (Vos, 2012, p. 117). Interestingly, sources from the 17th century name a few storms near Texel in which ships sank. In the period that the BZN2 would have sunk, two storms were named, one in 1671 and one in 1674 (Vos, 2012, p. 52). In total, 1276 find numbers were issued in the field, most consisting of multiple artefacts. Around 31 % of these artefacts are metal, consisting of copper based metals like bronze and brass, tin objects and concretions. Furthermore, 21 % of the artefacts are ceramics and 18 % are wood. 10 % are clay pipes, 6 % are glass and 4 % are bone, mostly animal but also a few human remains. The remaining percentages consist of small amounts of other materials, like rope and stone (Vos, 2012, pp. 128-129).

In 2012, a report was published on the archaeological research conducted in the area Burgzand (Vos, 2012). The twelve found shipwrecks are discussed in this publication, including the BZN2 (Vos, 2012, pp. 109-141). Vos discusses many aspects of the wreckage in short. The focus of this report is on the layout of the ship, and which artefacts were found in what location. Vos also describes the dating of when the ship sailed and when it wrecked. For these aspects, Vos used the expertise and reports of other archaeologists.

One such archaeologist was Piet Kleij, a ceramic specialist. Because of his findings, the conclusion was made that the BZN2 was of Dutch origins, and named the tinglazed wares of this ship as part of the cargo, together with a few redware pieces. The other ceramics were either for personal use, or it was ambiguous whether they were part of the cargo or personal property. Most of the ceramics were Dutch, with a few pieces from the German Rhineland, Southern Europe and Denmark. Purely looking at the ceramic finds, assumptions were made that it was a Dutch ship. However, much of the cargo of wood, metals and textiles are from the Baltic Sea area (Vos, 2012, p. 138). Whether it is a Dutch ship or a Baltic ship is unknown, but the ship undoubtedly traded between these areas.

A short paragraph in the thesis of Den Booij (2019) is dedicated to the trade route of the BZN2. Den Booij concludes that the ship was part of 'doorgaande vaart'. This means that the route was probably from the Mediterranean, to Amsterdam, to the Baltic Sea area and back again (De Booij, 2019, pp. 80-81). This is supported by Vos (2012), stating that the amount of ammunition and usable cannons onboard is unusual for a trade purely between the Netherlands and the Baltic Sea, therefore pointing towards a possibility of trade with the Mediterranean or at least Southwest Europe (Vos, 2012, p. 138).

1.3. Motivation and problems

The goal of this research was to analyse the blue pigment in the glazes of the ceramic artefacts found. Cobalt, used for this blue pigment, tends not to have a source that is pure cobalt, as it is mostly found together with other ores. These ores also differ in each source, which means each cobalt source has a unique elemental composition. This is helpful, as it is easier to link the pigment to the source (Bjørnland et al., 2024, p. 2).

In the BZN2 collection, there is a high amount of Dutch tinglazed objects, next to a relatively large collection of Westerwald jugs. Most of these ceramic objects are decorated with blue pigment. The composition of this blue pigment can give further insight into where this pigment was sourced from, which in turn allows for more knowledge into the usage of specific cobalt sources in different locations for different objectives, and can reconstruct the production of these ceramics.

Museum Batavialand houses many artefacts from multiple shipwrecks. Most of these shipwrecks were excavated during a time where there were not many laws and rules surrounding documentation. This has led to the shipwrecks still having many opportunities to research and analyse. Doing XRF research on these artefacts can further add information about their composition, variability and provenance of the artefacts on this ship, filling in the gaps of information.

For the world of archaeology, this research can give further insights into the production of artefacts that use blue pigment in their glazes, and where these pigments were sourced from. This can create a conversation about the organisation of production and large scale trade networks. This subject can also be interesting to see what non-destructive XRF analysis can mean for historic shipwrecks and their artefacts and if it is a helpful tool. The narrow dating of this shipwreck can be of interest, as it can help the dating of the blue pigment use, and thus when the source was active.

The main issue of doing research on shipwrecks, and in particular this ship, is the corrosion. Many of the artefacts have metal corrosion or other types of surface taint due to the long time that they have been underwater. This can cause issues for the XRF results, as it may show signs of more metal than there was initially. The salt water could have also had an effect on the glaze, possibly resulting in chemical reactions. Other than that, because the BZN2 has not been fully excavated, there is a high chance that not every artefact has been brought to the surface, and thus this research will not paint the entire picture of the ship.

1.4. Thesis outline

In this subchapter, the following chapters will be shortly discussed to explain what the layout of this thesis is, and what to expect. In chapter 2, the context in which the BZN2 finds itself will be explained. In broad lines, the 17th century maritime trade between the Netherlands and the Baltic Sea and a few examples between differences in ships at the time. Other than that, the technical aspects of the BZN2 will be named, for example its location, the ship itself and where the artefacts were found in what condition. Chapter 3 will be where the materials and methods will be explained. It will go into detail about the workings of an XRF, the samples taken and the data that was used. It will also discuss what artefacts were found on the BZN2 and which were sampled and then give a broad history about these types of artefacts to give further context. Blue pigment research will be further delved into, and lastly the literature study done for this thesis will be discussed.

Chapter 4 will be the results of the XRF measures. In this chapter, the artefacts will be split into groups, and will be analysed to see if there are any patterns or abnormalities. Multiple different diagrams and tables will be shown. Chapter 5 will be the discussion, where the results are further analysed and compared to literature, to see if any conclusions can be made regarding the main research question. It will discuss production sites of the pottery, production and provenance of the pigment, the maritime trade of these ceramics, comparable shipwrecks and their artefacts, the possible post-depositional changes and lastly, how applicable XRF research is to ceramic artefacts of shipwrecks. At the end, chapter 6 will be the conclusion, where the main research question is attempted to be answered.

Chapter 2: The context of the BZN2 in 17th century

In 1985, an organization called 'Afdeling Archeologie Onderwater (AAO)' was created, officially starting the specialism of maritime archaeology in the Netherlands (Vos, 2012, p. 23). It took slightly longer for the Netherlands to pick up diving for archaeology, due to the rough and dark waters (Vos, 2012, p. 24). The AAO specialized in creating methods and techniques for maritime archaeology in the Dutch waters, excavating the shipwrecks Aanloop Molengat and Scheurrak SO1 (Vos, 2012, p. 25). This is where maritime archaeology around the Netherlands started, which eventually allowed the Burgzand project to be executed. This chapter will contextualize the maritime situation of the 17th century and the BZN2, discussing the build and layout of the ship and its artefacts.

2.1. Maritime relationships and ships in the 17th century

As mentioned in chapter 1, the BZN2 likely traded between the Baltic Sea and the Netherlands, and possibly to the Mediterranean. It is clear that the BZN2 traded around the Baltic Sea, due to the Danish or Norwegian textile leads and the Polish cannons found in the wreck. It was common for the Dutch to trade with the Scandinavian countries. In the 16th century, Gustav I, the king of Sweden, began favouring the Dutch merchants over the Hansa (Tevali, 2021, pp. 75-76). An excavation in the town centre of Oslo, Norway, showed many 17th century Dutch wares. These mostly consisted of glass, pipes and ceramics (van Riel, 2024, p. 129), further establishing the Dutch trading relationship with Scandinavia. Many Dutch merchant ships also traded with Danzig, Poland, and this was apparently quite common. (Bogucka, 1973, p. 435). The Mediterranean sea was generally dangerous to sail through, due to the surrounding wars and pirates (Vos, 2023, p. 37). This is why any ship sailing there was often armoured with cannons. This is also a big part of the reason as to why it is thought of the BZN2 to have traded there as well.

2.1.2. Ship building in the 17th century

In the 16th and 17th century, the Netherlands took the lead in shipbuilding, as their focus shifted to building ships for long distances to sail to Asia. They were influenced by their own previous ship building practices, but also those of other European countries (van Duivenvoorde & Green, 2015, p. 9). Wood was likely the most necessary material needed to build a ship. Because the Netherlands did not have enough forests to supply the wood needed for everything, they imported the timber (van Riel, 2024, p. 126). Before the 17th century, mostly Norway dealt in large wood exports. This is where the Netherlands got their wood from as well. However, due to certain bans and wars, it became less popular to get wood from the Baltic Sea area (Kleij, 2023, p. 148). After the 1630s, it became more popular in the Netherlands to get wood from the Rhineland in Germany (Kleij, 2023, p. 149). However, much of the softwoods used for ships were still imported from Norway, while the oak came from Germany (van Duivenvoorde & Green, 2015, p. 10).

During the early ages of ship building, Scandinavian built ships in this time could still be compared to Viking ships in a way, using planks that overlap in the hull. This is different from other European countries, as those ships were often inspired by Mediterranean shipbuilding. Hanseatic ships used a combination of both traditions (van Riel, 2024, p. 134). During the 17th century however, there were many different types of ships popular for merchant trading. One of which was a ‘jacht’. This was named after the Dutch word for ‘hunt’, indicating its speed and the fact it was armed. This ship did not have the most optimal cargo hold however, as it was relatively small compared to other ships, being circa 50 tonnes (Winter & Burningham, 2001, p. 58). Another example of a Dutch ship was a flute. This was a very common ship, likely due to the price and effort it took to construct it, as both of these were low. It also did not need a very large crew to sail. A flute can carry a capacity of at least 150 tonnes. There were also variations of this ship specifically designed for timber transport (van Riel, 2024, p. 138).

2.2. The BZN2: Location, environment, construction and layout

In order to begin to understand the situation of the BZN2, this subchapter will discuss the location it was found in and the environment. After, it will discuss the practical information about the ship, go into detail of the layout of the wreck and discuss the previous research done on the artefacts that were found.

2.2.1. Burgzand, Texel and the Waddenzee

The BZN2 was found in the area called Burgzand, which is located in the Waddenzee east of Texel. The analysed Burgzand area was around 1500 by 1000 meters (Vos, 2012, p. 29). The natural processes of the soil together with the seawater made it so that the sand was constantly moved and removed from the wreck site, eroding the ship and its artefacts and exposing more and more of the ship (Vos, 2012, pp. 62-64). The water current often makes it so that light artefacts or organic materials flow away from the wreck, while heavy materials will sink further into the ground (Vos, 2012, p. 64).

The creation of the waters and sailing routes in the Waddenzee cannot be reconstructed with precision. It was a natural process which likely took centuries. For Texel, the storm surges starting from the 12th century were likely the most important ones in this process. It was therefore likely that maritime travel around Texel started in the 13th century (Vos, 2012, pp. 40-41). Storms were not uncommon in the Waddenzee. Often times, ships had to wait for a period of time at the anchorage at Texel before being able to sail, which is where a few catastrophic storms took place where many ships perished, like on Christmas eve in 1593 and in December of 1660 (Vos, 2012, pp. 50-51).

2.2.2. The BZN2 ship

The area of the BZN2 shipwreck is at least 30 by 15 meters. The ship itself would have been around 27.5 to 28.5 meters long and 6.5 to 7 meters broad. The ship likely sank while heeling, meaning it is now currently on its side. The orientation of the shipwreck is from the north to the south, with the back of the ship towards the north. The portside of the ship is almost complete, while the starboard is only fragmented, but could possibly be found further around the ship (Vos, 2012, pp. 112-113). Figure 2 shows a drawing of the ship from above, with a few visible finds like cannons and barrels.

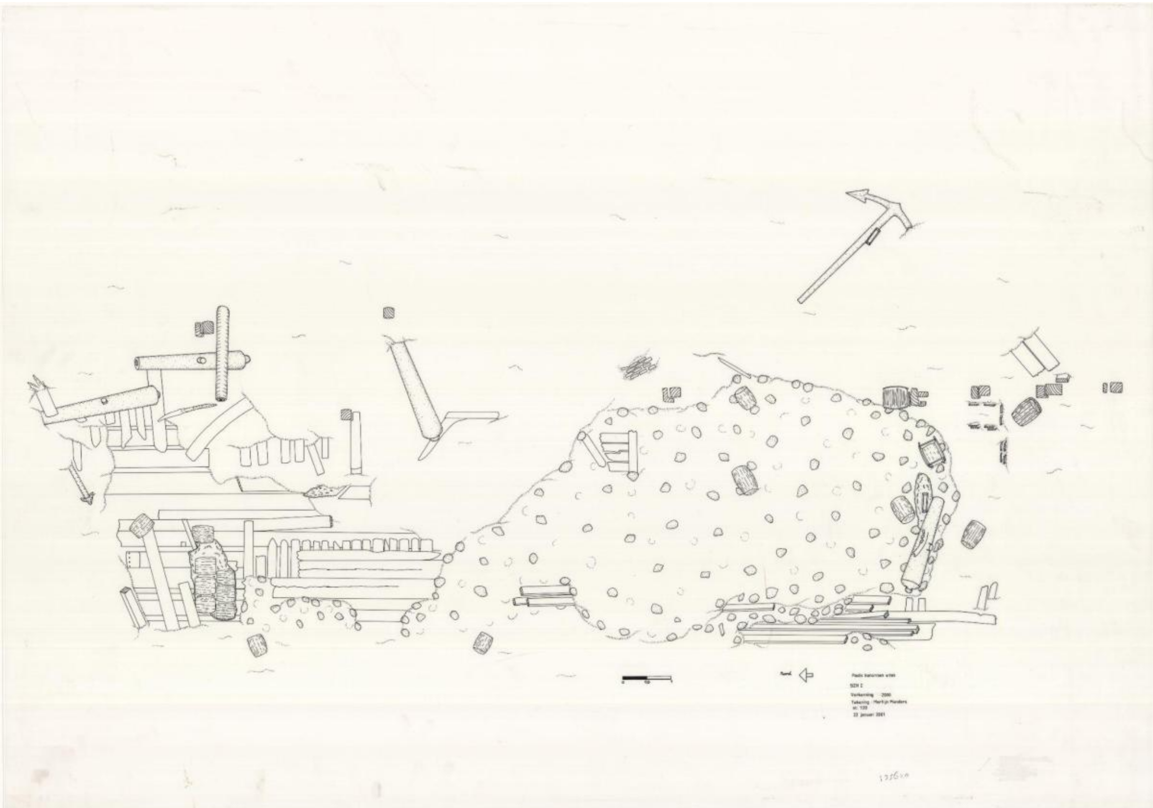

Figure 2. Architectural drawing of the BZN2 wreck from above. Drawn by Martijn Manders in 2001 (Batavialand, identification nr T-135620, https://collectienederland.nl/page/aggregation/maritieme-archeologische-rijkscollectie-bouwkundige-tekeningen/T-135620).

The ship type is speculated to be a ‘jacht’ or otherwise named ‘pinas’, but cannot be said for certain. This was originally a type of ship that was smaller than what was typically referred to as a ‘ship’. However, during the 17th century these terms were also used for larger ships (van Duivenvoorde & Green, 2015, p. 18). After the ship was analysed for the Burgzand project, it was covered in a safety netting to attempt to protect it from most damaging processes in order to protect it in its place.

2.2.3. The layout and where the artefacts were found

The ship was analysed twice, with the first description of the ship and its artefacts being from the year 2000, however the 2001 analysis was more in depth. The following figure 3 shows the site from above with all of the trenches they dug. A short description of the artefacts that were found in these trenches will be discussed here. Not every artefact and its position was described in detail by the chapter written by Vos (2012), however the artefact lists do tend to mention the trench it was found in.

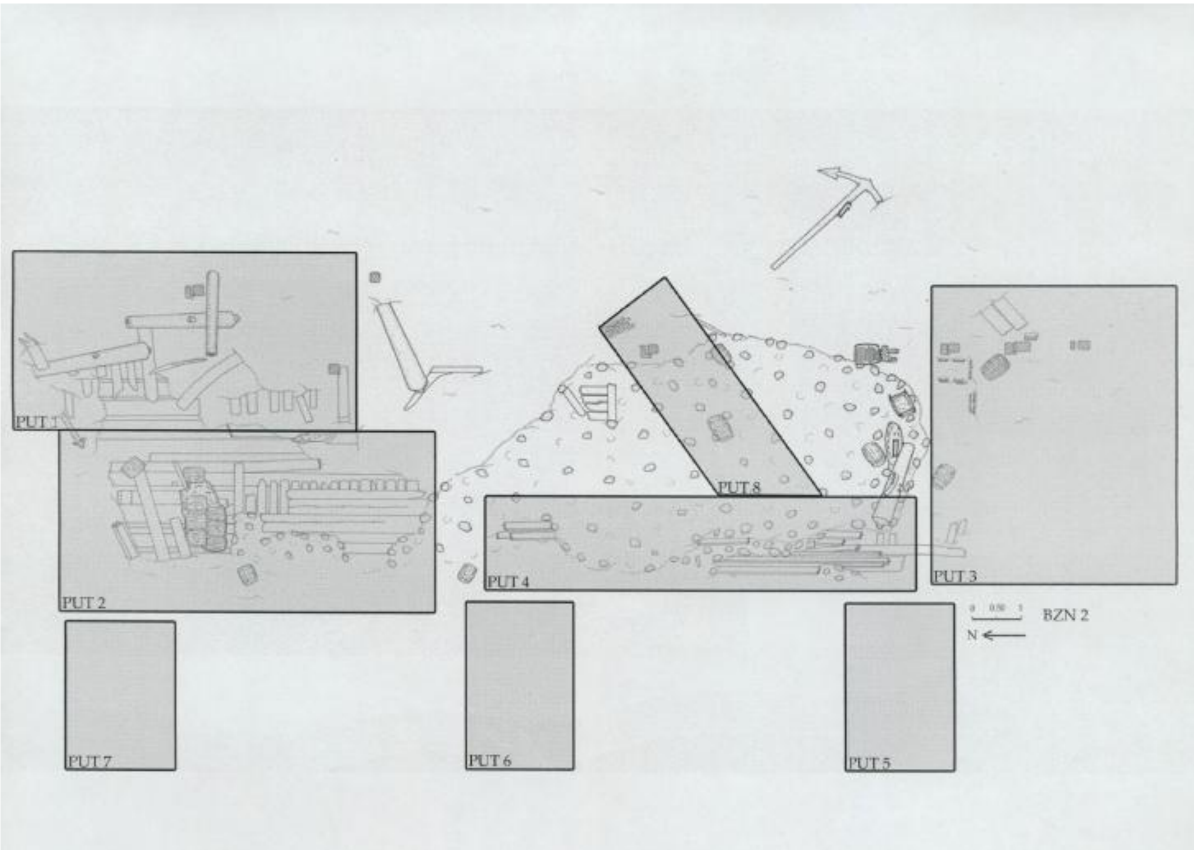

Figure 3. Trench layout of the 2001 assessment of the BZN2 (Vos, 2012, p. 114, Figure 7.3).

Starting in trench 1, which is the back of the ship. On the first deck is where a lead toilet was found. Between the first and second deck is also where three iron cannons were found, other (fire)weapons and musket balls, together with a few other metal finds. Items like the tin caps of cellar bottles, pipes and textile leads were found here as well. Lastly on this deck was a tool chest. Above the second deck were multiple luxury items, like Pisa plates, which could indicate these were the rooms for the ship officers. (Vos, 2012, pp. 114-117).

Trenches 2 and 7 are described together. Trench 2 is where the cargo hold was situated. Most of what was found here were the cellar bottles, the pipes, ceramics and textile leads. A few luxury items were found there, including the larger part of the Westerwald jugs. Due to trench 7 the rudder became visible here as well. (Vos, 2012, pp. 117-119).

Trench 3 is situated at the front of the ship. In this trench was presumably a room where the reserve items for the rigging was stored, due to the ropes that were found here. The second deck did not deliver any artefacts other than a shoe sole and some sewing pins. The cargo became visible from trench 3 below the first deck, showing barrels filled with tinned iron, of which similar ones were found in the 2000s analysis in the back of the ship. Other than that, chests with copper pins, textile leads and remains of textiles were encountered. Underneath these chests were short oak planks of high quality, and one large pine tree trunk. (Vos, 2012, pp. 119-125).

Trenches 4, 5, 6 and 8 are described together, being part of the middle area of the ship. In trench 8, a collection of spruce beams were encountered, of which it was concluded that they were part of the cargo. A barrel filled with copper ores and some yellow concentration which was likely yellow paint were found here as well. In the middle area of the ship was an upper deck oven, however due to the position of the ship's sinking it could have moved. Furthermore, in the middle of the ship is also where the Polish cannons were previously found. (Vos, 2012, pp. 125-127).

2.3. Material of the BZN2 and its previous research

Many of the artefacts have been rigorously determined and studied by multiple people. This subchapter will discuss the conclusions these people made based on the artefacts they studied.

Piet Kleij determined the ceramics of the BZN2 (Kleij, 2002). He determined each artefact using a method called the Deventer systeem. Other than that, Kleij made conclusions of the

artefacts using typology and use-wear traces. His conclusions pertained to what home port the ship belonged to and which artefacts belonged to the cargo and which were for personal use. His conclusions are as follows:
Because of the many Dutch-made artefacts that were meant for personal use of the inhabitants of the ship, it can be assumed that the ship was from the Netherlands (Kleij, 2002, p. 2). Most of the personal use artefacts were redware, which is indicated by the amount of soot and scratches. There are however a few cookpots, also known as 'grapes', with absolutely no signs of use, thus these may have been part of the cargo (Kleij, 2002, p.2). The Dutch majolica and faience tinglaze plates show no signs of use, and were certainly part of the cargo. The other faience objects, like pots for ointments, would have been very expensive back in those times, but they were badly damaged which means a conclusion could not have been made in regards to cargo or personal use (Kleij, 2002, pp. 3-5). A few international objects, like the Pisa ceramics, Weser ceramics, Westerwald jugs or the 'jydepot' are inconclusive as well. The Pisa objects would have been very expensive, however there was only a few sherds of these on board. This could have meant it was used by the captain, or perhaps private cargo. The Weser ceramics are often found in typical Dutch contexts, due to them being used for personal use. This, plus the relatively small amount found and the difficulty of seeing any use-wear signs, makes it uncertain if they were part of the cargo or not. They possibly could have been bought during the trade-route (Kleij, 2002, pp. 5-6). The origin of the ceramics found on the BZN 2 are thus overwhelmingly Dutch, largely German with a few Danish and Italian exceptions.

The hundreds of clay pipe fragments that were found in the wreck have been analysed by Den Brave for their bachelor's thesis. He concluded that due to the high amounts of unsmoked pipes and packing materials, they were part of the cargo. They all contained the markings 'EB', which Den Brave states is short for the Bird family. This pipe brand was created by Edward Bird, who came to Amsterdam from England. His son, Evert Bird, took over in 1665 after the death of his father. Den Brave also concluded that the pipes were made in Amsterdam, based on the shape and quality of the pipes. Due to the dating of the wreck and the style of pipes, it seems as though the pipes are dated between 1665 and 1675. (Den Brave, 2006, as cited in Vos, 2012, p. 132).

Jaap Kottman analysed the glass storage bottles. These particular bottles are four-sided, and started appearing around the 16th century and were popular from the 16th to 18th century. What was stored in these bottles on the BZN2 is unknown, as there were no signs of residue inside. Usually they are filled with wine, but they were also used for other alcoholic liquids.

The shards of around 80 bottles were found, with 77 tin caps to close the bottles. (Vos, 2012, p. 134).

Lilo Duinkerken, an intern at the Textile museum of Tilburg analysed a textile sample of the BZN2. The sample was in bad condition, and consisted of two different types of textiles which could not be separated, and thus a clear conclusion could not be made. (Vos, 2012, p. 136).

Nico Brinck (2000) described the cannons of the BZN2 in the Journal of the Ordnance Society. In total, twelve bronze cannons were found that were all damaged in different degrees. These cannons were dated between 1548 to 1602, thus quite a bit older than the BZN2 (Brinck, 2000, p. 8). Two of these cannons are identical, both having the inscription which mentions Sigismund August, at the time the grand duke of Lithuania for which the cannons were made for, and the year 1554 (Brinck, 2000, p. 8). One other cannon also mentions Sigismund August, only on this cannon he is referred to as king of Poland as well. The year on this cannon is 1560. This cannon also has the name of its maker, which is Hans Seber (Brinck, 2000, p. 10). Another cannon depicts the name Count Moritz, Baron of Arefsnes. There was another phrase on this cannon, but it has not been deciphered (Brinck, 2000, p. 12).

In general, the research done on this shipwreck is satisfactory, but better said, there is much more to be learned from this ship. Any chemical analysis had not been applied to the artefacts of this shipwreck, until this thesis.

Chapter 3: Materials and methods

Before we start with the results, the materials and methods used for this research should be established. As mentioned before, an XRF was used to do the elemental measures. This device was used on glazes that included a blue pigment. The following paragraphs will go into further details.

3.1. Sample set

In the previous chapter, the material and its research was discussed. Out of all of the artefacts from the BZN2, only the ones with blue glaze could be measured for this thesis. This left two types of artefacts: The Westerwald jugs and part of the tinglazed ceramics. The following subchapters will give a short context about these types of ceramics.

3.1.1. Westerwald

Westerwald is a type of stoneware produced in the Rhineland of Germany (Chitty & Stocker, 2019, p. 366). The clay of these vessels is found in the Westerwald mountain range, thus inspiring the name. This clay is ideal for a baking temperature of around 1200 to 1300 degrees Celsius, making the vessel strong and watertight (Scheurleer, 1972, p. 391). The Baroque-inspired style of this ceramic is typically a grey fabric, whereas other stoneware was typically more beige. The Westerwald stoneware was finished with decorative appliques, a clear salt glaze with a decorative blue glaze. Sometimes a purple glaze is added as well (Urbonaite-Ube, 2018, p. 197). As mentioned, the clear glaze on stoneware is a salt glaze, created by adding salt crystals to the kiln when firing the pottery, which then vaporizes and adheres to the stoneware items (Nevell et al., 2022, p. 299). Stoneware is typically used for drinking or pouring liquids, thus it was a relatively luxurious object to own (Heinonen, 2023, p. 261). Westerwald production really picked up in the 17th century and became very popular, likely due to the large migration of Siegburg and Raeren potters moving to Westerwald. This popularity continued on until losing popularity in the 18th century. However, production continued of this type of stoneware, and is still being produced today (Urbonaite-Ube, 2018, p. 197).

3.1.2. Tinglazed ceramics

The next group of artefacts present in this thesis are tinglazed ceramics. These types of ceramics are a light coloured, mostly white or beige, fabric, with a white glaze and oftentimes decorated with other colours of glazes. The most popular vessels to be made as these ceramics were plates. In the 16th century, tinglazed pottery became popular in the Netherlands, and started to be produced here (Bartels & Kottman, 1999, p. 201). The clay has to contain a high percentage of Calcium, more specifically 28 %, as this way the glaze will bind to the fabric better (Bartels & Kottman, 1999, p. 201). The tinglaze on these ceramics is not actually purely tin, but also contains lead. From 1640 onwards, the ratio of lead and tin was equal (p. 202).

Tinglaze ceramics can be split into two groups, being majolica and faience. There are two key differences between majolica and faience. Majolica is only tinglazed on the top or outside, and then only lead glazed on the bottom or inside. Faience is tinglazed all around and then fully covered in the lead glaze (Bartels & Kottman, 1999, p. 202). The way of baking the vessels is also different. Majolica gets stacked on top of each other using clay triangles ('proenen' in Dutch), leaving impressions on the topside of a plate, while faience gets baked in a way where the plates are separated, thus not creating damages (Bartels & Kottman, 1999, p. 207).

3.2. Blue pigment

Blue pigment originally took form as Egyptian blue, in 3000 BC. However, from 1400 AD, smalt became an important role in trading blue pigment. Smalt consisted of crushed dark Potassium blue glass which was made from cobalt (Bjørnland et al., 2024, p. 2). Another way to produce blue pigment was by creating zaffre, by using siliceous sand and melting them with Cobalt, Iron and Nickel oxides (Mühlethaler and Thissen, 1969, p. 48). As mentioned previously, cobalt has a unique combination of elements for every cobalt source, which is why it is perfect for provenance research (Bjørnland et al., 2024, p. 2). Specifically, cobalt can for example either be a manganese ore impurity, an arsenide associated with other ores like copper ($CoAs_{2–3}$), a sulhpide ($CoAsS$, Co_3S_4) or a cobaltiferous alum. Cobalt was also exclusively used for pigment, unlike other elements that could add colour (Gratuze et al., 2018, p. 1). What made cobalt a desirable pigment is because it is the most heat resistant pigment of all other pigments at that time (Bartels & Kottman, 1999, p. 78). Due to cobalt never being pure, there are a few elements that are commonly found in blue pigment found in multiple different sources. These elements are Cobalt, Iron, Nickel, Barium, Arsenic, Zinc, Copper and Manganese. To analyse them, the parts per million (ppm), intensities and correlations between the elements will be taken into account.

3.3. Portable X-ray Fluorescence (pXRF)

In order to measure the compositional elements of the pigments and glazes, a chemical analysis was required. The chemical analysis that was chosen for this was XRF, more specifically, a portable XRF. The XRF was selected to be the most efficient method to use, due to the easy use, portable qualities and non-destructiveness. Due to the artefacts being part of the Museum Batavialand depot collection, the preference was any non-destructive measures over destructive ones. A portable, non-destructive, quick and easy to use way of measuring was required, which the portable XRF is (Bezur et al., 2020, p. 17). In short, the XRF process works by sending an X-ray onto an object. The atoms of this object absorb the X-ray, eventually expelling an electron, leading to another electron filling the empty spot. The excess energy from this electron turns into a fluorescent photon. This process is unique for every atom, allowing for detection and examination by which the elemental composition can be determined (Bezur et al., 2020, p. 17).

In archaeology, the XRF has its possibilities and restrictions. Shackley (2011) sums up the positives and the negatives in his book about the possibilities of XRF in geoarchaeology. He states the positives are the non-destructive nature, the fact that minimal preparation is necessary, it is fast, easy to use and relatively cost-effective. The limitations of the XRF are the sample size limits, as they have to be large enough to be detected, the restricted elemental acquisitions due to the spectra and the fact that the XRF is for mass analysis, not small components (pp. 9-10). In the same book, Liritzis and Zacharias (2011) explain the common uses for an XRF in archaeology. They state the possibilities of an pXRF can be on-site material determination in large geoarchaeology projects, museum analysis, provenance studies, ceramic studies specifically to understand different clay deposits and decoration techniques, identifying the composition of different coins, and compositional analysis of manufactured glass (pp. 112-114). Liritzis and Zacharias do mention the specific issues for XRF for archaeological research, naming the issue with corrosion layers on artefacts making the results misleading, the thickness of a sample is important for measuring heavy elements and a sample needs to be flat for optimal readings (Liritzis & Zacharias, 2011, p. 132). However, they do stress the advantages of the XRF too, naming the non-destructive and non-invasiveness, the portability, its quickness and the accuracy of the measures (Liritzis & Zacharias, 2011, p. 135).

The pXRF used for this project is a Bruker Tracer 5g based on a Rhodium excitation source. This machine was on loan from the material lab of Leiden University, meaning it was only available for a limited time slot. The XRF measures a 8 millimetre area on the surface of the artefact. Measurements were conducted in air using a dual setting developed specifically for measuring both light and heavy elements in glass materials. Each measure included a 15 seconds livetime at 50kV and 33.2 µA with a 25µm Ti 200µm Al 75µm Cu filter installed combined with a 30 seconds livetime at 15kV and 21.8 µA with no filter. The semi-quantitative values used in this research are based on the Bruker factory built ‘glass’ calibration. Certified reference materials NIST610 and NIST 612 were run as a control to monitor machine drift. (D. Braekmans, personal communication, August 17, 2025.).

It is important that the objects being measured have a flat surface which is as close to the 8 millimetres point as possible, as the measure is very shallow. It is also important that the surface is clean, and has the least amount of corrosion possible. In order to measure the blue pigments, it is important to line up the blue decoration with the 8 millimetres point of the XRF measure. The XRF contains a camera, which can be turned on to check if the artefact is positioned correctly.

One issue could be that XRF may restrict future research in regards to luminescence dating. The XRF essentially adds radiation to the object, resulting in potential luminescence dating being unreliable, due to it being based on the level of radiation in the object, but only if a sample was taken from the same 8 millimetres spot as the XRF measurement (D. Braekmans, personal communication, November 20, 2024.).

3.4. Sample selection

A selection of objects was made of which the glazes would be measured. This selection consisted of the objects of which the glaze was still in good shape. Some blue pigments were affected by corrosion, had been damaged, or were barely visible anymore. The artefact shown in figure 4 shows artefact BZN2-571. This was once a blue glazed majolica plate, but due to the post-depositional changes it has tainted brown and the blue is barely visible anymore. Measuring this would likely lead to warped and low scores that could not be used to compare. Most of the blue decorations occurred on the inside of the objects, like the top

Figure 4. Artefact BZN2-571 which shows an example of an item that was not included in the selection (Batavialand, objectnr BZN2-571, https://collectienederland.nl/page/aggregation/maritieme-archeologische-rijkscollectie-maritieme-vondsten/60031251).

side of a plate, but there were some objects where the decoration was on the outside. These objects were the Westerwald jugs and a small cup.

For this thesis, 44 objects had been measured totalling 54 measures. The objects consisted of 27 plates, 16 jugs and one bowl. Due to time constraints, most artefacts were only measured once. A few artefacts were measured in both of the two XRF sessions. During the first session, the goal of the thesis was different, thus the blue pigment was not the focus of the measures. A few measures however were done on blue pigment, and are therefore included in this thesis. Beside that, during the first XRF session, the tripod for the XRF had not been used. This caused some issues, as not every object could be positioned in a way where the blue pigment would have been close enough to the 8 millimetre area of the XRF. The second XRF session the tripod was installed, which resulted in being able to finish the measures, making sure every blue pigment was measured. Five of the Westerwald jugs found on the BZN2 were not measured, due to them having been placed in different museums. Due to the XRF being on loan for a short amount of time and needing transport, the decision was made not to travel to these museums to measure the glaze.

What should be kept in mind is that ceramics that are stored in sea water for prolonged periods of time can be altered. The seawater tends to affect the calcium and magnesium. The ceramics tend to lose calcium, but gain it in magnesium (Béarat et al., 1992, p. 152). Thus, the ceramics of the BZN2 may have different results than similar ceramics that have not been submerged. However, this mostly concerns the fabric and thus clays of the ceramics (Béarat et al., 1992, p. 161) which is not the main focus of this thesis.

The list of samples taken can be found in appendix A and appendix B at the end of this thesis. Appendix A shows the list of samples in order of sample number, while appendix B shows the samples in order of artefact number. This list can be used as a reference for the rest of this thesis.

3.5. Data treatment

After the XRF is done measuring, the data is received from Leiden University in Oxygen %. To make it better to read and compare to literature, it was calculated and converted to parts per million (ppm) using a converter tool. The data was stored in Google Spreadsheets. This is also what all of the diagrams and tables were created with for the thesis.

In order to show the data in this thesis in a readable way, histograms were chosen to be displayed. Because not many artefacts were measured, it was possible to showcase the results without it being overwhelming, making sure to split the histograms up per type of ceramic. This was done to get a clear and quick look of the different compositions without having to look at the many different numbers. However, for transparency and further information, the different elements and ppm values are displayed in a table underneath the histograms.

In the previous subchapter about blue pigment, multiple elements that could possibly be part of the composition were named. These elements, plus the potassium from smalt, were examined by themselves. For this, histograms were made as well and another table was added. For a clearer look to see any correlations and possible different types and groups of pigments, scatterplots were created. This was done mostly between elements of the blue pigment, like Cobalt and Iron.

3.6. Literature

For this thesis extensive literature research took place. Many sources were found using the Leiden University online library, allowing access to articles that are usually not accessible.

Researching the basics of the ceramics used in this thesis was the first step. Finding out where they were typically produced, what materials were used and what the production process looked like is key to eventually do more specific research related to the blue pigments. *Hollants porcelain en straetwerck* by S. Ostkamp (2014), *Analytical study of Delftware's reproductions* by Wouters (2020) helped put together information on Dutch faience and majolica. Literature sources like Chitty and Stocker's (2019) *Westerwald stoneware at Kelmscott manor* and Scheurleer's (1972) *Duits steengoed met wapens of portretten van Oranje vorsten* helped paint a picture of the Westerwald stoneware.

In order to find out what exactly can be done with pigment analysis, the following source was used. Bjørnland et al. (2024) was used to highlight the possibilities of pigment analysis, while also sharing their limitations in *The production of smalt and other cobalt compounds at the Blaafarveværket, Modum, Norway.* In order to find out more about the specific cobalt composition of these finds and what information it can lead to, the results need to be compared to literature sources. Due to the ceramics of this research being produced in Germany and the Netherlands, it is likely for the cobalt to be mined in Saxony, Germany, specifically the ore mountains. Another important thing to look for is the specific dating of the

17th century. Popular cobalt ore and production could have been different in the centuries before. A few sources that will be used in this thesis are Zlámalová Cílová et al. (2020), *Smalt production in the Ore Mountains: Characterization of samples related to the production of blue pigment in Bohemia.* This source mostly focuses on the Ore Mountain area that is situated in the Czech Republic. Gratuze's (2013) *Provenance analysis of glass artefacts* shows a table with the provenance sites of multiple different cobalt sources, including the dates that they were used.

To find out what blue pigment analysis can mean for researching (maritime) trading during the 17th century, a basic understanding of European maritime trade is needed. A source for example *Archaeological perspectives on the Norwegian-Dutch timber trade (1500-1700 CE)* by van Riel (2025) helped paint a picture of the Dutch trading relationship with the Baltic Sea area, including Norway, as previous research of the BZN2 pointed to Baltic Sea trading.

Chapter 4: Results

The ceramic assemblage of the BZN2 that uses blue pigment can be divided into roughly two types; Westerwald and tinglaze wares. These types will be discussed separately. In the tinglaze wares, there were five recurring decorations. This results chapter will start by discussing the different types as a whole, and then comparing any objects with the same decoration.

4.1. Westerwald

4.1.1. The general glaze composition

In total, 16 Westerwald jugs were measured on their blue pigment. BZN2-903 is seen in figure 5 as an example of what these jugs look like, though each of them are unique. They are stoneware with a grey fabric colour, often decorated with appliques. The blue glaze on the jugs is semi-transparent, and often covers a large portion of the vessel. All of the Westerwald jugs from the BZN2 contained a lions head on the neck of the jug.

Figure 5. The BZN2-903 Westerwald jug (Batavialand, objectnr. BZN2-903, https://collectienederland.nl/page/aggregation/maritieme-archeologische-rijkscollectie-maritieme-vondsten/60023377).

All of the jugs were determined to be from the Deventer systeem type s2-kan-7, except for BZN2-701 and BZN2-1228 for which the types were not documented. Because the jugs were all almost completely whole, they were measured in size. The following table 1 will show the measurements of the jugs, going from shortest to tallest in centimetres. The shortest jug, BZN2-906, was also the only jug measured that contained a purple glaze as well. One other jug like that was found on the BZN2 but was at the time of measurement in an exhibition of the Rijksmuseum van Oudheden. That jug was also 5.5 centimetres taller. There seems to be a shorter collection of jugs, ranging from 17.5 to 20.3, and a taller group which ranges from 22.0 to 24.0. Between the two groups is a gap of 1.7 centimetres, allowing for a clear distinction. It is clear that the size of every jug varies, however artefacts BZN2-836, -837, -903 and possibly BZN2-904 as well seem to have the same decorations, in regards to the button appliques and the lion heads.

Table 1. The sizes of the BZN2 Westerwald jugs.

Artefact nr.	Height	Max. diameter	Bottom diameter
BZN2-906	17.5	9.3	6.0
BZN2-907	18.5	10.0	6.5
BZN2-701	18.5	10.5	Not documented
BZN2-1174	19.0	9.0	5.5
BZN2-21	19.0	9.1	6.5
BZN2-975	19.0	10.6	5.4
BZN2-837	20.0	10.0	6.3
BZN2-972	20.3	9.4	6.0
BZN2-908	22.0	11.5	6.0
BZN2-772	22.0	12.3	7.2
BZN2-902	22.5	11.6	6.5
BZN2-1228	22.5	12.5	Not documented
BZN2-904	22.7	11.5	7.0
BZN2-974	23.5	12.6	7.4
BZN2-836	23.6	12.0	7.0
BZN2-903	24.0	12.2	7.2

The following histogram in figure 6 shows the elemental composition per sample. It is clear that the overwhelming amount of Silicon (Si) is from the fabric and glaze. Thus in order to view the composition of the rest of the glaze better, the Si gets taken out of the diagram. This histogram can be seen in figure 7. The calcium (Ca) is also part of the composition of the fabric. The most prominent remaining elements are Aluminum (Al), Potassium (K), Iron (Fe) and Cobalt (Co). There are also varying amounts of Strontium (Sr), Barium (Ba), Zinc

(Zn) and Tin (Sn). There does not seem to be a connection between the small sized jugs and the large sized jugs in regards to the distribution of elements.

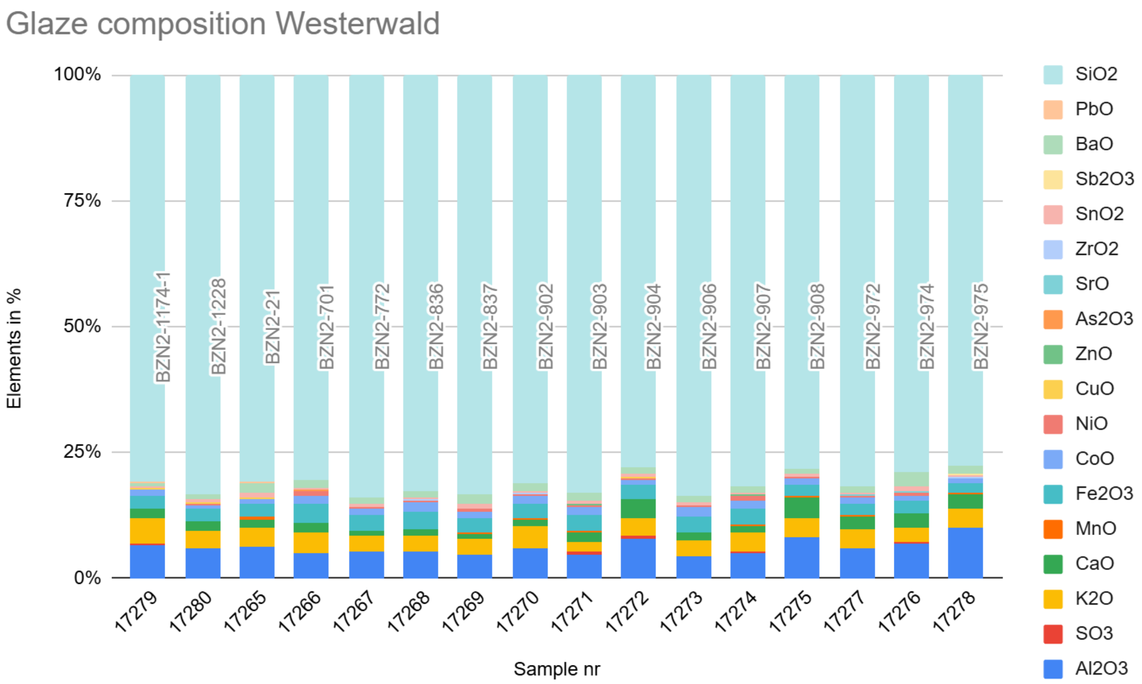

Figure 6. A histogram showing the glaze composition of the BZN2 Westerwald jugs.

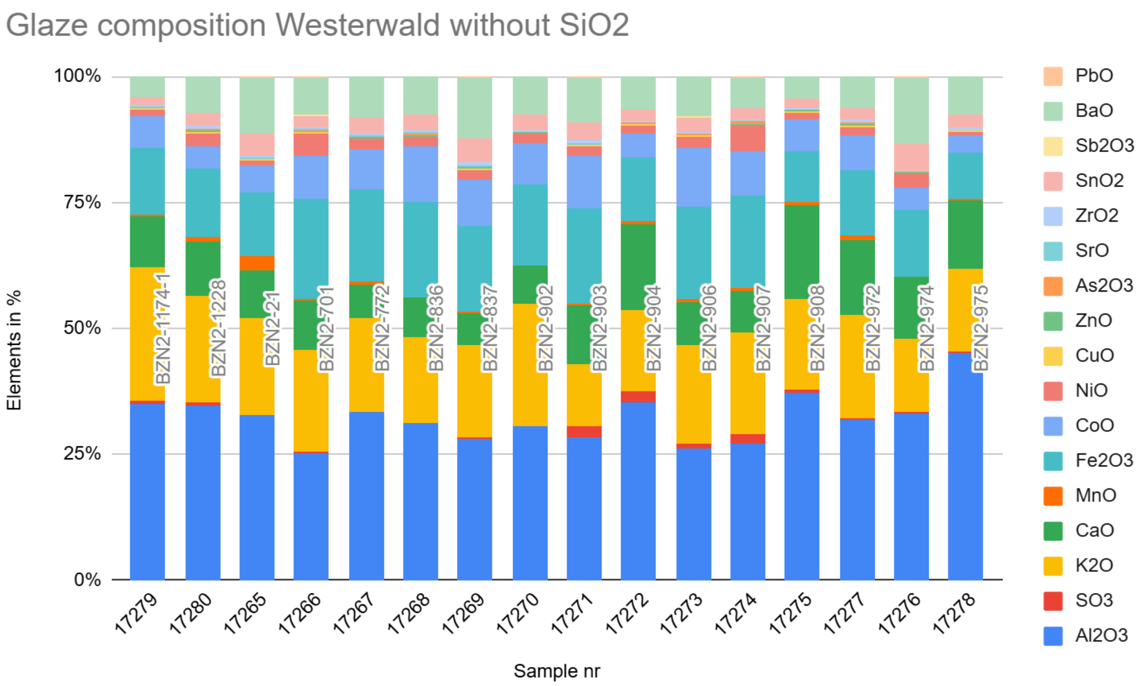

Figure 7. A histogram showing the glaze composition without SiO2 of the BZN2 Westerwald jugs.

Table 2 on the next page shows the XRF results of the glaze from the Westerwald jugs. Cobalt ranges from 1246 to 9061 ppm. Not all contain Arsenic (As) or Sulfur (S). All do contain Nickel (Ni), ranging from 511 to 4503 ppm, but most between 1246 and 1650 ppm. All but one contain Manganese (Mn), ranging from 112 to 710 ppm, with one outlier of 1450 ppm. The one sample that does not contain Mn also has the lowest Co ppm. All measures contain small amounts of Copper (Cu) (51 to 288 ppm) and Zn (36 to 324 ppm, but most between 90 and 170 ppm). High levels of Al (5916 to 27769 ppm, but most between 10000 to 20000 ppm) and K (4161 to 29436 ppm but most 10000 to 20000 ppm) are present as well. These high levels of K point to the usage of smalt. Fe ranges from 3082 to 15472 ppm, the highest concentration being between 9000 to 13000 ppm. Only one item did not contain Mn, but in general, this item has much lower values than the rest of the artefacts. It could be that the measure was not fully done on the right spot, the pigment had faded too much or that it is a separate type. A list of all the elements and their symbols can be found in appendix C, as now the named elements will only be referred to by their symbols.

Table 2. The XRF results from the glaze of the Westerwald jugs in ppm.

Sample nr	Artefact nr	MgO	Al2O3	SiO2	P2O5	SO3	K2O	CaO	TiO2	MnO	Fe2O3	CoO	NiO	CuO	ZnO	As2O3	SrO	ZrO2	SnO2	Sb2O3	BaO	PbO
17265	**BZN2-21**	<LOD	11240	129418	<LOD	<LOD	10459	4388	<LOD	1450	5727	2714	556	131	59	< LOD	66	176	2218	< LOD	6545	112
17266	**BZN2-701**	<LOD	14782	214208	<LOD	112	18810	7622	<LOD	276	15472	7458	4005	189	96	355	100	197	2190	59	7496	129
17267	**BZN2-772**	<LOD	14267	196422	<LOD	<LOD	12471	3888	<LOD	234	10354	5001	1415	142	124	< LOD	104	218	1995	< LOD	5905	82
17268	**BZN2-836**	<LOD	15405	207666	<LOD	<LOD	13279	5206	588	150	12328	8121	1285	167	113	264	200	354	2144	41	6268	94
17269	**BZN2-837**	<LOD	8098	126596	<LOD	58	8227	2536	<LOD	148	6488	3911	845	110	145	< LOD	144	205	2062	< LOD	5922	104
17270	**BZN2-902**	<LOD	14216	176756	<LOD	<LOD	17569	4757	<LOD	112	9911	5662	1119	173	87	56	90	220	2117	< LOD	5831	71
17271	**BZN2-903**	<LOD	13207	202075	<LOD	753	8986	7341	<LOD	221	11667	7199	1246	145	151	46	224	387	2329	55	6993	148
17272	**BZN2-904**	2594	22097	196014	<LOD	1124	15814	14518	<LOD	370	10557	4375	1714	161	106	188	121	221	2077	38	6769	121
17273	**BZN2-906**	<LOD	13715	238186	<LOD	341	16191	6117	<LOD	485	12661	9061	1650	262	97	120	104	276	2226	95	6980	93
17274	**BZN2-907**	<LOD	16770	245190	<LOD	939	19489	6860	<LOD	487	15166	8048	4503	192	131	536	89	270	1893	59	6508	170
17275	**BZN2-908**	3216	27769	239683	391	269	21080	19075	2119	465	10058	7060	1444	259	168	101	117	370	1853	86	5537	93
17276	**BZN2-974**	<LOD	5916	59278	<LOD	54	4161	2987	<LOD	<LOD	3082	1246	691	51	36	< LOD	46	<LOD	1476	< LOD	3990	77
17277	**BZN2-972**	<LOD	17206	215056	131	154	17242	10928	<LOD	572	9254	5688	1308	207	324	118	156	257	1993	< LOD	5512	111
17278	**BZN2-975**	<LOD	25465	174257	<LOD	140	14451	10406	656	342	6864	2766	511	225	74	< LOD	102	336	2264	47	7024	83
17279	**BZN2-1174-1**	2174	24788	265678	165	201	29436	9692	1993	201	12660	6410	1301	288	294	< LOD	115	366	1682	37	4699	119
17280	**BZN2-1228**	<LOD	17487	221708	< LOD	215	16822	7374	< LOD	710	8982	3334	2043	262	77	315	106	250	2011	< LOD	6071	93

4.1.2. Blue pigment composition

Taking a closer look to only the elements that could potentially be part of the blue pigment we can see the following in figure 8. Smalt is made from a potassium (K) glass, thus it is kept in this subchapter to keep the possibility of smalt usage. In the possible smalt composition, the alkali metal K and the transition metal Fe share a similar amount. Co and Ba also share a similar amount with each other. As, Zn, Cu, Ni and Mn are all very small amounts, with Ni being slightly larger.

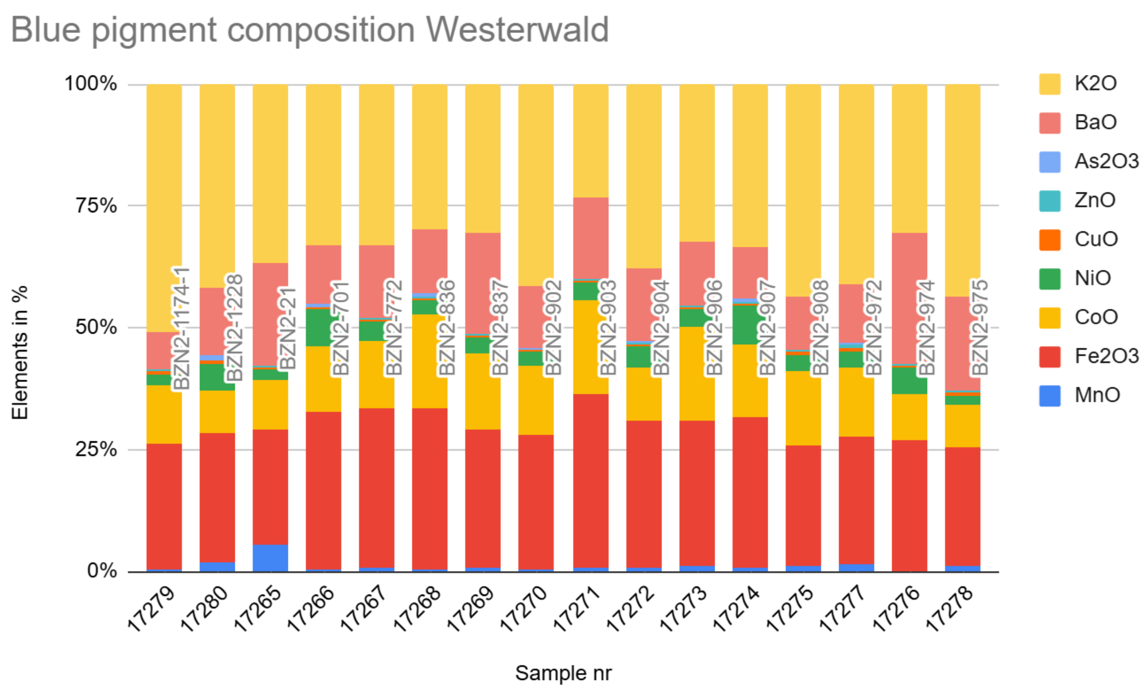

Figure 8. The blue pigment XRF results of the BZN2 Westerwald jugs.

This second histogram in figure 9 shows the cobalt composition, which means the K from the smalt is not included. Here it shows that Fe is a very large part of the pigment. Co is also more visible here, and Ba too. It also shows that As, Zn, Cu, Ni and Mn are still very small.

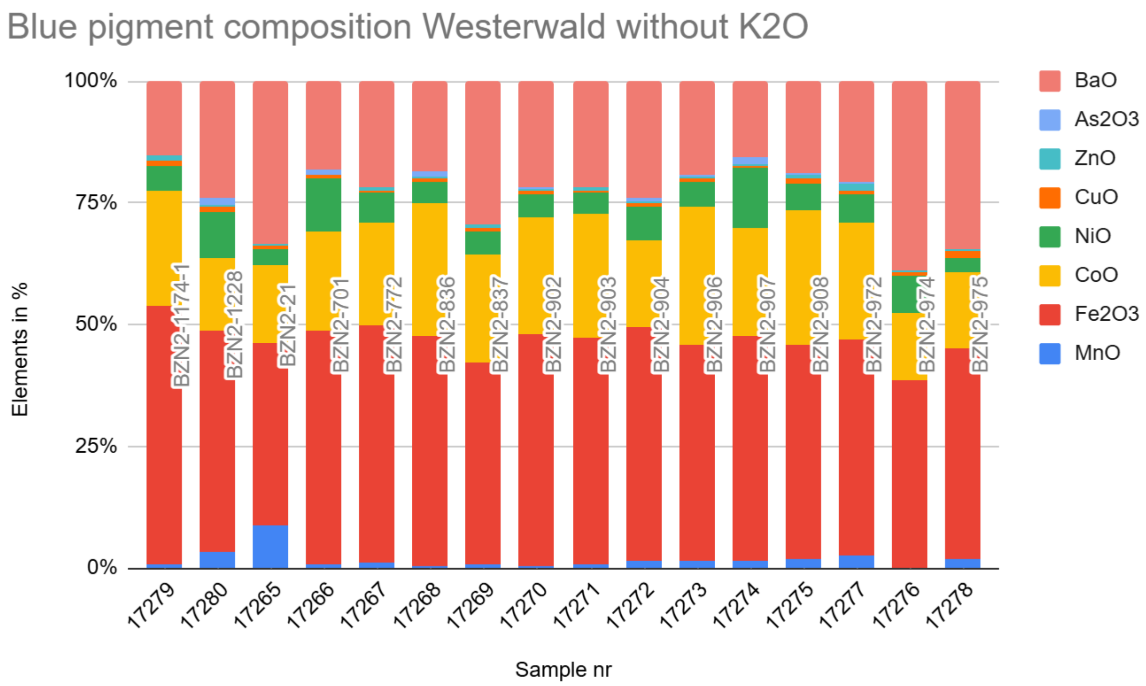

Figure 9. The blue pigment XRF results without K_2O of the BZN2 Westerwald jugs.

Multiple elements were compared with each other using a scatterplot. In the scatterplots, the sample numbers are displayed by the points. These scatterplots will be focussed on the relationship between Co and other elements, to see what elements were highly present in the cobalt ore. As mentioned in chapter 3, Al is sometimes found with Co, thus a few scatterplots were created to see if there is a correlation. The K_2O and Al_2O_3 scatterplot in figure 10 does show a concentration around the 20000 K ppm and 30000 Al ppm. There is also a trendline that can be discerned in this scatterplot, but it could be more convincing.

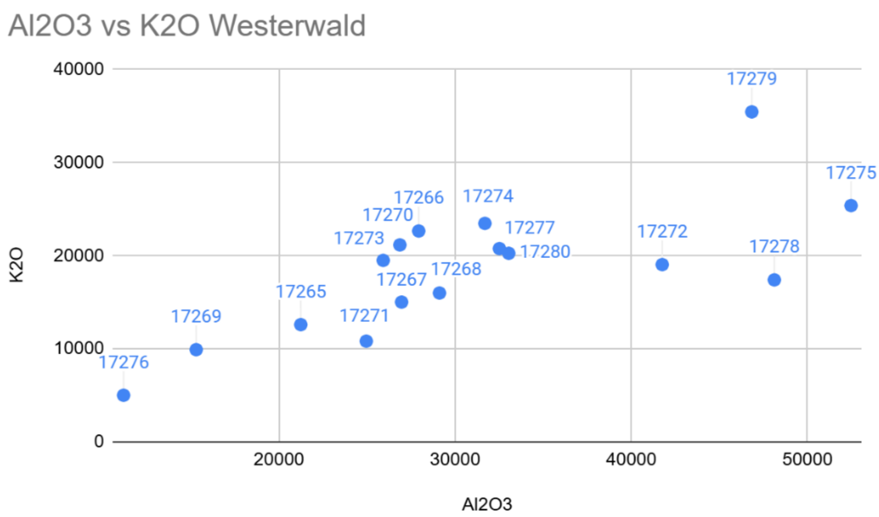

Figure 10. A scatterplot showing Al_20_3 and K_20 of the Westerwald jugs.

The Co and Al scatterplot in figure 11 does not show a trendline, thus there is no real correlation between the Co and Al. It therefore seems the Al may have played a role in creating the smalt or glaze, but it was not present in the raw material. There also do not seem to be distinct different groups, though the concentration of points in the middle right could potentially be a group.

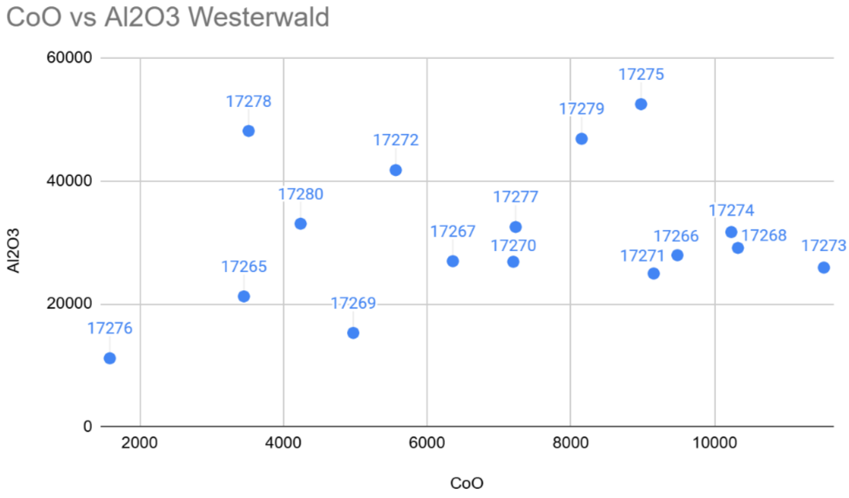

Figure 11. The scatterplot between CoO and Al_2O_3 of the Westerwald jugs.

The Co and K scatterplot in figure 12 also barely shows a correlation, but a slight trend is there. No distinct groups are visible.

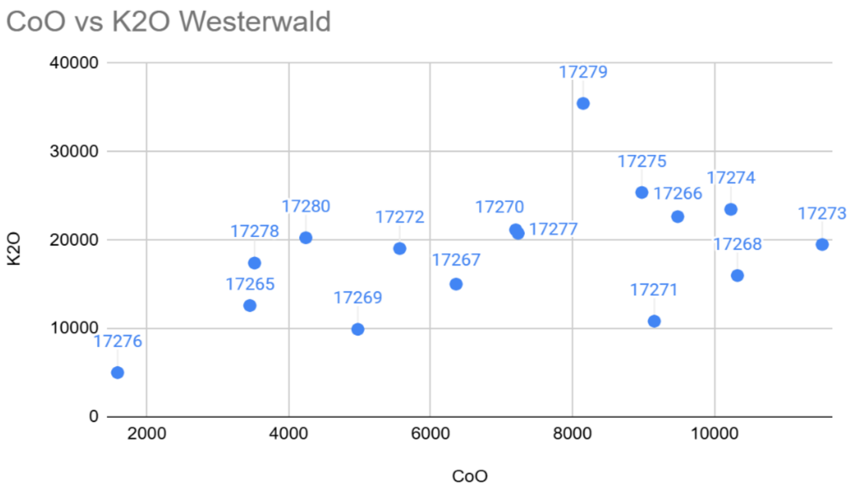

Figure 12. A scatterplot showing CoO and K_2O of the Westerwald jugs.

If we look at the scatterplot in figure 13 below, you can see that there are two groups visible: one with a lower Mn value and one with a higher Mn value. There is also one specimen that lies very far away from the other jugs. This is BZN2-21. This jug has a very high amount of Mn, but a relatively low Co. In fact, the Co ppm values are the lowest out of the entire group. There is not really a correlation between Mn and Co in this situation. The Mn does not go higher than 1000 ppm, except for the BZN2-21 sample 17265. It seems that although the Co ppm values go higher, the Mn stays relatively stable. Sample 17276 is missing from this scatterplot, as the Mn was below the limit of detection. There does not seem to be a connection between the size of the jugs or the decorations and the results of the Co and Mn.

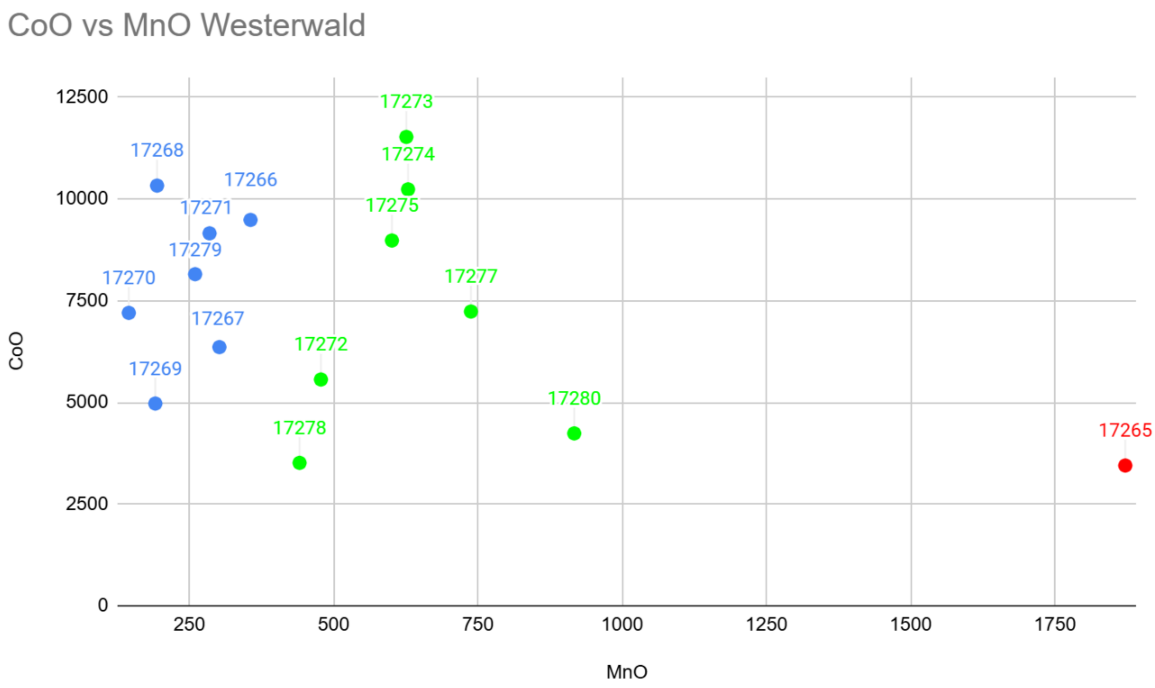

Figure 13. A scatterplot showing CoO and MnO of the Westerwald jugs, with the different groups highlighted with different colours.

There is a clear trendline between Cobalt and Iron, as seen in the scatterplot in figure 14. There is however no clear correlation between the colour groups in the previous scatterplots and this one. The

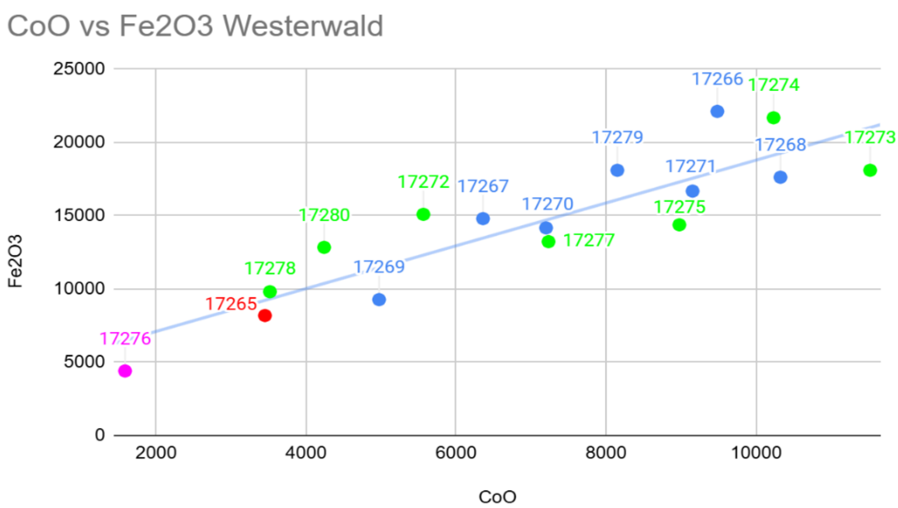

Figure 14. The scatterplot showing CoO and Fe_2O_3 of the Westerwald jugs, with the different groups highlighted with different colours.

green and the blue points are mixed through each other. Only the sample that was not on the previous CoO and MnO scatterplot is now present as the absolute lowest point for both iron and cobalt. What should also be noted is that measure 17265, the previous outlying point, is the second lowest in this scatterplot, and also very low in all of the scatterplots before the Co and Mn. So although the Mn and Co scatterplot shows multiple different groups, this Fe and Co scatterplot does not, but it does show a clear connection between the elements.

It doesn't seem that there is a correlation between Nickel and Cobalt, as seen in figure 15. The two samples on the far right, sample 17266 and 17274, were also far to the right of the Cobalt and Iron scatterplot, but not as dramatically as in this one. Again, 17265 and 17276 are to the far left corner, with 17278 as well which has also been quite low in the previous scatterplots. However, there do seem to be a few different groups. First are the outlying samples. Then there is a trendline that goes steeply upwards from the bottom left up. In the middle of this trendline is the start to another line, which goes downwards. This line at least seems to include the samples 17280, 17272 and 17267. Looking back at previous scatterplots, these samples are always close to another, at times being in a line. These three jugs are also part of the taller group of jugs. The jugs with the similar decorations do not seem to show a pattern in the scatterplot.

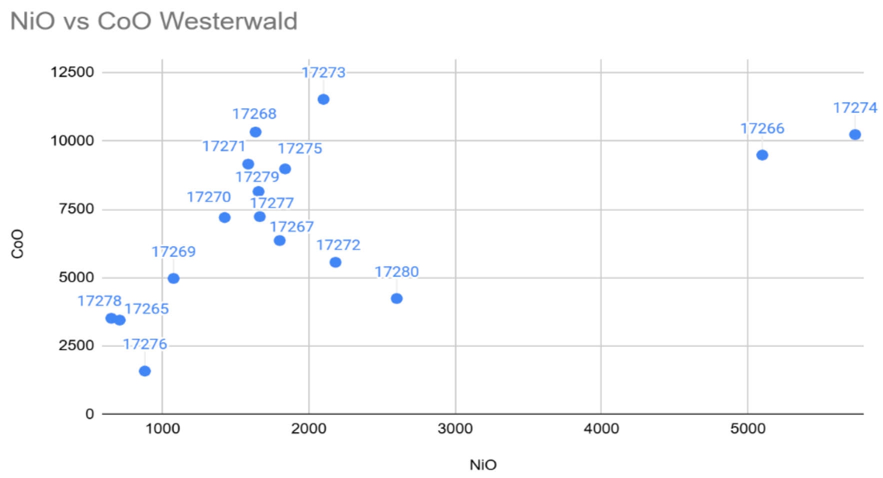

Figure 15. The scatterplot showing NiO and CoO of the Westerwald jugs.

The table below again shows the ppm values of the artefact elements, only including the possible blue pigment elements to make it more organised than the previous table. In this case, artefact BZN2-974 has the lowest Co, not BZN2-21 as mentioned in the scatterplot, however this was already discussed previously as this sample also has the lowest Mn ppm values. BZN2-21, or sample 17265, has a very high Mn content, while the rest of the elements are on the lower side, compared to the other samples. Although the samples show a lot of different variable ppm values, sample 17276 which is artefact BZN2-974, also stands out due to the absent Mn and otherwise very low elemental concentrations.

Table 3. The XRF results of the blue pigment from the Westerwald jugs in ppm.

Sample nr	Artefact nr	K2O	MnO	Fe2O3	CoO	NiO	CuO	ZnO	As2O3	BaO
17265	**BZN2-21**	10459	1450	5727	2714	556	131	59	< LOD	6545
17266	**BZN2-701**	18810	276	15472	7458	4005	189	96	355	7496
17267	**BZN2-772**	12471	234	10354	5001	1415	142	124	< LOD	5905
17268	**BZN2-836**	13279	150	12328	8121	1285	167	113	264	6268
17269	**BZN2-837**	8227	148	6488	3911	845	110	145	< LOD	5922
17270	**BZN2-902**	17569	112	9911	5662	1119	173	87	56	5831
17271	**BZN2-903**	8986	221	11667	7199	1246	145	151	46	6993
17272	**BZN2-904**	15814	370	10557	4375	1714	161	106	188	6769
17273	**BZN2-906**	16191	485	12661	9061	1650	262	97	120	6980
17274	**BZN2-907**	19489	487	15166	8048	4503	192	131	536	6508
17275	**BZN2-908**	21080	465	10058	7060	1444	259	168	101	5537
17276	**BZN2-974**	4161	< LOD	3082	1246	691	51	36	< LOD	3990
17277	**BZN2-972**	17242	572	9254	5688	1308	207	324	118	5512
17278	**BZN2-975**	14451	342	6864	2766	511	225	74	< LOD	7024
17279	**BZN2-1174-1**	29436	201	12660	6410	1301	288	294	< LOD	4699
17280	**BZN2-1228**	16822	710	8982	3334	2043	262	77	315	6071

4.2. Tinglaze wares

4.2.1. The general glaze composition

38 measures of the tinglaze wares were done. As was expected, the elements that show up most are Si, mostly due to the fabric, and Pb and Sn, which comes from the glaze. These results can be seen in figure 16. When Si and Pb have been taken out of the diagrams, a better look can be taken at the smaller elements in figure 17. Here, the most prominent elements next to Sn are Mg, Al, K and Ca. The tinglaze wares include the element Mg, which the Westerwald did not have. The tables showing the ppm values will be included in the subsequent subchapters, due to the large number of elements and samples making the tables too complex.

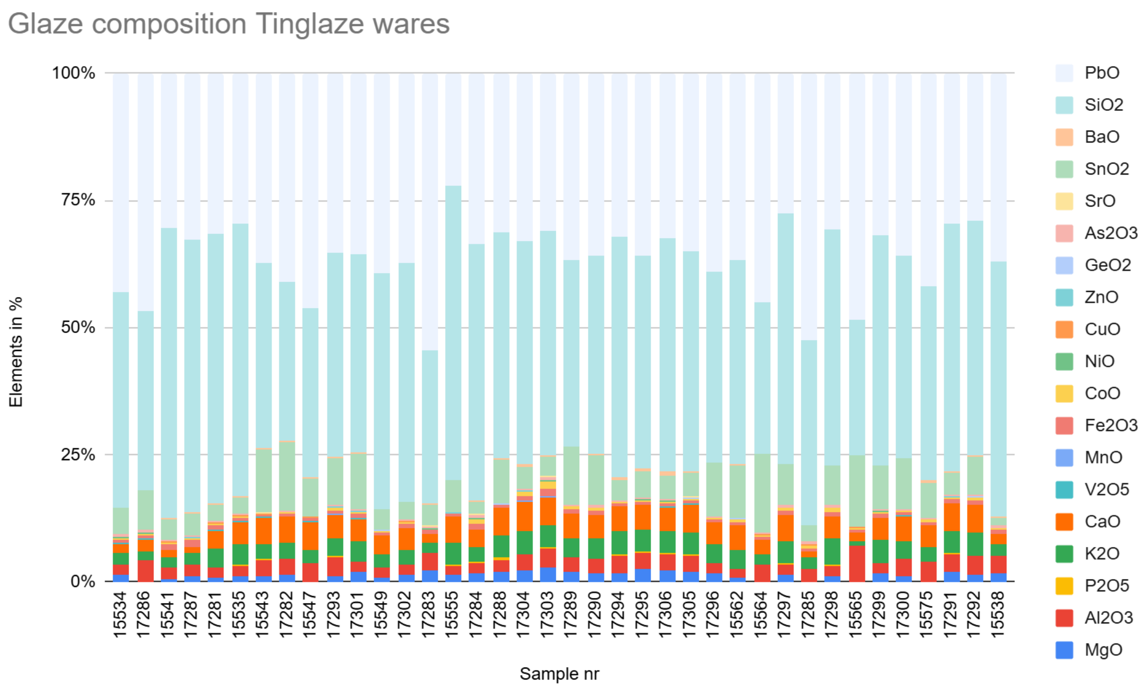

Figure 16. The histogram showing the glaze composition of the tinglaze wares.

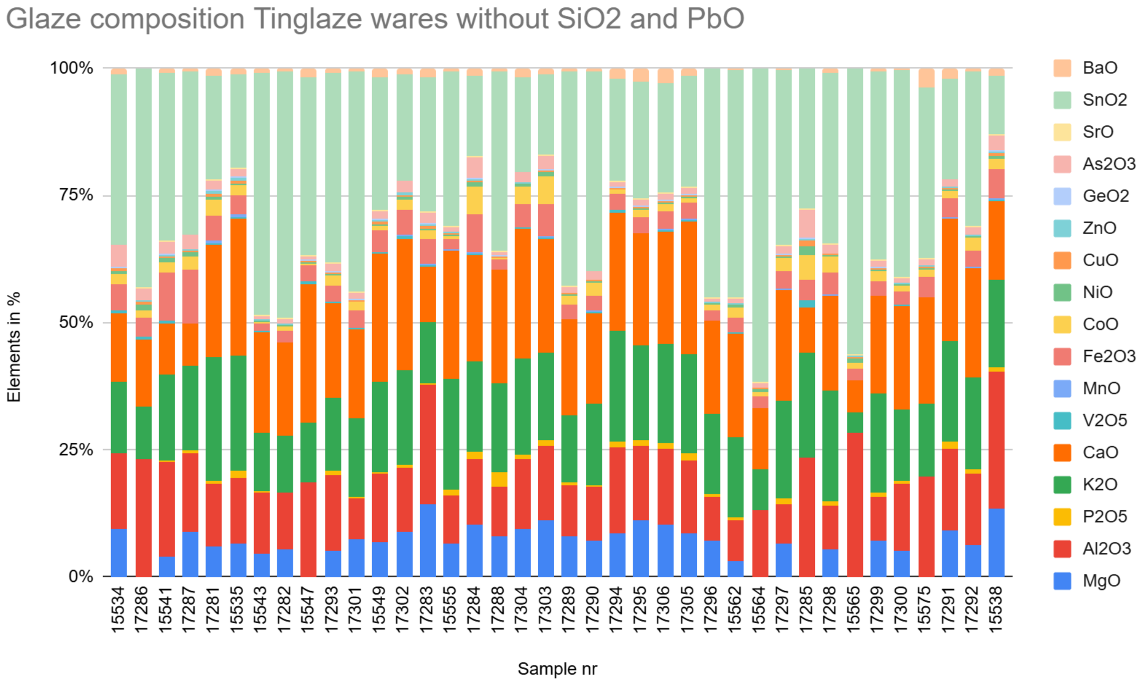

Figure 17. The histogram showing the glaze composition of the tinglaze wares without SiO_2 and PbO.

4.2.2. Blue pigment composition

Figure 18 shows the composition of the blue pigment. Because of the high levels of K, another histogram was created without the K, being figure 19.

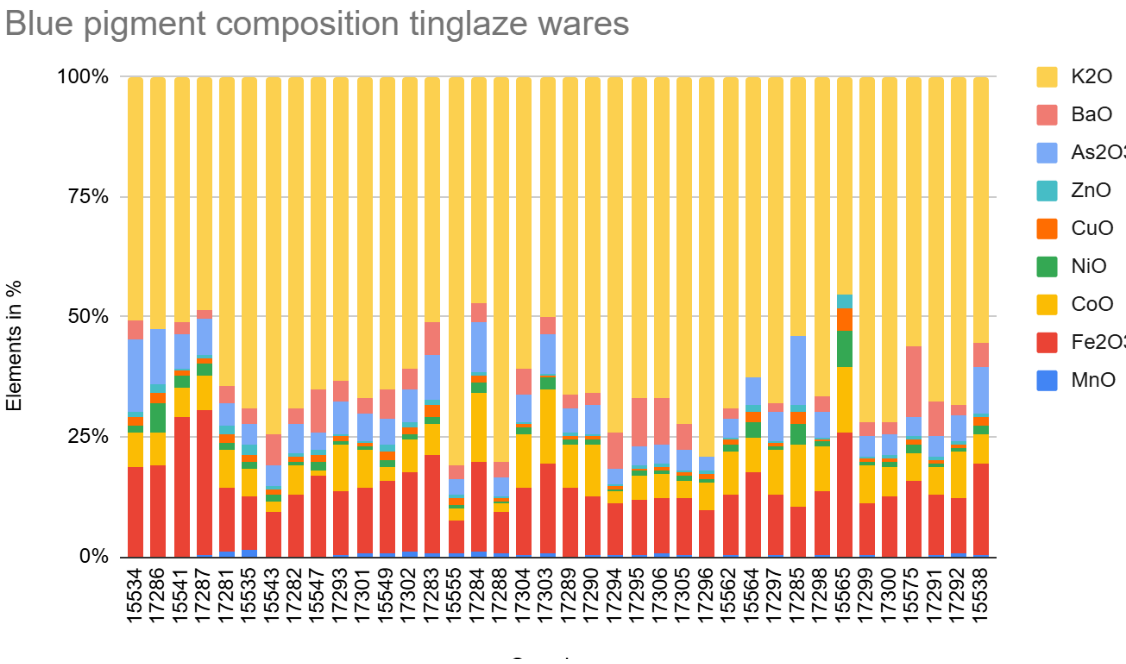

Figure 18. The composition of the blue pigment from the tinglaze wares.

The composition of the blue colourant in the tinglaze wares are largely based on Co combined with Fe, but do also have high levels or As and Ba. Ni tends to vary a lot, at times being barely visible and other times coming close to the size of Fe. There are five samples that do not include Ba, and one sample that also does not include any As, which is sample 15565. In these results, there is a lot of variability, thus multiple scatterplots have been made to see if there is a pattern.

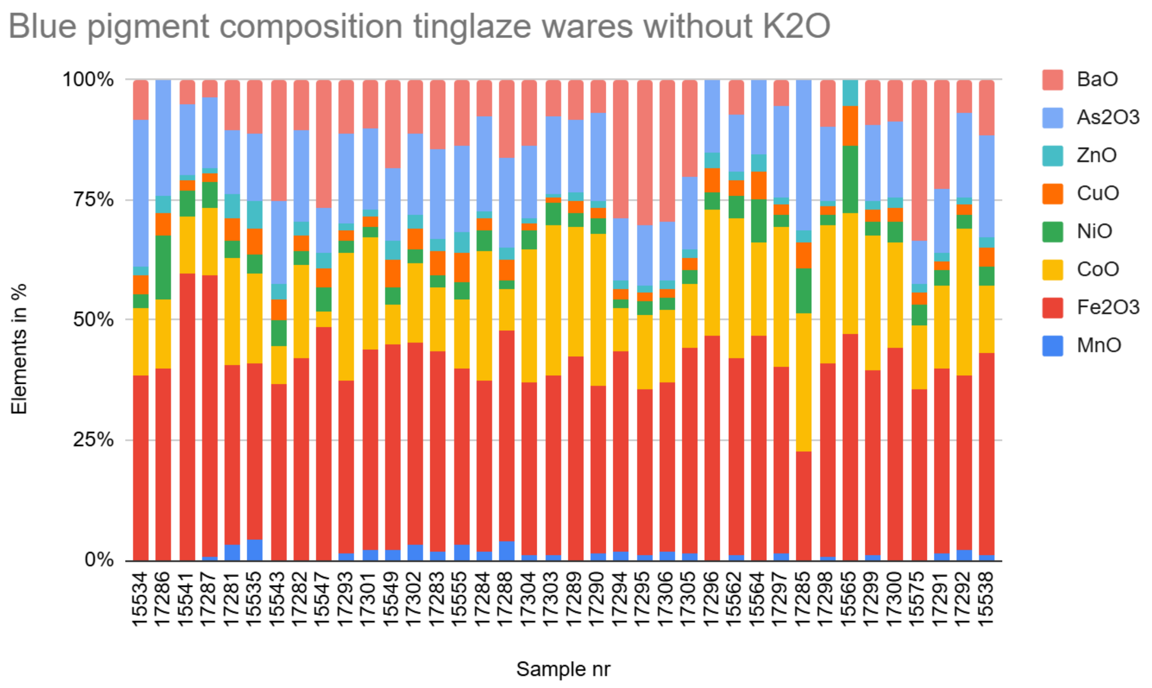

Figure 19. The composition of the blue pigment from the tinglaze wares without K_2O.

The K and Al scatterplot in figure 20 shows two different trendlines. One of which is more clear with more points, but the other one is visible as well. It could be that there were artefacts found from multiple different makers, or that only some belonged to the cargo while the rest

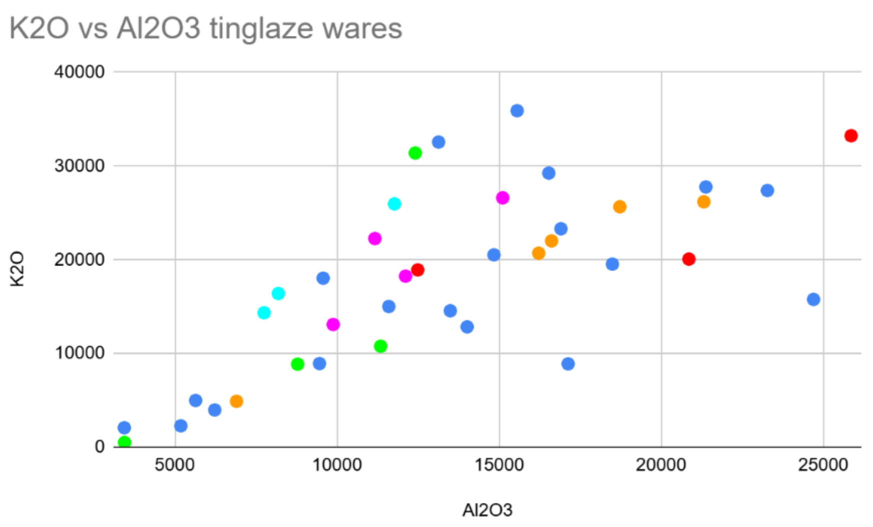

Figure 20. The K_2O and Al_2O_3 scatterplot of the tinglaze wares, with the different colours showing the different decorations on the ceramics. Green = fruit basket, orange = coat of arms, teal = fruit, pink = decorated borders, red = fruit dishes and blue = remaining artefacts.

was personal use items. The different coloured points show the artefacts with similar decorations. The green point is the fruit basket decoration. The orange points are the coat of arms plates. The teal points are the fruit decorations. The pink points are the plates with the decorated borders. The red points are the fruit dishes. The last colour is blue, which is for any of the remaining artefacts that could not be connected with the help of their decorations.

The Co versus Mn scatterplot shows an accumulation of points within the 400 ppm Co to 4000 ppm Mn in figure 21. This could very well be items that are related. There are fewer points in this plot than in the other, due to Mn being lower than the limit of detection for a small collection of artefacts. Overall, there does not seem to be a correlation between CoO and MnO.

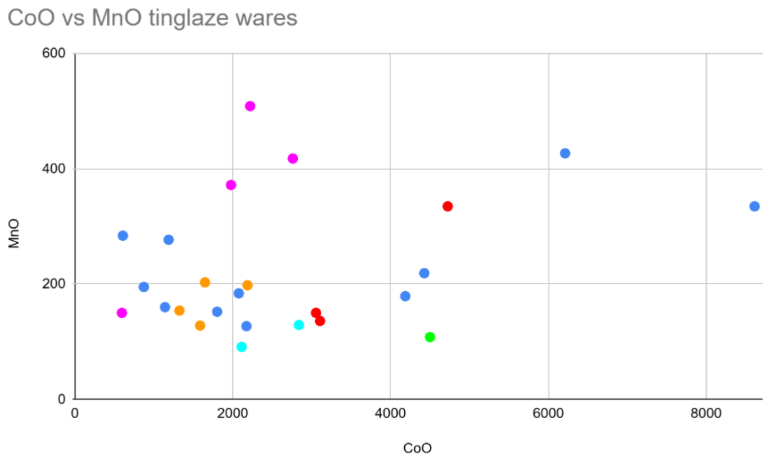

Figure 21. The CoO and MnO scatterplot for the tinglaze wares, with the different colours showing the different decorations on the ceramics. Green = fruit basket, orange = coat of arms, teal = fruit, pink = decorated borders, red = fruit dishes and blue = remaining artefacts.

The Westerwald jugs showed a strong correlation between the Cobalt and the Iron. The following scatterplot in figure 22 shows the cobalt and iron correlation for the majolica and faience. Although it is less obvious, there does still seem to be a slight correlation. The green mostly consists of very low Fe and Co, with one outlier. The orange mostly seems to bundle around the 2000 ppm values of cobalt, with one with very low ppm values. Although for the teal colour there are only three points, they do line up very well. Of the pink points, most are

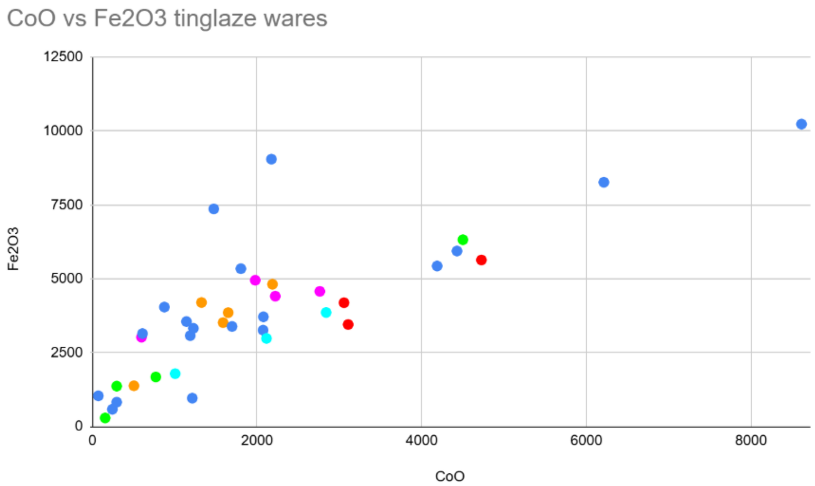

Figure 22. CoO and Fe_2O_3 scatterplot for the tinglaze wares, with the different colours showing the different decorations on the ceramics. Green = fruit basket, orange = coat of arms, teal = fruit, pink = decorated borders, red = fruit dishes and blue = remaining artefacts.

also very close to one another with the exception of one slightly lower. For the red points there is no apparent connection between these other than the fact that two of the points are slightly closer to each other. There almost seem to be two trendlines, thus showing two different groups. One that goes from the bottom left corner to the top right corner, and one that goes from the bottom left corner upwards, more steeper than the other trendline.

The CoO and NiO scatterplot shows trendlines like the Fe and Co plot. Most of the concentration is before 4000 ppm Co, but it does seem that the higher the Co ppm, the higher the Ni ppm. What can be seen is that just as in the previous plot, there are two outliers to the right. These are the same sample numbers, 17284 and 17303, as the outliers of the plot before this one.

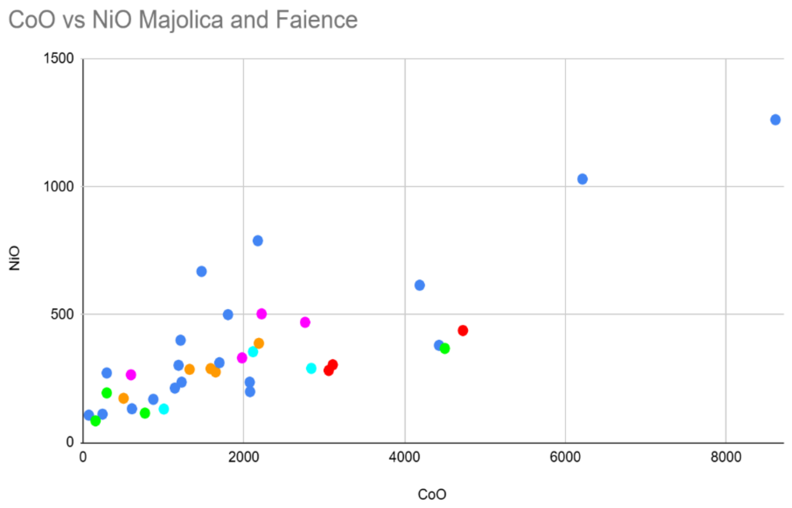

Figure 23. The CoO and NiO scatterplot for the tinglaze wares, with the different colours showing the different decorations on the ceramics. Green = fruit basket, orange = coat of arms, teal = fruit, pink = decorated borders, red = fruit dishes and blue = remaining artefacts.

The blue pigment composition will be shown here in table 4, as there is now a more limited amount of elements, making it more clear. In general, the cobalt ranges from 56 to 6773 ppm. Only one sample does not contain traceable As (15565). Ni is between 66 and 991 ppm. There are quite a few that do not contain Mn, but also a large amount that do. Many of these are between 100 and 400. All contain Cu (40 to 489 ppm, very varying amounts) and Zn (26 to 570 ppm).

The K ranges from 420 to 29814 ppm, but most are higher than 10000 ppm. As was also present in all measures, ranging from 147 to 3464 ppm, with one measure being below the detection limit. The Fe ranges from 201 to 7158 ppm. What should be kept in mind is the fact that some of the artefacts of this ship contained iron rust on the surface, due to the water in combination with metal objects. Though, during the measuring, spots on the artefacts were chosen with either no or very little visible iron on it.

Table 4. The XRF results of the blue pigment from the tinglaze wares.

Sample nr	Artefact nr	K2O	MnO	Fe2O3	CoO	NiO	CuO	ZnO	As2O3	BaO
15534	**BZN2-23**	7411	< LOD	2323	964	185	292	122	1998	640
17286	**BZN2-244**	1890	< LOD	575	232	213	77	55	375	< LOD
15541	**BZN2-403**	10665	< LOD	5150	1159	525	189	126	1361	573
17287	**BZN2-403**	12086	98	6328	1709	620	223	147	1740	478
15535	**BZN2-568**	22094	394	3084	1746	395	489	570	1283	1179
17281	**BZN2-568**	18489	324	3198	2172	369	444	500	1238	1154
15543	**BZN2-572-1**	8945	< LOD	955	232	152	135	93	484	839
17282	**BZN2-572-1**	7355	< LOD	1172	605	90	97	89	571	376
15547	**BZN2-572-9**	3299	< LOD	725	56	84	70	52	156	507
17293	**BZN2-618**	16666	116	2930	2403	221	221	133	1629	1161
17301	**BZN2-624-1**	14976	143	2595	1633	156	158	107	1132	806
15549	**BZN2-624-3**	10872	116	2114	468	208	319	212	824	1157
17302	**BZN2-624-3**	15153	288	3461	1555	260	402	265	1498	1188
17283	**BZN2-625**	7385	124	2484	898	167	354	165	1211	1105
15555	**BZN2-666**	29814	215	2151	934	237	418	294	1128	1037
17284	**BZN2-678**	17041	331	5781	4885	809	476	240	3464	1598
17288	**BZN2-679**	24283	220	2199	478	103	237	149	1005	1045
17303	**BZN2-680-1**	22742	259	7158	6773	991	241	138	3356	1863
17304	**BZN2-680-1**	19354	139	3798	3292	483	170	123	1733	1862
17289	**BZN2-685**	12465	< LOD	2279	1630	185	135	126	872	573

Sample nr	Artefact nr	K2O	MnO	Fe2O3	CoO	NiO	CuO	ZnO	As2O3	BaO
17290	**BZN2-686**	15706	105	2414	2442	238	166	118	1357	613
17294	**BZN2-687**	23057	151	2826	687	132	178	142	947	2519
17295	**BZN2-725**	17189	99	2459	1248	227	158	122	967	2764
17305	**BZN2-727-1**	21300	119	2935	1042	224	200	144	1127	1768
17306	**BZN2-727-1**	18277	157	2695	1296	216	164	150	1008	2883
15562	**BZN2-747-3**	13617	70	2085	1662	278	177	115	661	462
17296	**BZN2-747-3**	11909	< LOD	1250	790	102	161	95	436	< LOD
15564	**BZN2-747-6**	1723	< LOD	407	190	87	56	36	147	< LOD
17297	**BZN2-747-6**	27035	170	4153	3482	298	263	160	2191	746
17285	**BZN2-747-7**	4142	< LOD	671	953	314	182	89	1002	< LOD
15565	**BZN2-747-8**	420	< LOD	201	121	66	40	26	< LOD	< LOD
17298	**BZN2-747-8**	26067	84	4421	3539	289	191	138	1853	1364
17299	**BZN2-747-9**	21557	100	2698	2232	227	189	139	1226	838
17300	**BZN2-749**	16220	< LOD	2367	1333	245	176	135	913	599
15575	**BZN2-759-1**	4064	< LOD	963	396	135	78	53	262	1155
17291	**BZN2-759-1**	21743	153	3367	1720	304	211	164	1267	2557
17292	**BZN2-793**	27593	259	3941	3716	344	266	171	2046	972
15538	**BZN2-794**	13096	118	3735	363	392	401	197	2070	1296

As mentioned before, there was a selection of different decorations present on the plates that were grouped together by colour in the previous scatterplot. The following subchapters will further explain the decorations and the similarities or differences within the compositions, both in percentages and in ppm values.

4.3. Fruit basket

The picture below shows the artefact BZN2-747-8. The motif shows a fruit basket. The plate is nearly whole, only missing some pieces from the rim of the plate. Furthermore, it is stained from the environment it was buried in. The other fruit basket plate, BZN2-572-1, is more faded and less whole. The plates are faience, meaning they contain a white glaze on both the top and the bottom of the vessel.

Figure 24. The fruit basket decoration on the BZN2-747-8 faience plate (Batavialand, objectnr. BZN2-747-8, https://collectienederland.nl/page/aggregation/maritieme-archeologische-rijkscollectie-maritieme-vondsten/60036609).

4.3.1. The general glaze composition

After the main elements, Si and Pb, are removed from the graphical representation shown in figure 25, the Sn from the tin glaze becomes more readily identifiable.

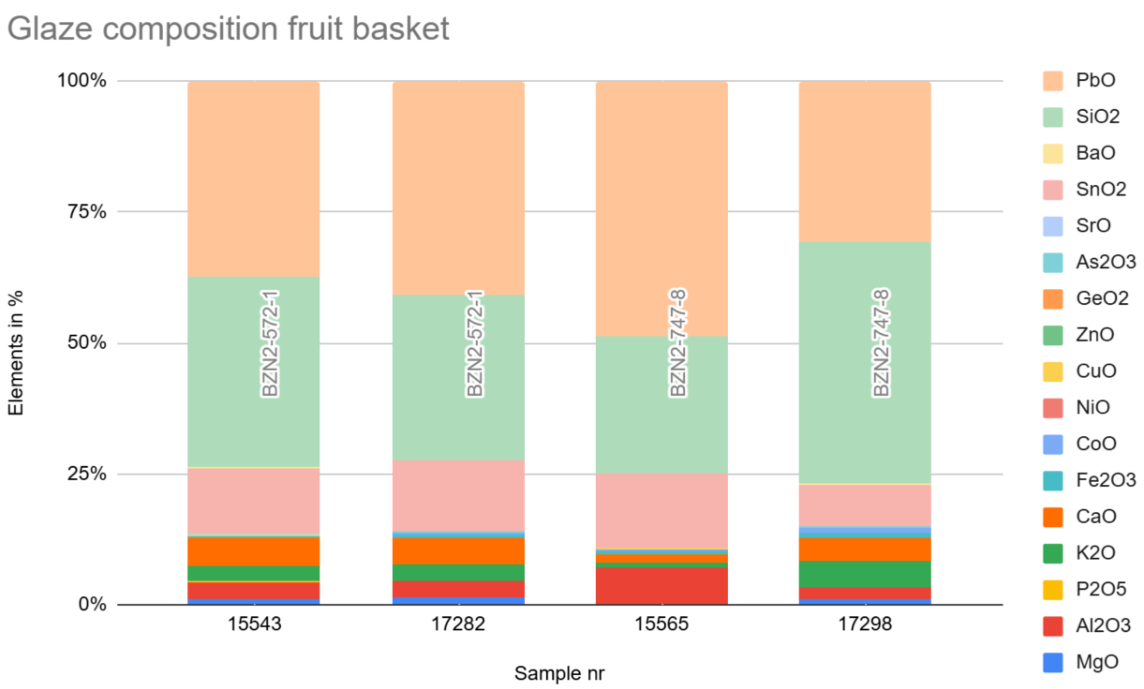

Figure 25. The composition of the glaze from the fruit basket decoration.

What is now also more visible in figure 26 is that the first measure taken from the 747-8 artefact most likely was erroneous. This was done during the first round of measurements, before the blue pigment became the subject of research. This is the same sample, 15565, as mentioned before that did not include Ba or As. Two samples were taken from the 572-1, as a test to see if the first measure went well. As is visible, these are only slightly different. However, 572-1 and 747-8 had the same motif, but the composition intensities are different. 747-8 was in slightly better shape than 572-1, as the latter was more faded.

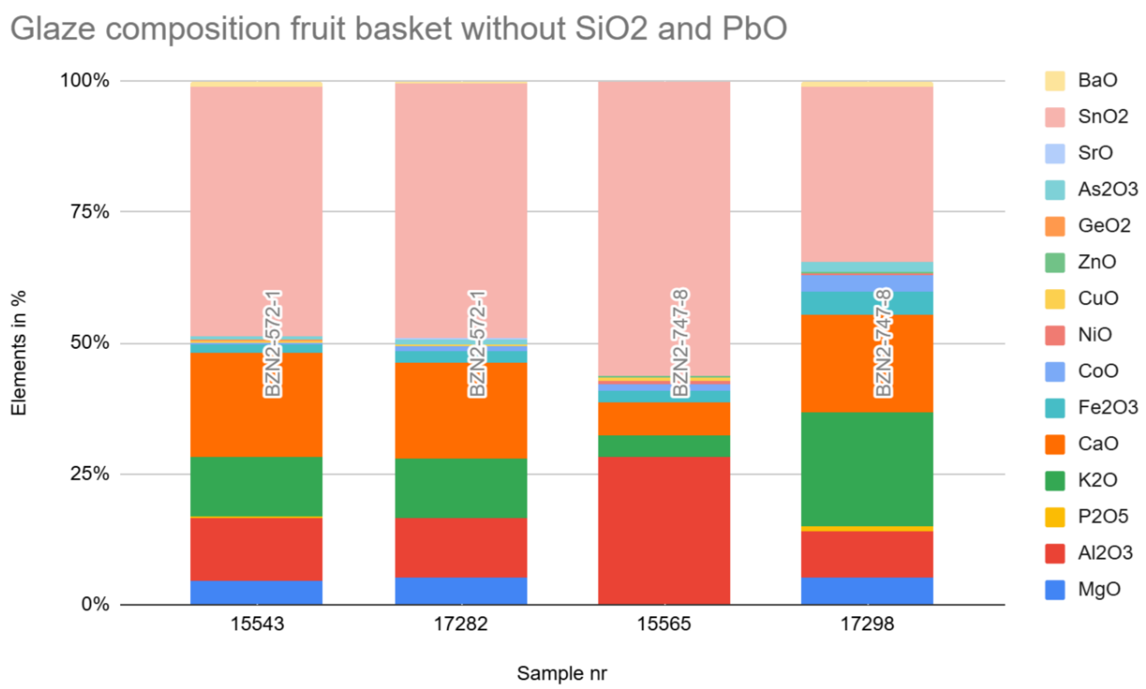

Figure 26. The composition of the glaze from the fruit basket decoration without SiO_2 and PbO.

Table 5 shows the ppm values of the four artefacts with the fruit basket decoration. Taking the cobalt values as an example, the ppm values vary from 121, to 232, to 605 and to 3539 ppm. So although the amounts in the histograms are comparable, the ppm values are vastly different. These ppm results can not be compared properly. What is mentionable, is that in three of the four measures done, the Mn is lower than the limit of detection.

Table 5. The XRF results of the fruit basket decoration in ppm.

Sample nr	**Artefact nr**	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O_5**	**K_2O**	**CaO**	**TiO_2**	**V_2O_5**	**Cr_2O_3**	**MnO**	**Fe_2O_3**	**CoO**	**NiO**	**CuO**	**ZnO**	**GeO_2**	**As_2O_3**	**SrO**	**SnO_2**	**BaO**	**PbO**
15543	**BZN2-572-1**	2555	6006	60127	122	8945	13272	<LOD	164	< LOD	<LOD	955	232	152	135	93	66	484	147	35202	839	115449
17282	**BZN2-572-1**	2527	4651	41669	<LOD	7355	10338	<LOD	<LOD	< LOD	<LOD	1172	605	90	97	89	51	571	121	30025	376	100544
15565	**BZN2-747-8**	<LOD	1826	6068	<LOD	420	538	<LOD	<LOD	< LOD	<LOD	201	121	66	40	26	<LOD	< LOD	21	5410	<LOD	20633
17298	**BZN2-747-8**	4610	6571	134852	588	26067	19168	38	<LOD	151	84	4421	3539	289	191	138	127	1853	245	37766	1364	165891

4.3.2. Blue pigment composition

The following graph in figure 27 for the blue pigment shows something more clearly than the last graph. One of the 747-8 measure, sample 15565, is very different from the 572-1 measures. Sample 17298 includes more noticeably more Fe and Co, but less Ni, Cu and Zn. Now, as mentioned before, 572-1 was far more faded than 747-8, which might explain why these percentages are so different. In general, the measures all seem to be much different from each other.

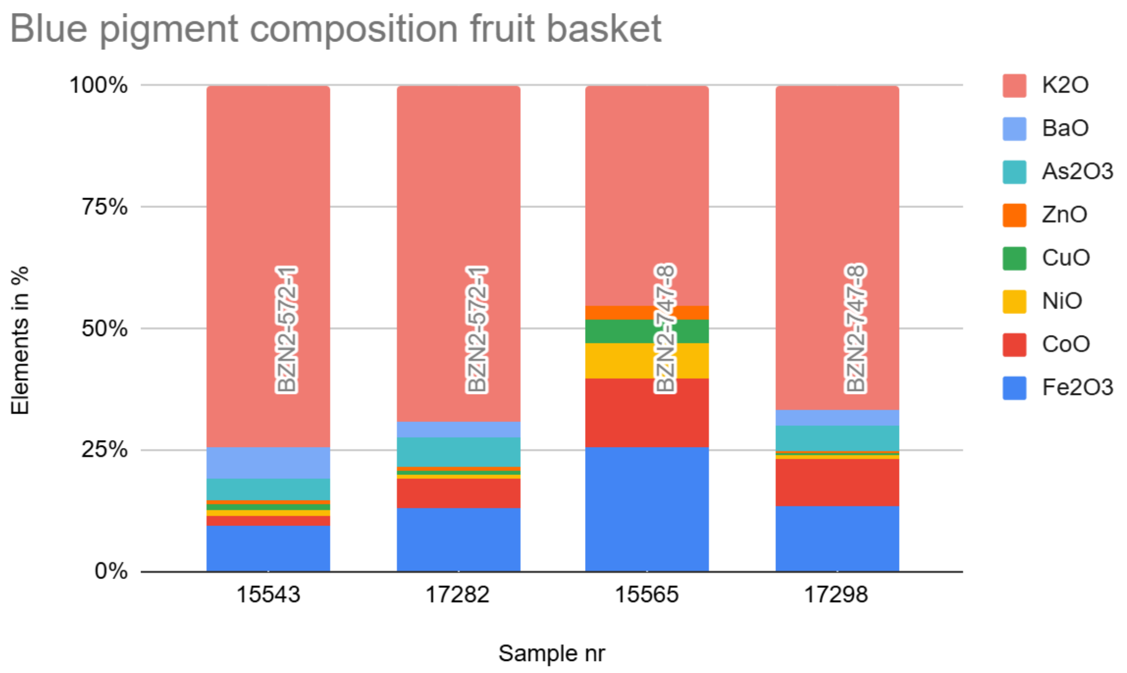

Figure 27. The blue pigment composition of the fruit basket.

As seen in figure 28, sample 17298 includes more noticeably more Fe and Co, but less Ni, Cu and Zn. Now, as mentioned before, 572-1 was far more faded than 747-8, which might explain why these percentages are so different. In general, the measures all seem to be much different from each other.

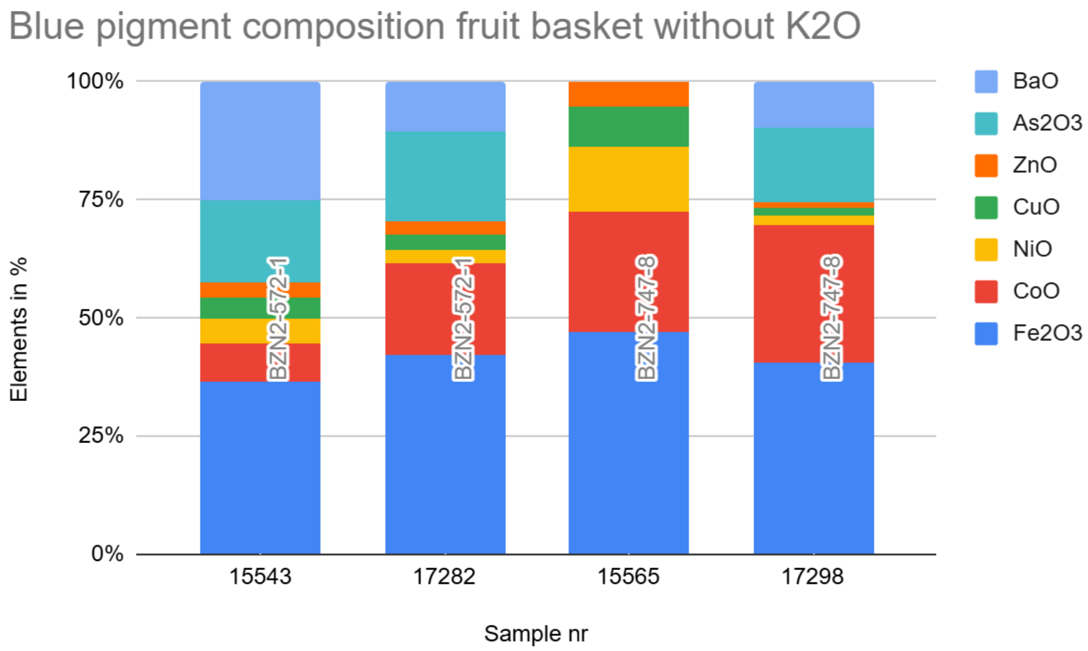

Figure 28. The blue pigment composition of the fruit basket without K_2O.

The following table 6 allows you to focus on the ppm values of the blue pigment, which shows what was previously speculated. Because of the faded blue pigment of 572-1, the ppm values are also far lower than the still very bright blue of 747-8. This can especially be seen in the K possibly from the smalt and the Mn, Fe and Co.

Table 6. The XRF results of the blue pigment from the fruit basket decoration in ppm.

Sample nr	Artefact nr	K2O	MnO	Fe2O3	CoO	NiO	CuO	ZnO	As2O3	BaO
15543	BZN2-572-1	8945	< LOD	955	232	152	135	93	484	839
17282	BZN2-572-1	7355	< LOD	1172	605	90	97	89	571	376
15565	BZN2-747-8	420	< LOD	201	121	66	40	26	< LOD	< LOD
17298	BZN2-747-8	26067	84	4421	3539	289	191	138	1853	1364

4.4. Coat of arms

There are three items that contain a decoration of a coat of arms or shield of some sort. Below is the artefact BZN2-725, which is the only plate with this design that is still nearly whole. The artefacts BZN2-727-1 and -759-1 consist of multiple sherds, where only part of the motif can be seen. However, due to the likeness of the motif, they can be identified as having the same decoration as 725. 727-1 seems to have two different coats of arms in its collection, one of which is very similar to 725, thus these sherds were measured separately.

Figure 29. The tinglaze plate BZN2-725 showing a coat of arms decoration (Batavialand, objectnr. BZN2-725, https://collectienederland.nl/page/aggregation/maritieme-archeologische-rijkscollectie-maritieme-vondsten/60031434).

4.4.1. The general glaze composition

The histogram in figure 30 presenting the percentages of the elements show that all measures taken from this decoration are very similar. Only the first measure of the BZN2-759-1, sample 15575 is different, but this measure was taken in the first XRF session. These measures contain less Sn, and more Mg, Al, K and Ca compared to the previous decoration.

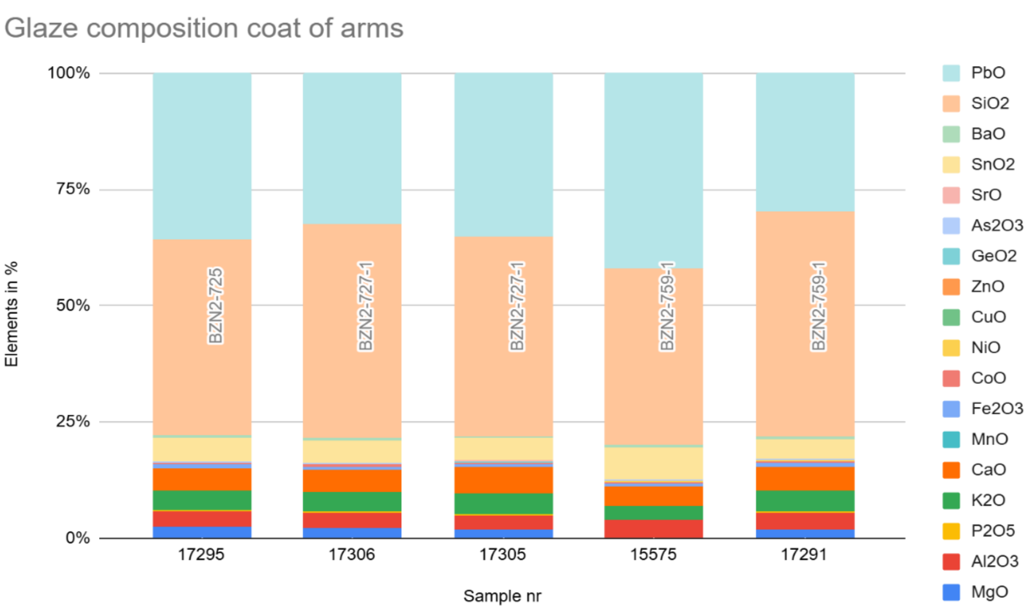

Figure 30. The glaze composition of the coat of arms decoration.

Figure 31 further shows sample 15575 being different. Sample 17305 seems to contain less Ba while containing more Ca.

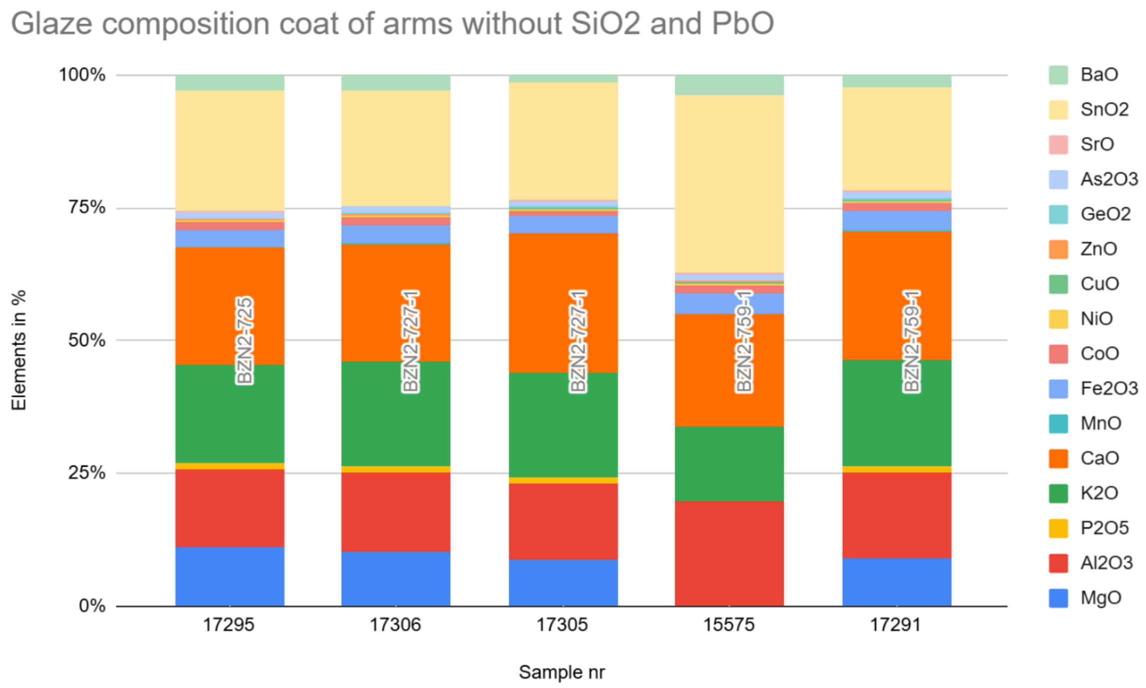

Figure 31. The glaze composition of the coat of arms decoration without SiO_2 and PbO.

Table 7 shows the ppm values of the coat of arms measures. Ignoring sample 15575 due to the different results, the Co ppm values are relatively close to one another. They include a measure of 1042, 1248, 1296 and a slight outlier of 1720 ppm. It seems that in most elemental ppm values, the second 759-1 measure, sample 17291 is always slightly higher than the rest. This can be seen in the Fe and Ni as well. On the contrary, the Cu and Zn measures are more similar.

Table 7. The XRF results of the coat of arms decoration in ppm.

Sample nr	Artefact nr	MgO	Al2O3	SiO2	P2O5	SO3	K2O	CaO	V2O5	Cr2O3	MnO	Fe2O3	CoO	NiO	CuO	ZnO	GeO2	As2O3	SrO	SnO2	BaO	PbO
15575	**BZN2-759-1**	<LOD	3654	30500	<LOD	<LOD	4064	5213	<LOD	< LOD	<LOD	963	396	135	78	53	24	262	76	9208	1155	62725
17291	**BZN2-759-1**	7185	11280	136801	781	<LOD	21743	22834	<LOD	< LOD	153	3367	1720	304	211	164	133	1267	258	20312	2557	155207
17295	**BZN2-725**	7432	8585	97189	535	< LOD	17189	17389	<LOD	< LOD	99	2459	1248	227	158	122	105	967	225	19907	2764	153876
17305	**BZN2-727-1**	6785	9910	120388	739	3414	21300	24303	207	139	119	2935	1042	224	200	144	144	1127	259	22477	1768	180769
17306	**BZN2-727-1**	7041	8795	111945	562	974	18277	17733	222	< LOD	157	2695	1296	216	164	150	120	1008	231	19149	2883	145520

4.4.2. Blue pigment composition

The blue pigment compositions in figure are very similar, almost identical to one another, with the exception of the first 759-1 measure, sample 15575. Other than some of the Ba, the differing amounts are barely visible. The second histogram does highlight better that sample 17305 is also slightly different.

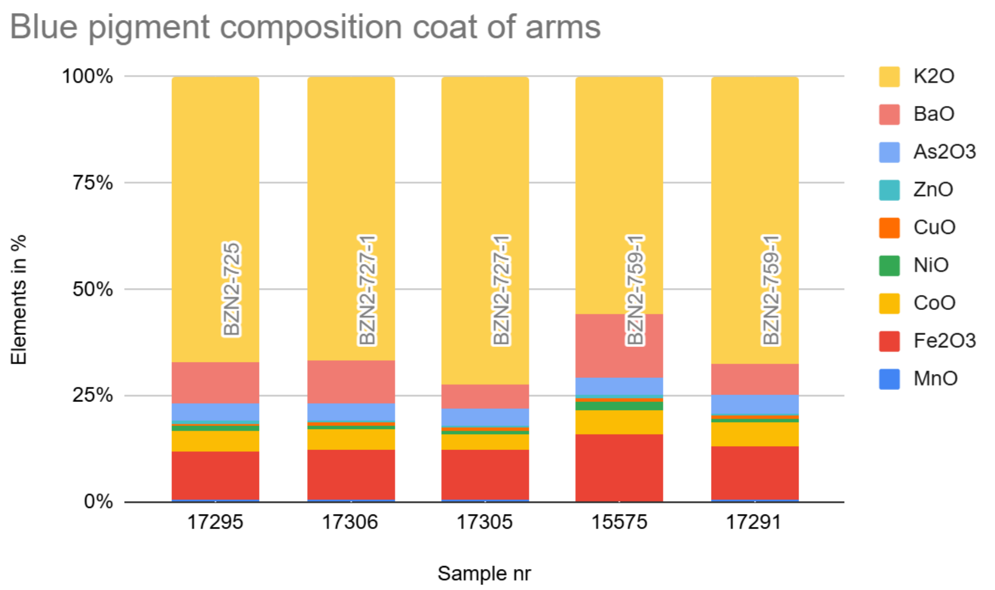

Figure 32. The composition of the blue pigment on the coat of arms decoration.

Figure 33 shows the similarities between sample 17295 and 17306 very well. The only visible difference is that 17306 seems to have a little bit less Ba, but more Mn.

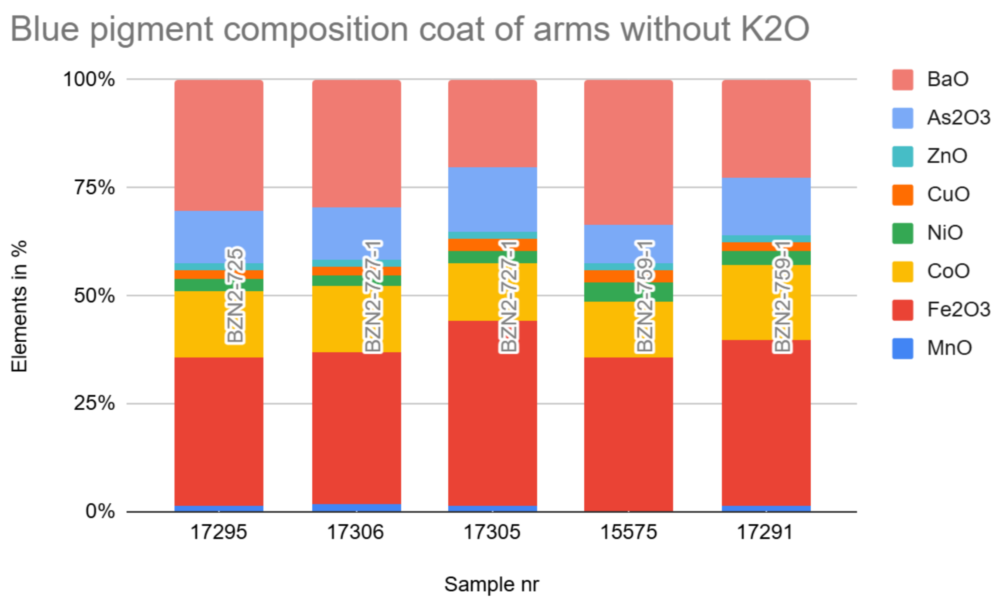

Figure 33. The composition of the blue pigment on the coat of arms decoration without K_2O.

Most of the ppm values for the blue pigment elements are very close to each other, with a few exceptions. As mentioned before, sample 15575 is very different. But the other measures are similar, which can be seen in Fe for example. The only large difference is in Ba. In most cases, sample 17291 has the highest ppm values, with a few exceptions in for example Mn.

Table 8. The XRF results of the blue pigment on the coat of arms decoration.

Sample nr	Artefact nr	K2O	MnO	Fe2O3	CoO	NiO	CuO	ZnO	As2O3	BaO
15575	**BZN2-759-1**	4064	< LOD	963	396	135	78	53	262	1155
17291	**BZN2-759-1**	21743	153	3367	1720	304	211	164	1267	2557
17295	**BZN2-725**	17189	99	2459	1248	227	158	122	967	2764
17305	**BZN2-727-1**	21300	119	2935	1042	224	200	144	1127	1768
17306	**BZN2-727-1**	18277	157	2695	1296	216	164	150	1008	2883

4.5. Fruit

The following decoration is a collection of fruits. The next figure shows BZN2-747-9. The other artefact, 747-3, is only a sherd of a plate, but due to the top part of the decoration it could be identified to be the same motif as 747-9.

Figure 34. Artefact BZN2-747-9 with the collection of fruits decoration (Batavialand, objectnr. BZN2-747-9, https://collectienederland.nl/page/aggregation/maritieme-archeologische-rijkscollectie-maritieme-vondsten/60036610).

4.5.1. The general glaze composition

In total, two different artefacts had this decoration and three measures were taken. The results of these measures can be seen in figure 35.

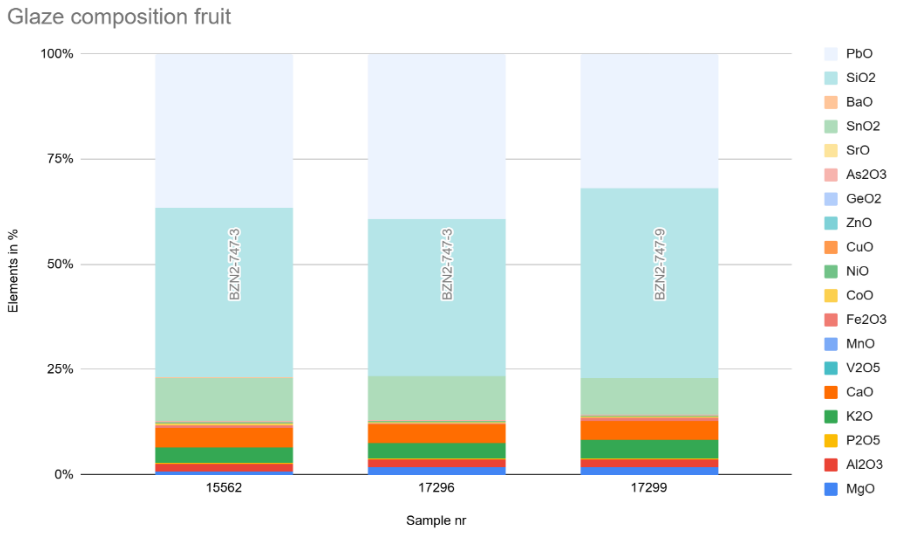

Figure 35. The glaze composition of the collection of fruit decoration.

After leaving out the Pb and Si in the histogram of figure 36, it shows that there is a large percentage dedicated to Sn. The Al and Mg are a smaller percentage, while K is larger. These measures look more like the measures done on the fruit basket decoration.

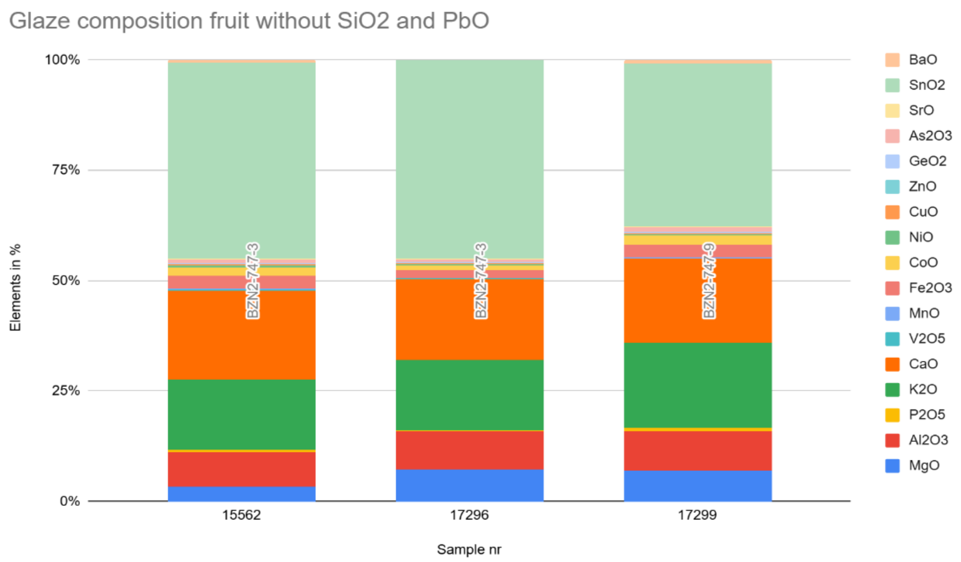

Figure 36. The glaze composition of the collection of fruit decoration without SiO_2 and PbO.

Table 9 shows the ppm values of the measures. The cobalt measures consist of 1005, 2114 and 2839 ppm. In general, most elemental ppm values of the artefacts are not comparable. Sample 15562, a sample taken in the first measuring session, in some cases has lower ppm values, while in others the highest of the group, often competing with sample 17299. Sample 17296 is often in the middle in regards to the amount of ppm values, but also often has the lowest amount.

Table 9. The XRF results of the collection of fruit decoration in ppm.

Sample nr	Artefact nr	MgO	Al2O3	SiO2	P2O5	K2O	CaO	TiO2	V2O5	Cr2O3	MnO	Fe2O3	CoO	NiO	CuO	ZnO	GeO2	As2O3	SrO	SnO2	BaO	PbO
15562	**BZN2-747-3**	2036	4335	83858	233	13617	14894	<LOD	161	< LOD	70	2085	1662	278	177	115	90	661	176	36268	462	142164
17296	**BZN2-747-3**	3973	4103	67932	172	11909	11941	<LOD	117	< LOD	<LOD	1250	790	102	161	95	68	436	153	32266	<LOD	131381
17299	**BZN2-747-9**	5649	6230	122121	415	21557	18290	84	< LOD	112	100	2698	2232	227	189	139	123	1226	212	38883	838	160670

4.5.2. Blue pigment composition

Figure 37 shows the composition of the blue pigment on the fruit decoration. About three quarters of blue pigment elements are K, possibly due to the smalt. The second 747-3 measure is actually slightly more different than the other two measures of this motif. There is barely any Ba compared to the other tinglaze artefacts.

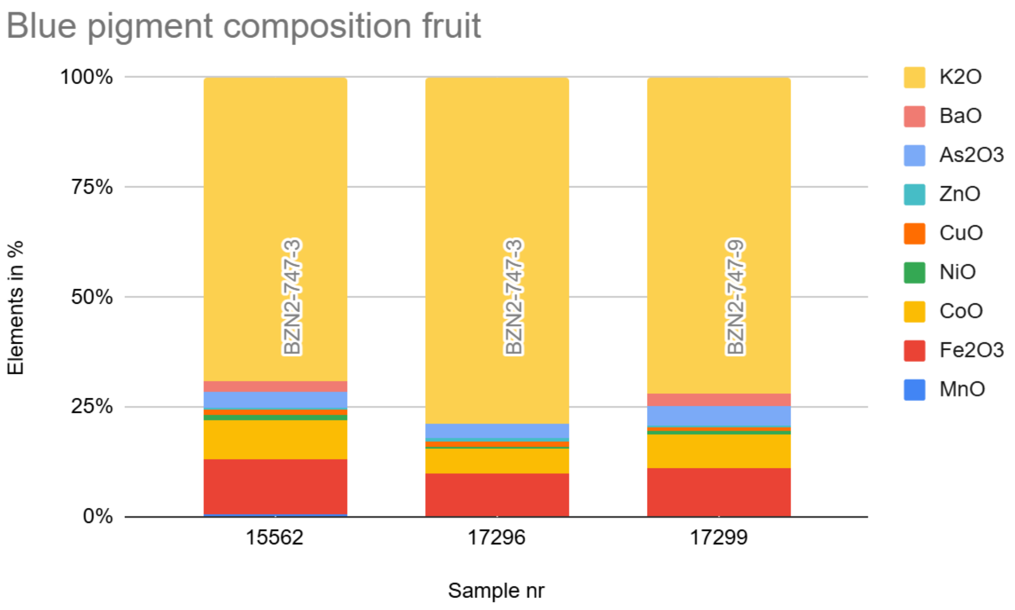

Figure 37. The blue pigment composition of the collection of fruit decoration.

As seen in figure 38, the blue colourant composition mostly consists of Fe, but Co and As also take up a large portion.

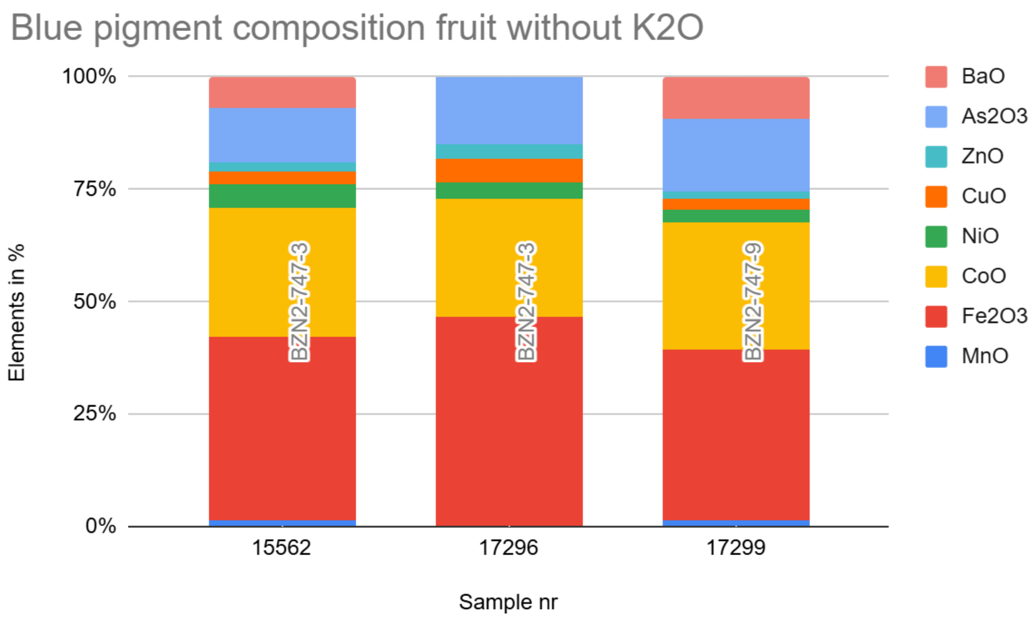

Figure 38. The blue pigment composition of the collection of fruit decoration without K_2O.

In table 10 it is seen as well that the Ba and Mn for the second 747-3 measure, the amount is lower than the limit of detection. The other ppm values of the Ba are not very high either, but they were high enough to be detected. It is interesting, as the second 747-3 measure was done with the blue pigment in mind, while the first one was not. In general, there are quite large ppm differences between all of the measures.

Table 10. The XRF results of the blue pigment on the fruit decoration in ppm.

Sample nr	Artefact nr	K2O	MnO	Fe2O3	CoO	NiO	CuO	ZnO	As2O3	BaO
15562	**BZN2-747-3**	13617	70	2085	1662	278	177	115	661	462
17296	**BZN2-747-3**	11909	< LOD	1250	790	102	161	95	436	< LOD
17299	**BZN2-747-9**	21557	100	2698	2232	227	189	139	1226	838

4.6. Border

The next decoration are plates with a similarly decorated border. The majolica plate seen in figure 39 is artefact BZN2-568. The border is filled with what can best be described as S-shapes. This artefact is relatively whole, but the artefact 624-3 is only part of the edge of the plate, thus only the border decoration is present. The usual white glaze on the top is now a light blue, with dark blue decorative glaze.

Figure 39. The tinglaze plate BZN2-568 with the decorated border (Batavialand, objectnr. BZN2-568, https://collectienederland.nl/page/aggregation/maritieme-archeologische-rijkscollectie-maritieme-vondsten/60031248).

4.6.1. The general glaze composition

Figure 40 shows that here is a smaller amount of Sn compared to the previous decorations. There were two measures taken of two artefacts. The results of these measures differ from each other slightly, which can point to different spots on the artefacts being used for the measures.

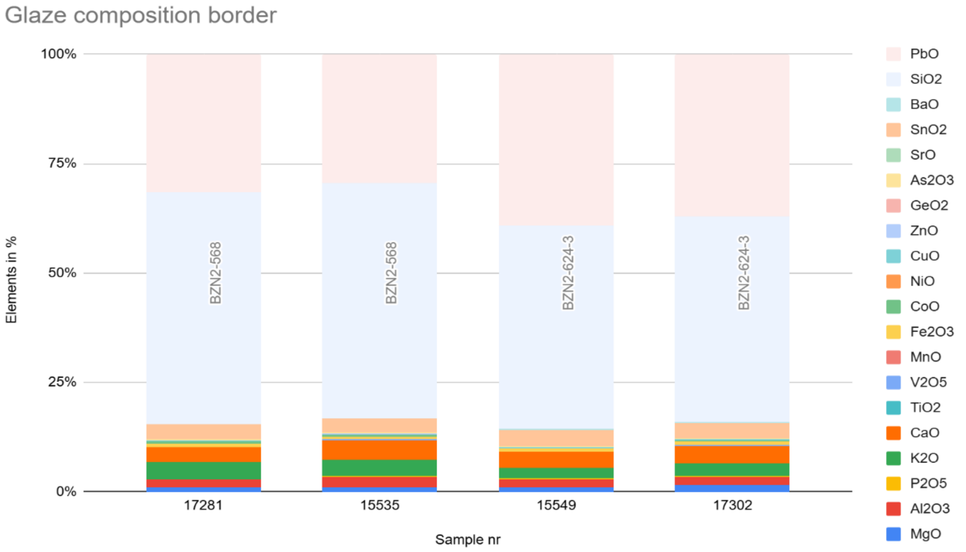

Figure 40. The glaze composition of the plates with the decorated borders.

Sample 15549 seems to be the most different in figure 41. This sample has more Sn than the rest. Though the K seems to be comparable to that of sample 17302. The Al and Mg seem to be almost the exact same throughout the four samples.

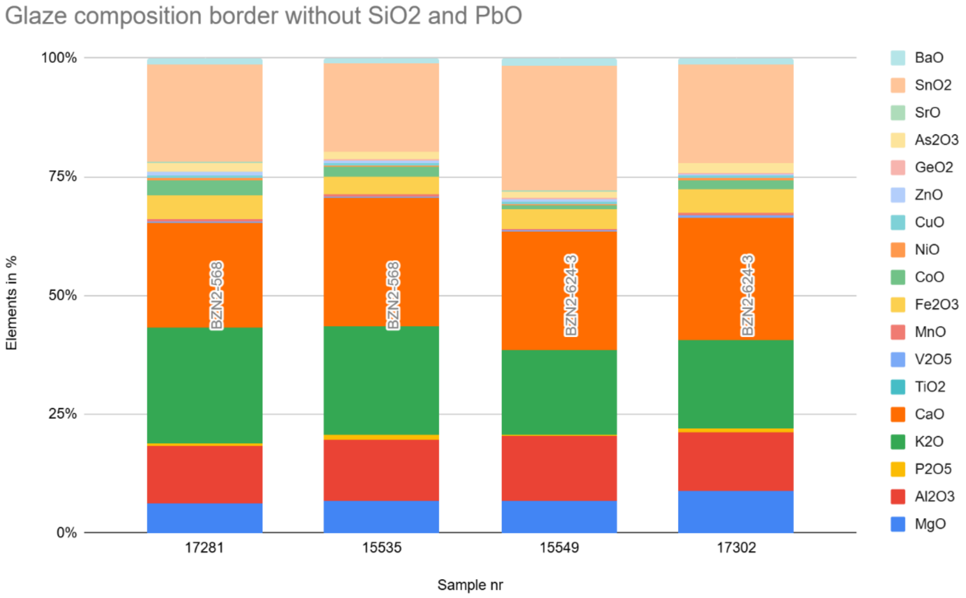

Figure 41. The glaze composition of the plates with the decorated borders without SiO_2 and PbO.

As seen in table 11, the measures are relatively close to each other in ppm values, with the exception of sample 15549 of object BZN2-624-3. The ppm values of this measure is significantly lower than the other ppm values, taking for example the Co. The other three measures lie between 1555 and 2172 ppm, while 15549 is 468 ppm. The BZN2-568 measures practically always are very similar, with a few insignificant exceptions, and the other 624-3 measure is not far away from the other ppm values.

Table 11. The XRF results of the glaze from the decorated border plates in ppm.

Sample nr	Artefact nr	MgO	Al2O3	SiO2	P2O5	K2O	CaO	TiO2	V2O5	MnO	Fe2O3	CoO	NiO	CuO	ZnO	GeO2	As2O3	SrO	SnO2	BaO	PbO
15535	**BZN2-568**	4690	7998	174930	618	22094	22654	94	181	394	3084	1746	395	489	570	161	1283	188	17088	1179	178708
17281	**BZN2-568**	3379	5912	145492	199	18489	14435	< LOD	169	324	3198	2172	369	444	500	122	1238	153	14730	1154	161262
15549	**BZN2-624-3**	3011	5231	109899	113	10872	13076	< LOD	143	116	2114	468	208	319	212	117	824	137	15086	1157	172974
17302	**BZN2-624-3**	5329	6413	136301	292	15153	18050	74	278	288	3461	1555	260	402	265	161	1498	177	16001	1188	199825

4.6.2. Blue pigment composition

The largest part of the blue colourant is as usual K which can be seen in figure 42. Each measure is unique, being slightly different from one another. Fe, Co and As seem to make up the largest part of the pigment next to K.

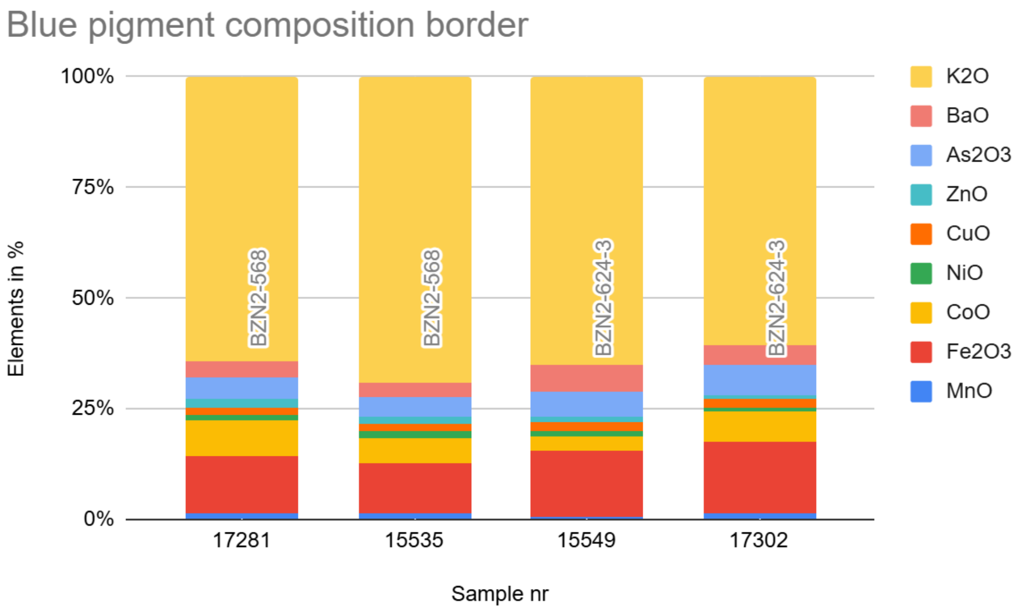

Figure 42. The composition of the blue pigment on the decorated border.

Sample 15549 In figure 43 looks to be the most different from the rest of the measures. The Fe is lower, while Ba is higher. Furthermore, the amount of Ni, Cu and Zn seem to be comparable with each other.

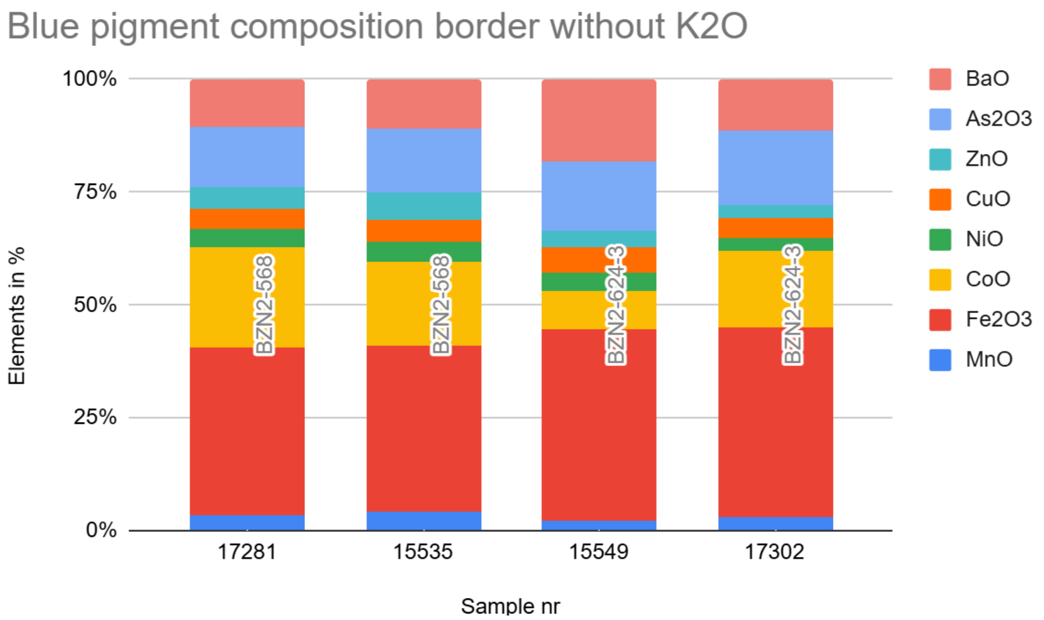

Figure 43. The composition of the blue pigment on the decorated border without K_2O.

Sample 15549 also seems to be most different in table 12 below. The ppm values of this sample are often more than 100 ppm lower, and for certain elements more than 500 to 5000 ppm lower.

Table 12. The XRF results of the blue pigment from the decorated borders.

Sample nr	Artefact nr	K2O	MnO	Fe2O3	CoO	NiO	CuO	ZnO	As2O3	BaO
15535	BZN2-568	22094	394	3084	1746	395	489	570	1283	1179
17281	BZN2-568	18489	324	3198	2172	369	444	500	1238	1154
15549	BZN2-624-3	10872	116	2114	468	208	319	212	824	1157
17302	BZN2-624-3	15153	288	3461	1555	260	402	265	1498	1188

4.7. Fruit dish

This decoration displays a fruit dish. The figure shows the complete BZN2-618 plate. 686 only misses part of the top but is still relatively whole, while 793 is only a sherd. This sherd does clearly show the dish, which is why it is comparable to the other fruit dish.

Figure 44. The fruit dish decoration of BZN2-618 (Batavialand, objectnr. BZN2-618, https://collectienederland.nl/page/aggregation/maritieme-archeologische-rijkscollectie-maritieme-vondsten/60031315).

4.7.1. The general glaze composition

The first two artefacts seen in figure 45 below are very similar, with slight differences mostly in the Al and Mg, and the third sample 17292 has less Sn, but more Ca and K. The third sample also contains less Pb but more Si.

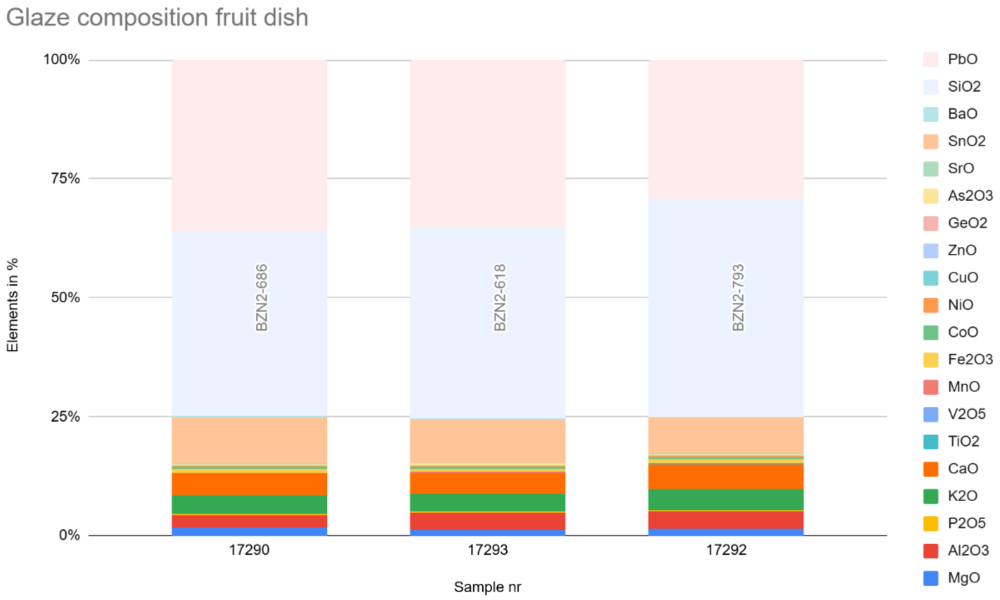

Figure 45. The glaze composition of the fruit dish decoration.

Figure 46 further shows the similarities of samples 17290 and 17293. Sample 17292 does look very similar, but the Sn difference is notable.

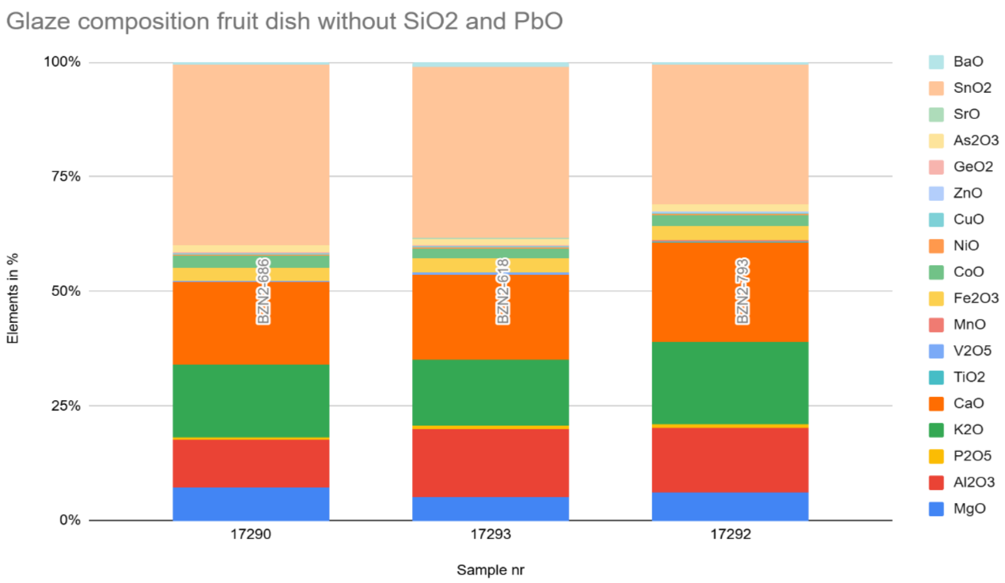

Figure 46. The glaze composition of the fruit dish decoration without SiO_2 and PbO.

The ppm values of the artefacts are close to each other, with the BZN2-793 always being quite a bit higher as seen in table 13. For example, the Co of BZN2-686 and BZN2-618 are 2403 and 2442 ppm, while the cobalt of BZN2-793 is 3716.

Table 13. The XRF results of the glaze from the fruit dish decoration in ppm.

Sample nr	Artefact nr	MgO	Al2O3	SiO2	P2O5	K2O	CaO	TiO2	V2O5	Cr2O3	MnO	Fe2O3	CoO	NiO	CuO	ZnO	GeO2	As2O3	SrO	SnO2	BaO	PbO
17290	**BZN2-686**	5084	6611	85417	211	15706	15077	42	138	< LOD	105	2414	2442	238	166	118	102	1357	175	36503	613	137200
17292	**BZN2-793**	6899	13684	158771	645	27593	28384	345	< LOD	129	259	3941	3716	344	266	171	181	2046	298	44013	972	186023
17293	**BZN2-618**	4212	11036	105674	450	16666	18379	< LOD	249	< LOD	116	2930	2403	221	221	133	131	1629	235	40893	1161	172623

4.7.2. Blue pigment composition

The composition of the blue pigment for the fruit dish has a similar amount of Fe and Co as can be seen in figure 47. Sample 17929 has slightly more K, while sample 17293 has more As and Ba.

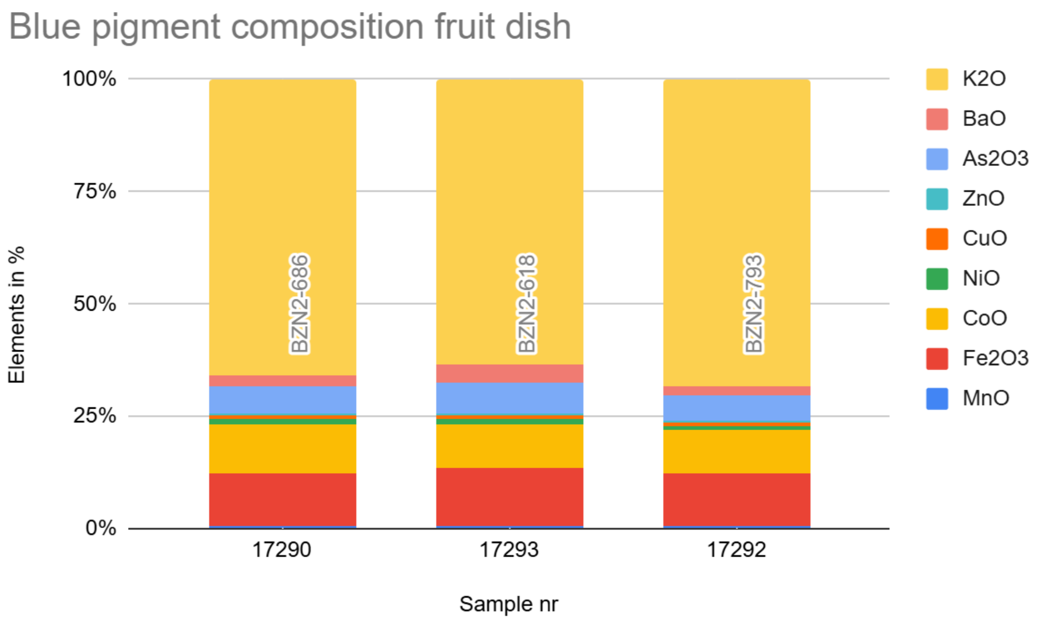

Figure 47. The blue pigment composition of the fruit dish decoration.

The next histogram highlights the larger amount of As and Ba form sample 17293. However, this sample does seem to have a smaller amount of Co.

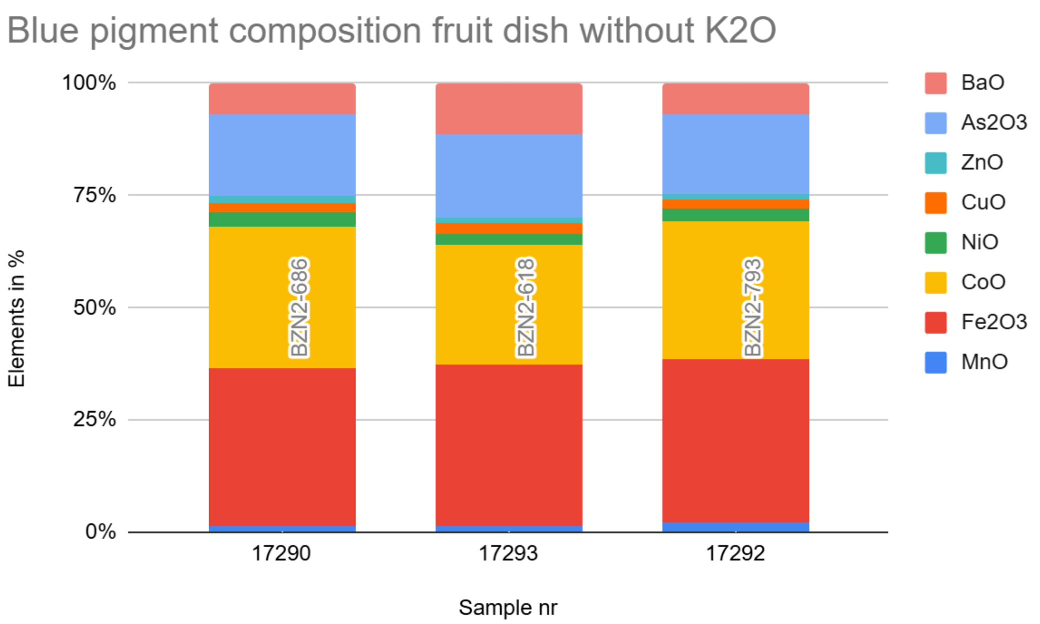

Figure 48. The blue pigment composition of the fruit dish decoration without K_2O.

Table 14 shows the ppm values of the blue pigment from the fruit dish decoration. Sample 17290 and 17293 are very similar in ppm values, with a few exceptions. Ba for example is almost doubled between the two, and Cu differs slightly more as well. Sample 17292 tends to have much higher measures. This was seen in the previous scatterplots as well. The only exception is for Ba, where 17292 has a lower ppm than 17293.

Table 14. The XRF results of the blue pigment on the fruit dish decoration in ppm.

Sample nr	Artefact nr	K2O	MnO	Fe2O3	CoO	NiO	CuO	ZnO	As2O3	BaO
17290	**BZN2-686**	15706	105	2414	2442	238	166	118	1357	613
17292	**BZN2-793**	27593	259	3941	3716	344	266	171	2046	972
17293	**BZN2-618**	16666	116	2930	2403	221	221	133	1629	1161

4.8. Remaining artefacts

4.8.1. The general glaze composition

The remaining artefacts that had blue decorations but could not be linked to other decorations will be discussed here. The exact amounts differ greatly, but there is mostly the same composition. Largely existing out of Si and Pb as seen in figure 49.

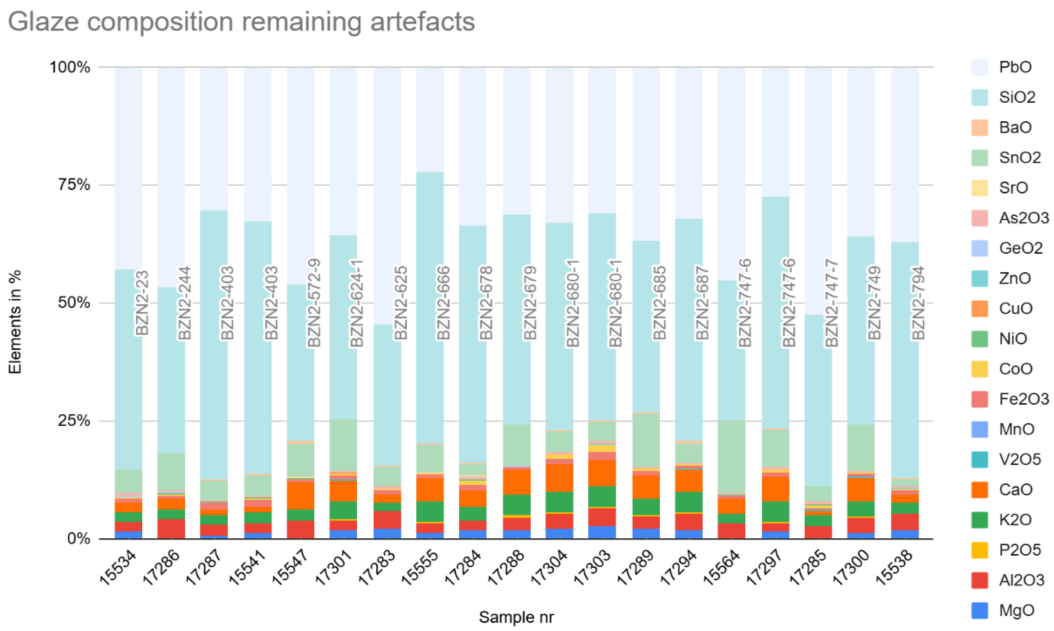

Figure 49. The glaze composition of the remaining artefacts.

After excluding those from the histogram in figure 50, the largest part is now Sn, with Ca and K following. The results of these remaining artefacts are certainly more diverse in percentages than the ones where the decoration is the same, but the compositions are the same.

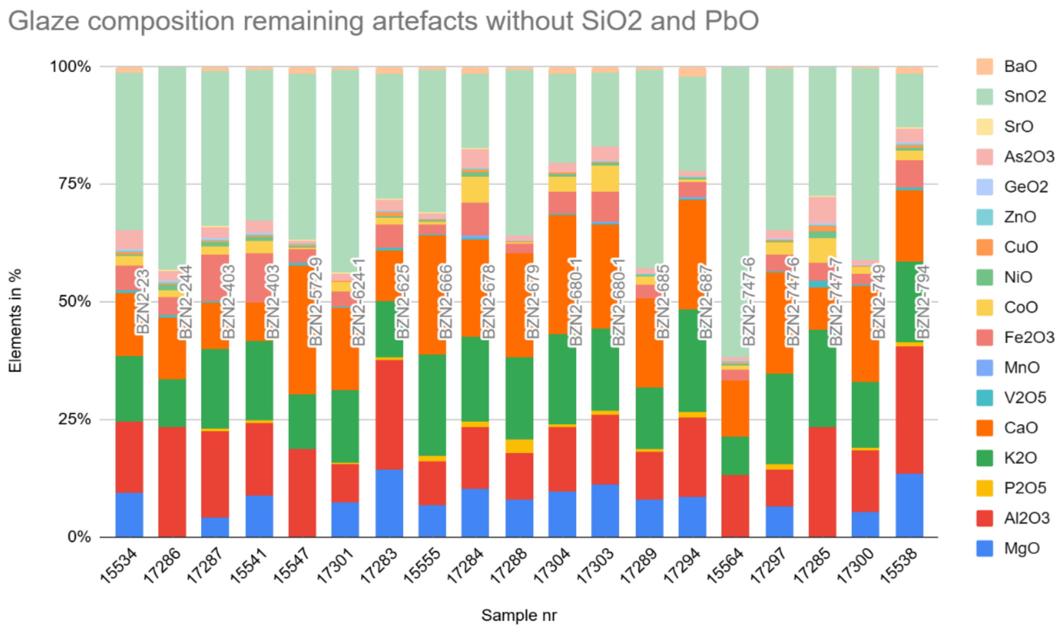

Figure 50. The glaze composition of the remaining artefacts without SiO_2 and PbO.

Because there is nothing that clearly links these artefacts together in the large overview of table 15, other than the fabric and the fact that blue pigment is used, the ppm values are also vastly different. Cobalt for example ranges from 56 to 6773 ppm.

Table 15. The XRF results of the glaze from the remaining artefacts.

Sample nr	Artefact nr	MgO	Al2O3	SiO2	P2O5	SO3	K2O	CaO	TiO2	V2O5	Cr2O3	MnO	Fe2O3	CoO	NiO	CuO	ZnO	GeO2	As2O3	SrO	SnO2	BaO	PbO
15534	**BZN2-23**	3633	5009	86095	< LOD	< LOD	7411	6035	< LOD	780	< LOD	< LOD	2323	964	185	292	122	111	1998	93	16739	640	161405
17286	**BZN2-244**	< LOD	2745	20354	< LOD	< LOD	1890	2078	< LOD	85	< LOD	< LOD	575	232	213	77	55	11	375	54	7551	< LOD	49844
15541	**BZN2-403**	1889	7418	162824	125	< LOD	10665	5450	285	161	< LOD	< LOD	5150	1159	525	189	126	128	1361	103	19819	573	160061
17287	**BZN2-403**	4596	7143	160485	206	< LOD	12086	5127	437	< LOD	< LOD	98	6328	1709	620	223	147	148	1740	115	21960	478	181351
15547	**BZN2-572-9**	< LOD	3299	25411	< LOD	< LOD	3299	6537	< LOD	103	< LOD	< LOD	725	56	84	70	52	20	156	73	14959	507	65228
17301	**BZN2-624-1**	5157	5068	83209	172	< LOD	14976	14378	< LOD	234	< LOD	143	2595	1633	156	158	107	91	1132	184	39644	806	140895
17283	**BZN2-625**	6281	9066	66866	124	978	7385	5609	< LOD	164	< LOD	124	2484	898	167	354	165	139	1211	169	15185	1105	225110
15555	**BZN2-666**	6697	8233	222337	836	1923	29814	29768	363	231	207	215	2151	934	237	418	294	158	1128	282	39614	1037	158035
17284	**BZN2-678**	7131	7855	167926	689	< LOD	17041	16928	159	304	132	331	5781	4885	809	476	240	175	3464	197	14249	1598	206425
17288	**BZN2-679**	7957	8750	143157	2019	< LOD	24283	26468	234	< LOD	182	220	2199	478	103	237	149	147	1005	295	46173	1045	185803
17303	**BZN2-680-1**	10684	12318	130180	728	8168	22742	25297	< LOD	252	137	259	7158	6773	991	241	138	137	3356	243	19527	1863	170716

Sample nr	Artefact nr	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	V_2O_5	Cr_2O_3	MnO	Fe_2O_3	CoO	NiO	CuO	ZnO	GeO_2	As_2O_3	SrO	SnO_2	BaO	PbO
17304	**BZN2-680-1**	7076	8949	109058	402	< LOD	19354	22237	< LOD	244	< LOD	139	3798	3292	483	170	123	112	1733	204	18041	1862	152093
17289	**BZN2-685**	5457	6139	72542	209	< LOD	12465	15380	< LOD	< LOD	< LOD	< LOD	2279	1630	185	135	126	95	872	175	37898	573	135897
17294	**BZN2-687**	6599	11314	136733	597	< LOD	23057	21134	< LOD	282	< LOD	151	2826	687	132	178	142	143	947	258	19912	2519	171223
15564	**BZN2-747-6**	< LOD	1823	14270	< LOD	< LOD	1723	2224	< LOD	< LOD	< LOD	< LOD	407	190	87	56	36	< LOD	147	45	12613	< LOD	40280
17297	**BZN2-747-6**	6615	6952	168374	926	< LOD	27035	26259	390	211	258	170	4153	3482	298	263	160	159	2191	306	45652	746	173831
17285	**BZN2-747-7**	< LOD	2986	37145	< LOD	< LOD	4142	1562	< LOD	181	< LOD	< LOD	671	953	314	182	89	50	1002	44	5233	< LOD	98828
17300	**BZN2-749**	4453	9788	107218	352	< LOD	16220	20586	141	221	< LOD	< LOD	2367	1333	245	176	135	114	913	205	44935	599	179559
15538	**BZN2-794**	7459	13071	167932	329	< LOD	13096	9988	238	245	< LOD	118	3735	363	392	401	197	219	2070	171	8161	1296	230500

4.8.2. Blue pigment composition

The pigment composition varies greatly in figure 51. The limited amount of elements however does make it easier to read the histograms. Sample 15555, a faience bowl, and sample 17288, a faience plate, seem to have relatively similar amounts, while being completely different from the other samples in regards to the smalt histogram.

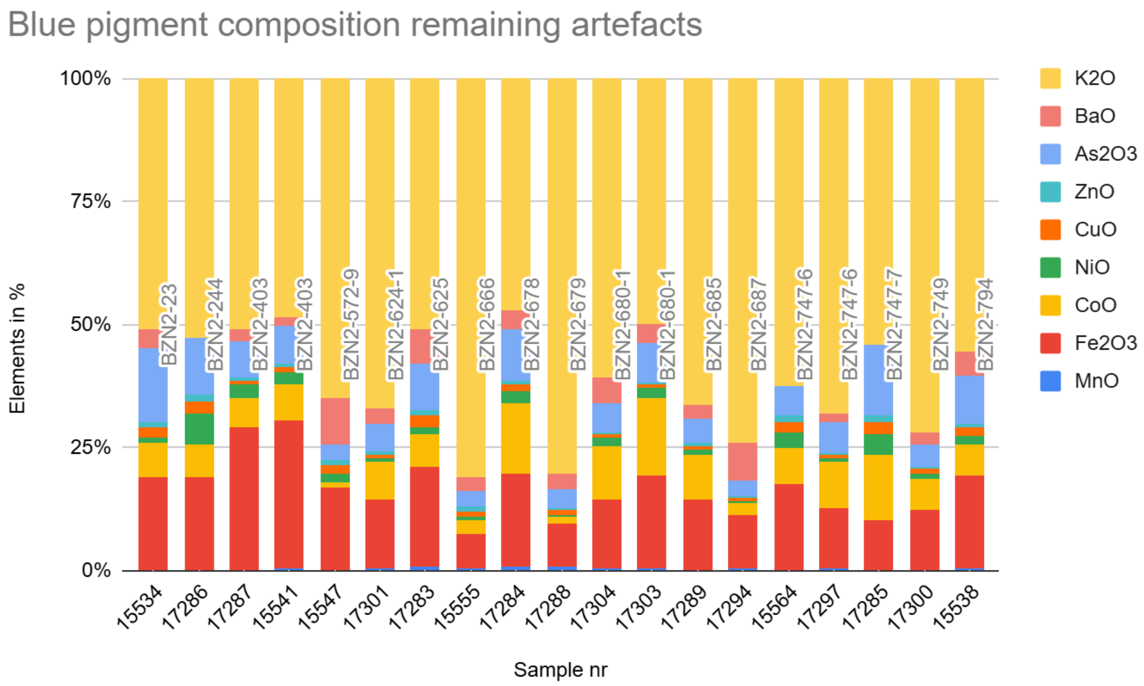

Figure 51. The composition of the blue pigment on the remaining artefacts.

In figure 52, three samples do not contain any Ba, but are otherwise not similar to one another. Sample 17285, artefact BZN2-747-7, stands out. This artefact contains no Ba and no Mn, and a smaller amount of Fe. This is a majolica plate with the inscription WI5 or WIS on the back. Artefact BZN2-403, of which samples 15541 and 17287 were taken, are of a southern European sherd. In the histogram it shows that this artefact contains more Fe than the other artefacts.

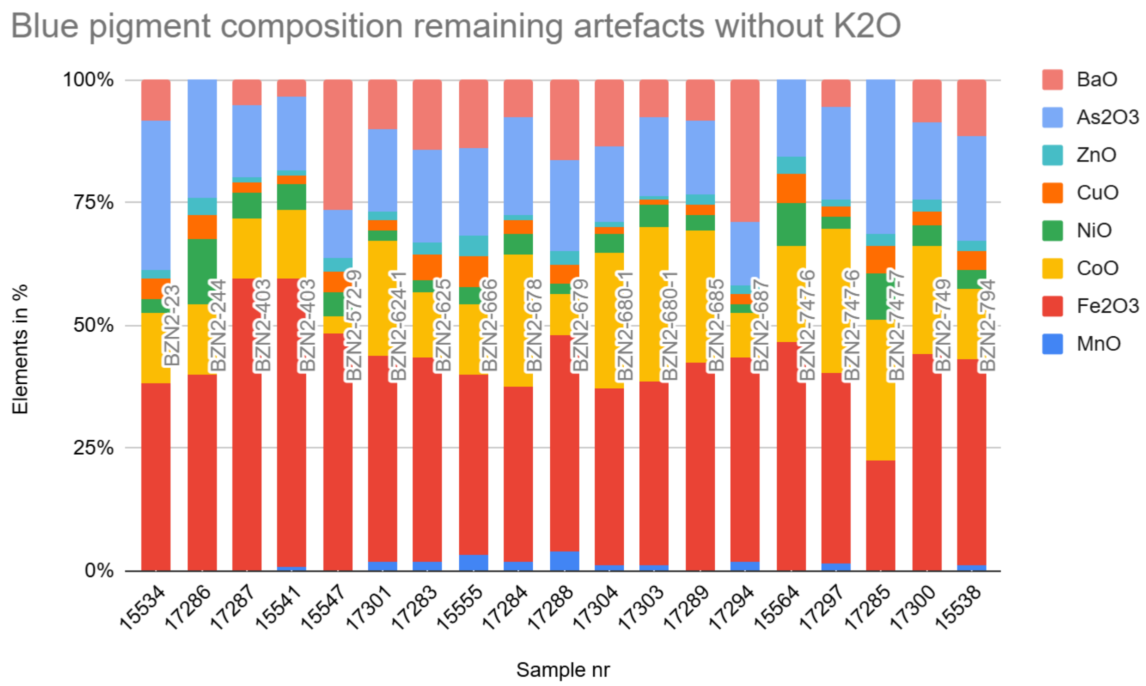

Figure 52. The composition of the blue pigment on the remaining artefacts without K_2O.

There are three samples that had Ba under the limit of detection which can be seen in table 16. These are samples 17286, 14464 and 17285. These samples also had the same with Mn, although Mn was below the limit of detection of a few other samples as well. Ba generally lies between 478 and 1863 ppm, with an outlier of 2519 ppm from sample 17294. The samples with no Ba also have very low K ppm compared to the others.

Table 16. The XRF results of the blue pigment on the remaining artefacts.

Sample nr	Artefact nr	K2O	MnO	Fe2O3	CoO	NiO	CuO	ZnO	As2O3	BaO
15534	**BZN2-23**	7411	< LOD	2323	964	185	292	122	1998	640
15538	**BZN2-794**	13096	118	3735	363	392	401	197	2070	1296
15541	**BZN2-403**	10665	< LOD	5150	1159	525	189	126	1361	573
15547	**BZN2-572-9**	3299	< LOD	725	56	84	70	52	156	507
15555	**BZN2-666**	29814	215	2151	934	237	418	294	1128	1037
15564	**BZN2-747-6**	1723	< LOD	407	190	87	56	36	147	< LOD
17283	**BZN2-625**	7385	124	2484	898	167	354	165	1211	1105
17284	**BZN2-678**	17041	331	5781	4885	809	476	240	3464	1598
17285	**BZN2-747-7**	4142	< LOD	671	953	314	182	89	1002	< LOD
17286	**BZN2-244**	1890	< LOD	575	232	213	77	55	375	< LOD
17287	**BZN2-403**	12086	98	6328	1709	620	223	147	1740	478
17288	**BZN2-679**	24283	220	2199	478	103	237	149	1005	1045
17289	**BZN2-685**	12465	< LOD	2279	1630	185	135	126	872	573
17294	**BZN2-687**	23057	151	2826	687	132	178	142	947	2519
17297	**BZN2-747-6**	27035	170	4153	3482	298	263	160	2191	746
17300	**BZN2-749**	16220	< LOD	2367	1333	245	176	135	913	599
17301	**BZN2-624-1**	14976	143	2595	1633	156	158	107	1132	806
17303	**BZN2-680-1**	22742	259	7158	6773	991	241	138	3356	1863
17304	**BZN2-680-1**	19354	139	3798	3292	483	170	123	1733	1862

Chapter 5: Discussion

In order to fully be able to answer the main research question of this thesis, the literature and XRF results will be analysed and discussed in this chapter.

5.1. Pottery production sites

Westerwald stoneware was typically produced in Westerwald, as the name indicates, but also in places like Altenrath or Raeren (Bartels & Kottman, 1999, p. 65) in the Rhineland. What the production of Westerwald stoneware needed was quick access to clay, wood and communal kilns, which was found in Westerwald, making it an ideal place for producing (Chitty & Stocker, 2019, p. 374). So far, Westerwald has been named as the production site of these stoneware jugs, but this site really consisted of multiple different settlements that produced in the same general area. What made them be grouped together, was the fact that they used the same clay and techniques to create the stoneware (Urbonaite-Ube, 2018, p. 197). Therefore, there will not be a large difference between the stoneware created at one settlement in comparison to another settlement in regards to the clay.

A guild was formed in 1643 called the jug-bakers' guild, or in German, the Kannenbäckerzunft. This guild consisted of potters operating around the town Grenzhausen, Grenzau and Höhr, which were popular Westerwald production sites (Chitty & Stocker, 2019, p. 372). As mentioned, there were no private kilns. The Westerwald makers used communal kilns that were mostly positioned in the producing towns (Chitty & Stocker, 2019, p. 374). The kilns used for the stoneware are of a horizontal design (Nevell et al., 2022, p. 299). There were certain masters who ran the workshops and these kilns. Sometimes, they would even purchase a sort of permit for clay-digging. However, locals continued digging clay as well and created their own vessels, making use of these communal kilns (Chitty & Stocker, 2019, p. 374).

The Westerwald jugs from the BZN2 were all unique. Although four of the jugs have similar decorations, the scatterplots did not show a pattern except for the Co and Fe, which will be discussed further in the next subchapter as it pertains the blue pigment. The jugs were of different sizes however, only differing a few centimetres. Due to these types of jugs primarily being made in the Westerwald region, that limits the production area greatly. However, within this area there were multiple potters. The different decorations, sizes and XRF results point to multiple potters having been involved in the making of the BZN2 Westerwald jugs.

Tinglazed pottery was produced all over Europe, the Netherlands being no exception. Kleij (2002) determined all BZN2 tinglazed pottery to have been made in the Netherlands itself, with the exception of BZN2-403 likely being South-European, due to its thick tinglaze. It is clear that this artefact is different from the others, as it had a higher concentration and ppm values of Fe. Due to majolica having been made all over the Netherlands, with not a single dominating location, the specific location that these majolica plates were made were not ascertained (Kleij, 2002, p. 3). However, Kleij assumes that the faience ceramics that were found in the wreck of the BZN 2 were created in Delft. Delft was the largest Dutch faience production centre in the 17th century. An estimate of 80 million faience objects were made in Delft between 1650 to 1750. In comparison, a small majolica production centre was analysed, and in a period of 14 years it was estimated to have made 630.000 majolica objects (Bartels & Kottman, 1999, p. 208).

The XRF results of the tinglazed pottery were very variable. The concentrations, the ppm values and the scatterplots all showed different results. Other than the artefacts that included identical decorations, it is unlikely that all of the tinglaze wares were created by the same makers. There is a possibility of them having been created in the same city, but this cannot be either confirmed or rejected.

5.2. Pigment provenance and cobalt mining and production sites

During the 17th century, one of the most popular ways of trading blue pigment was done through smalt or zaffre. Smalt is often made of potassium (K) glass (Cílová et al., 2020, p. 1202), which was found in large amounts in the XRF measures of the BZN2. The largest European smalt production site that also shipped to the Netherlands was in Saxony, Germany. The cobalt ores here were mined specifically from the Ore Mountains, also known as the Erzgebirge. These mountains stretched through the German-Czech Republic border, allowing for the north-west Bohemia region of the Czech Republic to also mine and produce cobalt. This production site was also shipping cobalt to the Netherlands. However, the Netherlands itself also produced smalt. The cobalt ores were mined in Saxony, but were directly shipped to the Netherlands (Zlámalová Cílová et al., 2020, p. 1203). Countries like France, England and Spain also produced blue pigments, but in much smaller amounts (Bjørnland et al., 2018, p. 3).

It would make the most sense that the cobalt being used in the German and Dutch ceramics of the BZN2 came from this Erzgebirge, as it was the largest European mining site with good trading connections to the production countries of the ceramics. Most sources claim that the cobalt used for the Westerwald stoneware was mined in Saxony (Chitty & Stocker, 2019, p. 374). Kleij (2002) shared that there is a large possibility for the Dutch faience to have been made in Delft (p. 4). The smalt used for Delftware came from either Saxony or a place called the Zaan in the Netherlands (van Iperen et al., 2025, p. 191). Each workshop and each individual painter did have their own recipe for their perfect blue glaze, often combining smalt and zaffre in different measures (van Iperen et al., 2025, p. 192). However, in the glaze of the BZN 2 ceramics, no Bismuth (Bi) was found, which was an identifier of the Erzgebirge ores in Germany. A study done on the Delftware that is in the Rijksmuseum shows that those Delftwares do contain Bi (Wouters, 2020, p. 5). The composition of these artefacts are otherwise comparable to the Dutch faience from the BZN2. The artefacts part of the Rijksmuseum collection contain very intricate and detailed designs, while the BZN2 has relatively minimal designs in comparison, apart from a few examples.

Giannini (2017) further shares the chemical association of the Erzgebirge Schneeberg cobalt during the 16^{th} to 18^{th} century. This composition exists of Co-As-Ni-Bi-W-Mo-U-Fe. Neither Tungsten (W) or Uranium (U) were found in either the tinglaze wares or the Westerwald stoneware through pXRF, due to these elements not being part of the XRF spectra, and thus no possibility of picking these elements up in a measure exists. This makes the composition of Giannini difficult to compare. Bi was also not found in the BZN2 ceramics, however Bi is part of the XRF spectra. Furthermore, Mühlethaler and Thissen (1969) wrote an article in which they gave two examples of smalt compositions. The first one being 66-72 % SiO_2, 10-21 % K_2O, 0-8 % As_2O_3 and 2-18 % CoO, with impurities of Ba, Ca, Na, Mg, Ni, Fe, Cu, Mn. The second composition consists of 65-71 % SiO_2, 16-21% K_2O and 6-7 % CoO, thus not including any As. The impurities of this composition being Al_2O_3 (p. 49). Comparing these results with the BZN2 blue pigment can be delicate, as the Mühlethaler and Thissen's research was based purely on a smalt sample, while the research of this thesis is based on the results of the blue glaze on a ceramic object further covered with a top glaze. This makes using the exact percentages problematic as they could have been modified by the other steps of the glazing process.

Although finding the exact cobalt source is difficult, there are a few identifiers found in the BZN2 artefacts that could at least identify what kind of source it could have been. The cobalt composition consists of As, Ba, Co, Cu, Fe, Mn, Ni and Zn for both the tinglaze wares and the Westerwald jugs. The Westerwald cobalt shows high levels of Fe with a strong correlation between Fe and Co, which could point to the cobalt being primarily acquired from iron ores. In the tinglaze pottery however, this correlation is less clear. There does seem to be some connection, but not as strong as the Westerwald jugs. However, in the case of the tinwares, there is also a correlation between Co and Ni, whereas Westerwald did not have one. The tinglaze cobalt mostly seems to come from an iron and nickel deposit. It therefore seems like the cobalt acquired for the BZN2 ceramics come from different cobalt ores. The Westerwald jugs show uniformity and clearer trendlines, making it more likely that the cobalt ores came from the same region. However, the Co and Ni scatterplot showed at least three different trends. The tinglazed ceramics were more scattered but still showing a trend. It is possible that certain artefacts were made from cobalt ores from the same area, while others were made from different cobalt sources. The Co and Fe and the Co and Ni both vaguely show two trendlines, meaning at least two different groups. For one tinglaze sherd is certain that they are their own group, being the South-European tinglaze sherd. Therefore, one can estimate a minimum of six different blue pigments.

5.3. BZN2 maritime trade of the ceramics

In the 17th century, the Netherlands was known for its vast maritime trade. The Dutch traded in many things over many different countries. This subchapter however will focus on the trade route and items of the BZN2. This means Dutch trade to the Baltic Sea area and possibly trade to the Mediterranean sea, with trade goods being Westerwald stoneware and Dutch tinglaze wares.

Before the Westerwald jugs were able to be traded from the Netherlands to other parts of the world, prior trading took place to even create the Westerwald jugs. The salt used for the Westerwald stoneware glaze during this time was actually usually imported from the Netherlands or the Baltic area, as it could not be found in Germany itself (Chitty & Stocker, 2019, p. 374). For the cobalt of the Westerwald glaze, the raw ores were sometimes shipped to the Netherlands, as there was a cobalt processing industry in the Netherlands as well, further supporting the trade connections between the Netherlands and Germany (Chitty & Stocker, 2019, p. 374). The Westerwald stoneware trade to the Netherlands proceeded through Cologne, through inland waterways transport, thus also being part of maritime trade (Bartels & Kottman, 1999, p. 79). In general, the Westerwald stoneware was the main ceramics being exported from Germany in the 17th century (Barker & Majewski, 2006, p. 222).

Now to put the focus between the Netherlands and the Baltic Sea area. There is not much proof in historic written records that many ceramics were included in the traded goods to this area. However, a few sources do exist. These sources mention that ceramics would be traded in bulk and easy to sell (Tevali, 2021, p. 77). What also seems to be the case is that Rhenish stoneware was shipped to Dutch ports through the Rhine, from which it was then shipped to the Baltic sea area (Tevali, 2021, p. 80).

As mentioned in chapter 2, the trade between the Netherlands and the Baltic Sea was favourable. Norwegian excavations also at times show a presence of Dutch wares (van Riel, 2024, p. 129). One can therefore assume that Dutch tinglaze wares were traded with these countries, together with Tevali (2021), who said that ceramics were often easily traded goods (p. 77). The large amount of common artefacts in the Netherlands, like the Dutch tinglaze wares and Westerwald jugs, can point to them having just left the Netherlands where they gathered their cargo goods. However, the Polish cannons and other Baltic objects make it vague whether this is true or not. Perhaps the combination of these items, together with the fact it was an armoured ship points towards their travels taking them towards the Mediterranean next, but this is just speculation. The XRF results cannot be used in the further reconstruction of the trade of the BZN2 ceramic goods.

5.4. Comparable merchant shipwrecks

It is possible that shipwrecks of merchant ships during the same period will give more insight to the BZN2. It could be that more research was done on those wrecks, or more historical sources were connected to them. Therefore, we will shortly delve into a few comparable shipwrecks in this subchapter. There is no comparable XRF results between the next shipwrecks and the blue pigments on the BZN2 ceramics, thus only the type assemblages will be used for these comparisons.

In the same area of the BZN2, eleven other wreck sites were excavated as well. A few of these ships also sank in the 17th century and were merchant ships. Starting with the BZN8 which sank circa 1658, possibly during the 1660 storm. For a while, this was thought to be the VOC ship the 'Lelie', but this has been disproved. The cargo of this ship contained many Westerwald jugs, however these were mineral water jugs (Vos, 2012, p. 210). These jugs are in a different style and size than the jugs found on the BZN2. Furthermore, Kleij also analysed the ceramic artefacts of this ship, concluding a Dutch origin due to the redware, Dutch pipes and Dutch faience objects that showed signs of use. However, the build of the ship, a French coin and a tobacco box with a foreign inscription points to an international vessel (Vos, 2012, p. 216). This situation is comparable with the BZN2, where the used ceramics point to Dutch origins, while other objects may point to another country. The ceramic objects of the BZN8 are very comparable with the BZN2, mostly containing Westerwald, faience and a few Southern European pieces (Vos, 2012, p. 213). What makes this shipwreck unique however, is a bronze bell, made by famous bell-founders from France. During this time, these bell-founders made the bells for a large order for Amsterdam. The ongoing speculation is that this bell was part of that order, but due to its sound it was rejected and resold to an international buyer. This was supported by the fact that it was an outgoing ship from the Netherlands, instead of an incoming ship (Vos, 2012, pp. 213-215).

The next ship is the BZN9 which is also known as the two cannon wreck. This ship sank in the early part of the third quarter of the 17th century. This was a Dutch armoured merchant ship. Not many artefacts were excavated, likely due to the cargo possibly being rye (Vos, 2012, p. 234). The ceramics of this ship consisted of Dutch redware, Rhineland stoneware and Southern European, likely Italian, marbled wares. These Southern European wares were likely part of the cargo as well, but in a small scale (Vos, 2012, pp. 236-237).

The next two wreck sites are likely part of the same ship. These are BZN14 and BZN15. BZN15 was found 40 meters away from BZN14 (Vos, 2012, p. 312). For a while BZN15 was also thought to have been part of BZN2 due to the similar artefacts, but due to the dendrochronology dating it was closer to BZN14 (Vos, 2012, p. 318). BZN14 was also called the Potter, an armoured merchant ship that sank in the second half of the 17th century. Looking at the Batavialand database, the ceramic artefacts seem to consist of large amphora/pithos, redware, majolica and some stoneware.

Another comparable ship was called the ‘Aanloop Molengat’, named after the location it was found. It was found near the fairway Molengat, which is an important fairway towards Texel. It sank around 1640 (Maarleveld, 2013, p. 348). This Dutch ship was a ‘straatvaarder’, meaning that it traded near the Mediterranean. The cargo of this ship was very variable, but mostly consisted of metals and textiles (Maarleveld & Overmeer, 2012, p. 95).

A ship that sank in the Norwegian waters is called the Stoplelie. The cargo of this ship was Dutch light-yellow bricks, which were likely used as ballast. Other than that, it carried lead, pipes, Dutch faience and different types of ceramics (van Riel, 2024, p. 139). Specifically, Delftware, Frisian majolica and Raeren stoneware was found in this wreck (van Riel, 2024, p. 140). The conclusion of this wreck is that it dated to circa 1700, based on a pipe with a stamp that dated to 1698 (van Riel, 2024, p. 141).

Comparing the BZN2 collection to these ships, it shows that it is relatively comparable. Although the BZN2 seems to contain more ceramic wares in its cargo, it also shipped items like metal objects and textiles which was seen in the other wrecks as well. Ceramics were often part of the ships cargo when looking at these other ships, but never the main goods. In these comparable shipwrecks however, the specific Westerwald jugs are not present. The BZN8 did contain Westerwald, but these were mineral jugs and thus a different type. Overall, ceramics seem to be common on shipwrecks and the cargo. What does need to be mentioned is that none of these contemporary shipwrecks contained a cargo of wood, which the BZN2 did contain. However, as was established previously in chapter 2.1.2. it was common for the Netherlands and the Baltic area to participate in the wood trade together.

5.5. Post-depositional changes

When a ceramic object is deposited into a spot where it will remain for hundreds of years, the environment surrounding it will have an effect. This can be for example erosion from wind or water or stains from the soil. The objects of the BZN2 shipwreck have a very specific depositional location, that being seawater. The post-depositional effects is often different in each environment, and seawater is not an exception. The reason why post-depositional changes are important to consider when analysing elemental compositions, is the fact that this composition can be affected by what happened during its deposition. The elements of the BZN2 glazes could have been changed due to moisture, oxygen, pH levels and other contaminants (Odegaard & Warkinson, 2023, p. 1107). There are for example many ceramic artefacts from the BZN2 that have barnacle prints on them or were touched iron objects. This close proximity to iron resulted in the iron becoming stuck to the ceramic, and leaving behind rust on the ceramic objects. Take for example object BZN2-747-17 as seen in figure 53 above. This faience plate was not measured for its blue pigment in this thesis, as the surface was not clean

Figure 53. The effect the post-depositional environment can have on ceramics, shown on artefact BZN2-747-17 (Batavialand, objectnr. BZN2-747-17, https://collectienederland.nl/page/aggregation/maritieme-archeologische-rijkscollectie-maritieme-vondsten/60036617).

enough. The surface was faded and stained, likely due to these post-depositional changes. It would not have given an accurate measure of the blue pigment. The iron affecting the surface furthermore has an effect on the XRF measures. Iron is often found with cobalt, thus the iron in these measures thus will not be accurate, and the quality of the cobalt will be difficult to establish in the case of the BZN2 ceramics.

An experiment conducted by Bearcat, Dufournier and Nouet (1992) consisted of different clays or ceramics that were fired at different temperatures being placed in seawater for a prolonged period of time. They conclude that all clays lost weight percentages of Ca and gained weight percentages of MgO, but the molar fraction of the calcium lost was equal to what was gained of magnesium. Other changes were a loss of strontium, portlandite and larnite, but an appearance of brucite and a thin deposit layer on the surface of aragonite and calcite (pp. 152-158). Another study done on the difference between unglazed Roman ceramics from the Crikvenica production centre in Croatia that were deposited in a terrestrial environment versus a marine environment show that the ceramics from the seawater had higher levels of Mg, Ca and Na and a decrease in Si (Ferri et al., 2020, p. 19). However, neither this experiment or the previous one concerns the glaze and pigments of ceramics, just the fabric. As far as could be found, there is no scientific research done on the saltwater effects on ceramic glazes and pigments.

Another thing that the long term deposition in the sea likely did, is that the glaze of the tinglaze wares often faded or chipped away. In the case of the faience plates with the fruit basket decoration this is best seen. These consisted of two plates, one with a very faded blue and one with a still very bright blue. The ppm results of the faded plate were much lower than the results of the bright plate, which were often three to six times higher. The environment and corrosion of certain artefacts faded them to the point where they, mostly in regards to ppm values, could not be compared to studies where the artefacts are in better condition.

Because the exact effects of the seawater on the BZN2 ceramics cannot exactly be traced due to having no data to compare to of what the composition of these artefacts would have been like had they not been deposited in the sea, there can be no convincing conclusion can be made about the changes these artefacts would have experienced. A study done similar to that of Bearcat et al. (1992) or Ferri et al. (2020) on ceramic glazed artefacts with a blue pigment would be crucial to understanding these effects and could prove to be helpful for future research on this topic.

5.6. How applicable is XRF for shipwrecks?

X-ray fluorescence analysis on artefacts in general is a very helpful tool to understand elemental compositions and technicalities used to create the end results. This could go hand in hand with artefacts found on shipwrecks, due to the vast knowledge a shipwreck can give. (Post) medieval shipwrecks are often very narrowly dated, and if the voyage is reconstructed can give further insights into trade and society. This, together with XRF research can create good reference studies for these specific types of objects. Not only that, but many of the artefacts from shipwrecks are stored at a museum like Museum Batavialand, making XRF the perfect tool to use as it is non-destructive. At this moment in time, not nearly enough research has been done with these possibilities. However, this also means that not every limitation is known either.

In general, the problem with many excavated shipwrecks is the fact that most artefacts were from assessment projects. This means not the entire shipwreck was excavated, and thus not every artefact was brought to the surface. This means that certain ceramic groups may be underrepresented, and making definitive conclusions about a ship is nearly impossible. However, XRF research taking the focus away from the ship and taking a better look at the artefacts themselves, for example what their elemental composition is, are useful due to the close dating of shipwrecks and the knowledge of the ship's course. This type of research is not affected by whether the entire shipwreck is excavated or not, unless it is so minimally research that an estimated time of sinking cannot be said.

For the specific research of this thesis more research needs to be done into this topic. Research on long-term deposition in sea water and its effects, XRF research on the blue glaze of Westerwald and Dutch tinglaze artefacts and most importantly a combination of these topics is underrepresented but could prove to be very insightful and necessary.

Chapter 6: Conclusion

This thesis has shared the information gained about the blue glazed ceramics of the BZN2 shipwreck, their history and elemental composition in order to gain valuable insights on the 17th century ceramic production and maritime trade. This conclusion will attempt to answer the main research question **'What does the production and maritime trade look like for the blue glazed objects found on the BZN2 shipwreck?'** and its constructed sub-questions based on the results of this thesis. Not every one of these sub-questions could be answered using the XRF results, as they were mostly literary research focused. Each sub-question will be answered separately first, after which the main research question will be discussed.

What is already known about the BZN2, regarding its history, build, artefacts and its cargo?

This question was mostly answered in the first three chapters. The wreck was discovered in 1985 by divers, and subsequently archaeologically assessed in 2000 and 2001. On the ship, many cannons were found with Polish origins, giving it the name 'Polish cannon wreck'. The research concluded that the ship, possibly a 'jacht', was built between 1662 and 1665, and sank between 1670 and 1675. It was an armoured merchant ship, primarily trading between the Netherlands and the Baltic Sea area, with suspicions of trade with the Mediterranean, thus possibly being part of 'doorgaande vaart'. The cargo of this ship consisted of wood, textiles, differing metal scraps and objects, pipes, cellar bottles and ceramics. It cannot be said for certain whether this ship had a Dutch or Baltic home base, though the personal use objects point towards Dutch.

How typical is the BZN2 shipwreck in material content opposed to contemporary vessels?

The material content for the BZN2 was relatively normal when compared to other merchant shipwrecks from the 17th century. A cargo of textiles and metal was quite common, and the wood trade between the Netherlands and the Baltic area, mostly Norway, was also popular, although no wood had been found on the shipwrecks the BZN2 was compared to. The cannons found on the BZN2 that were actually used for protection were also common for merchant ships sailing towards the Mediterranean, but quite uncommon for ships going towards the Baltic. This is why the BZN2 was thought to be sailing around the south, together with the few Southern European ceramics found. The Polish cannons were quite a unique find, but were likely only taken for reforging. The BZN2 seems to contain more ceramic artefacts compared to contemporary shipwrecks.

How heterogenous are cargo loads with ceramics?

Ceramics were often taken by merchants as bulk goods. This was due to the fact that ceramics always sold easily. When looking at comparable shipwrecks, ceramics were therefore often part of a ship's cargo, though not often the main cargo. What can also be seen in the cargo of these ships and of the BZN2 is that the types of ceramics vary. The BZN2 has many different types of ceramics, like Dutch redware, Southern European ceramics, Westerwald jugs, tin-glaze wares and pipes. Within these types, namely the Westerwald and tinglaze wares, there seem to be many different decorations and sizes. Though a few decorated pieces contained the same decorations, the vast majority were all unique. Therefore it is not the case that the ceramics for a cargo are all the same, not between ships and not within a ship either.

What is the composition of the blue pigments on the ceramic artefacts of the BZN2?

The composition of the blue pigment used on the Tinglaze and Westerwald artefacts are a combination of As, Ba, Co, Cu, Fe, Mn, Ni, Zn and possibly K. Smalt is created with K and was a common way to create blue pigment together with zaffre. The high levels of K can therefore point towards the usage of smalt. The blue pigment of the Westerwald jugs and the tinglaze wares do differ however. The Westerwald jugs have a high connection between Co and Fe, while the connection between Co and Ni is more scattered. Meanwhile, the tinglaze artefacts had a connection between Co and Fe, though slightly less convincing than that of the Westerwald jugs. However, the tinglaze artefacts also had a strong connection between Co and Ni. The tinglaze artefacts were more varied in ppm values and concentrations, but also visually in regards to shapes and decorations.

What is the extent of blue glazed ceramic producers for the BZN2?

Each potter used their own combination for their pigment, making multiple different groups show up during pXRF research if there are multiple different producers. The fact that there are initially three types of ceramics, Westerwald and primarily Dutch tinglaze wares and one Southern European tinglaze sherd, already points to at least three different producers for the

BZN2 ceramics. Within the Westerwald collection, the scatterplot results between Co and Ni showed multiple groups, at least three, meaning that the jugs possibly came from different producers. From the Dutch tinglaze wares showed at least two different trendlines within the Co and Fe scatterplot and similar ones in the Co and Ni scatterplot. Figuring out exactly how many different producers were present in making these ceramics is impossible, but adding the previous statements up concludes at least six different producers. The possibility of there being more producers exists.

What effect can the post-depositional environment have had on the ceramics?

It is a well known fact that the post-depositional environment has an effect on the artefacts. Strictly looking at visible changes, it is clear that the surface of the ceramics was often tainted by the metal objects in the same wreck, sometimes leading to an orange stain from the rust. The water and the sand of the sea also eroded some of the artefacts, making the glaze chip away or the pigment fade. An example of which could be seen in the ppm differences in the artefacts with the fruit basket decoration, where one sample was very faded and the other still bright. Chemically speaking, saltwater has been proven to affect ceramics, for example Ca and Si can decrease as a result of long term exposure. That being said, it is an underrepresented field of research, thus no sources were found pertaining the saltwater effects on the ceramic glaze and blue pigments. The exact effect saltwater has had on the glaze can therefore not be said, but the likelihood of there being a chemical change is exists.

To what extent can the provenance of these pigments be established, comparing the XRF results to literature?

Finding the exact provenance of the blue pigments is very difficult. The uniqueness of cobalt compositions could potentially lead to finding the provenance of the cobalt. For this, the right sources had to have been researched in regards to composition and published in order to compare. In the case of the ceramics of the BZN2, no clear source was found that matched. Literature about the different sources often shares where the cobalt mines were processed and traded to, and for Germany and the Netherlands it was often the Erzgebirge in Germany. However, the BZN2 pigments were compared to known compositions of the cobalt mined there during the 17th century, and the results showed Bi in the results, which was not present in the BZN2 ceramics.

How applicable is XRF analysis in the study of materials found on historic ships?

The usage of XRF on artefacts from shipwrecks can prove to be very insightful for the world of archaeology. The unique circumstances of shipwrecks, for example their narrow dating and historical sources, can be a good baseline for examining artefacts with X-ray fluorescence. The XRF can also further help the research of a shipwreck, as it can measure the elemental composition of artefacts, which can give insights into provenance. A pXRF is also good for analysing museum artefacts, as it is non-destructive. Thus there are many possibilities for using XRF analysis on objects from a shipwreck for both learning more about the artefacts and the ship. However, the artefacts that were stored long term in seawater may have been affected which altered their chemical composition. The exact results of this alteration still needs more research.

Main research question: What does the production and maritime trade look like for the blue glazed objects found on the BZN2 shipwreck?

Now that the sub-questions have been answered based on the research of this thesis, the main research question can be discussed. The blue glazed objects consist of German Westerwald jugs and Dutch and South European tinglaze wares. At least six different producers were involved in the creation of these objects. The larger part of these ceramics were meant for trade, based on the previous research of Kleij (2002). It is likely that the BZN2 blue pigment was created using smalt, due to the high levels of K in both types of ceramics. Literature sources say the cobalt used for both types were likely to come from the Erzgebirge in Germany, however the cobalt composition does not completely line up with the known compositions, thus the exact provenance of the cobalt has not been established for the BZN2 ceramics. The composition of the blue pigments show a combination of As, Ba, Co, Cu, Fe, Mn, Ni, Zn and possibly K, with the Westerwald jugs showing a strong connection with Co and Fe, and the tinglaze wares with Co, Fe and Ni.

The origin country of the BZN2 is unknown, and the location they were sailing towards is unknown as well. The high amount of Dutch tinglaze wares and Westerwald jugs points to them leaving the Netherlands as they likely stocked up there to trade them somewhere else. In general, Westerwald jugs were the most popular traded ceramics from Germany in the 17^{th} century and were often traded to the Netherlands through inland maritime trade. From here, they could have been loaded onto the ship together with the Dutch wares. Van Riel (2024) stated that Dutch ceramic objects were found in places like Oslo, Norway. This, together with the fact that ceramics were common bulk goods to trade possibly meant that the ceramics were likely either going to be traded in the Baltic Sea area, however there is also a possibility they were going towards the Mediterranean area, based on the armoured status of the ship and many of the items on board coming from the Baltic region.

In general, the details of the BZN2 are still largely a mystery. Although more is now known about the blue glazed ceramics, namely their composition, not every question can be answered yet. Future research should include a study on salt water effects on glaze and pigments, more XRF measures or even other scientific methods on the BZN2 ceramics and of course more in depth analysis of the other BZN2 artefacts. Though ceramics can give much information, perhaps the metals, glass and wood can fill the remaining gaps of information. More research needs to be done to fully understand and reconstruct this ship and its voyage.

Abstract

This thesis focuses on the merchant shipwreck BZN2 located in the Waddenzee near Texel. This shipwreck sank between 1670 and 1675, carrying a cargo of textiles, metals, wood, cellar bottles and ceramics. The ceramics with a blue glaze are the main focus of the thesis, using non-destructive portable X-ray fluorescence (pXRF) to ascertain the elemental composition. The ceramics which included blue pigments were Westerwald jugs and tinglaze ceramics, mainly from Dutch origins. The goal of the thesis is to reconstruct the production and merchant trade of these particular ceramics. The results of the XRF measures show multiple different producers within the ceramic groups. Although the exact provenances of the ceramics nor the cobalt used for the blue pigment could not be traced, the elemental composition is now known for future research. The conclusion of this thesis added further knowledge to the BZN2 shipwreck and its blue glazed ceramics, while also exploring the possibilities of pXRF research for artefacts from shipwrecks, showing that more research into this topic is necessary and what it could potentially add to the world of archaeology.

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Appendix A: Sample list in order of sample number

Sample nr	Artefact nr
15534	BZN2-23
15535	BZN2-568
15538	BZN2-794
15541	BZN2-403
15543	BZN2-572-1
15547	BZN2-572-9
15549	BZN2-624-3
15555	BZN2-666
15562	BZN2-747-3
15564	BZN2-747-6
15565	BZN2-747-8
15575	BZN2-759-1
17265	BZN2-21
17266	BZN2-701
17267	BZN2-772
17268	BZN2-836
17269	BZN2-837
17270	BZN2-902
17271	BZN2-903
17272	BZN2-904
17273	BZN2-906
17274	BZN2-907
17275	BZN2-908
17276	BZN2-974
17277	BZN2-972
17278	BZN2-975
17279	BZN2-1174-1

17280	BZN2-1228
17281	BZN2-568
17282	BZN2-572-1
17283	BZN2-625
17284	BZN2-678
17285	BZN2-747-7
17286	BZN2-244
17287	BZN2-403
17288	BZN2-679
17289	BZN2-685
17290	BZN2-686
17291	BZN2-759-1
17292	BZN2-793
17293	BZN2-618
17294	BZN2-687
17295	BZN2-725
17296	BZN2-747-3
17297	BZN2-747-6
17298	BZN2-747-8
17299	BZN2-747-9
17300	BZN2-749
17301	BZN2-624-1
17302	BZN2-624-3
17303	BZN2-680-1
17304	BZN2-680-1
17305	BZN2-727-1
17306	BZN2-727-1

Appendix B: Sample list in order of artefact number

Sample nr	Artefact nr
17279	BZN2-1174-1
17280	BZN2-1228
17265	BZN2-21
15534	BZN2-23
17286	BZN2-244
15541	BZN2-403
17287	BZN2-403
15535	BZN2-568
17281	BZN2-568
15543	BZN2-572-1
17282	BZN2-572-1
15547	BZN2-572-9
17293	BZN2-618
17301	BZN2-624-1
15549	BZN2-624-3
17302	BZN2-624-3
17283	BZN2-625
15555	BZN2-666
17284	BZN2-678
17288	BZN2-679
17303	BZN2-680-1
17304	BZN2-680-1
17289	BZN2-685
17290	BZN2-686
17294	BZN2-687
17266	BZN2-701

17295	BZN2-725
17305	BZN2-727-1
17306	BZN2-727-1
15562	BZN2-747-3
17296	BZN2-747-3
15564	BZN2-747-6
17297	BZN2-747-6
17285	BZN2-747-7
15565	BZN2-747-8
17298	BZN2-747-8
17299	BZN2-747-9
17300	BZN2-749
15575	BZN2-759-1
17291	BZN2-759-1
17267	BZN2-772
17292	BZN2-793
15538	BZN2-794
17268	BZN2-836
17269	BZN2-837
17270	BZN2-902
17271	BZN2-903
17272	BZN2-904
17273	BZN2-906
17274	BZN2-907
17275	BZN2-908
17277	BZN2-972
17276	BZN2-974
17278	BZN2-975

Appendix C: The list of elements and their symbols in alphabetical order

Symbol	Element
Ag	Silver
Al	Aluminum
As	Arsenic
Au	Gold
Ba	Barium
Bi	Bismuth
Ca	Calcium
Cd	Cadmium
Ce	Cerium
Cl	Chlorine
Co	Cobalt
Cr	Chromium
Cu	Copper
Fe	Iron
Ga	Gallium
Ge	Germanium
Hg	Mercury
Ir	Iridium
K	Potassium
La	Lanthanum
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
Na	Sodium
Nb	Niobium
Ni	Nickel

P	Phosphorus
Pb	Lead
Pd	Palladium
Pt	Platinum
Rb	Rubidium
Re	Rhenium
Rh	Rhodium
Ru	Ruthenium
S	Sulfur
Sb	Antimony
Se	Selenium
Si	Silicon
Sn	Tin
Sr	Strontium
Th	Thorium
Ti	Titanium
U	Uranium
V	Vanadium
W	Tungsten
Y	Yttrium
Zn	Zinc
Zr	Zirconium