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From Bedrock to Porcelain

A study regarding the history of porcelain, Ytterby mine
and the discovery of yttrium in Sweden

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Abstract

Porcelain is a translucent vitreous material that consists of clay (kaolin), feldspar and quartz which has been mixed and heated together to cause a metamorphic reaction. In Sweden, the Porcelain industry was established in 1726 at Rörstrands castle in Stockholm and is today one of the oldest industries in Europe to produce porcelain. Around the 1790's Rörstrand got its feldspars and quartz from the Ytterby mine that was located at Resarö in Stockholm's archipelago making the raw material somewhat easy to access. Rörstrand owned the mine in the 1850's to 1926. During the time Ytterby mine was active, an amateur geologist by the name of Carl Axel Arrhenius, discovered an unusual black mineral in the quarry ore in 1787 which later led to the discovery of 8 new rare earth elements (REE) with the help of several Swedish chemists throughout time. These elements are Yttrium, Ytterbium, Gadolinium, Terbium, Thulium, Erbium, Holmium and scandium. This study will focus on the Swedish porcelain industry and how it has evolved throughout history and Rörstrand's role in the discovery of yttrium.

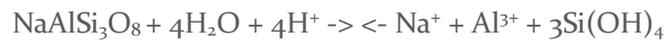
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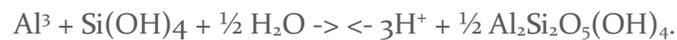
1 Introduction

Porcelain is a translucent vitreous material that consists of clay, feldspar and quartz which has been mixed and heated together to cause a metamorphic reaction, creating a lustering clear and relative strong material. The Chinese were the first known people to make porcelain, it consisted of kaolin (also known as Chinese clay) which they heated to around 1200 °C however china stone was used in different parts of China (Finley, 2010, pp. 82-95). There is a subdivision between porcelain, earthenware and stoneware, which, in the western world, is recognized based on chemical and physical properties as well as mineral composition. Earthenware is created from many different types of clay and requires a lower temperature when heated than porcelain. It is a very porous material thus, requiring an extra layer to create a useable porosity, this is usually a glass coating. Stoneware is heated to a temperature between that required to make porcelain and earthenware and its strength is higher than earthenware but lower than porcelain with a grayish colour and nearly nonporous (Finley, 2010, p. 81) thus the main difference to recognize stoneware from porcelain is by its colour.

Kaolin is a clay that has a high content of the mineral kaolinite (Pohl, 2011, p. 31). It is used for porcelain, ceramics, and medicine that relieves rashes and itching (Kluwer, 2009). Kaolinite is produced by the breakdown of feldspar in rocks such as granite which undergoes a chemical weathering where the feldspar dissolves in acid environments. This turns the feldspar into a soluble silica as shown;



this soluble silica then reacts with the ions and molecules in the soil (Al^3) creating a reaction that forms kaolinite by;



The combined reaction can be written;



(Nguyen, n.d., p. 2); (Doherty, 2002, p. 24). This process also removes other minerals such as iron, magnesium, calcium, potassium, and sodium, which become soluble in acidic environments, As these elements are removed the remaining material will form kaolin (Nelson, 2014). This implies that kaolin should be plentiful, supported by the National Center for Biotechnology Information where they write “*Kaolin is the most common mineral of a group of hydrated aluminum silicates*” (NCBI, n.d.). with this in mind I will be looking to see if Sweden has any deposits of Kaolin that could have been used for the Swedish porcelain industry.

Porcelain became popular after the Portuguese started its import to Europe. This was around the 16th century (Murphy-Gnatz, n.d.). In Sweden, the Porcelain industry was

established in 1726 at Rörstrands castle in Stockholm to experiment in the making and burning of stoneware, and is today one of the oldest industries in Europe to produce porcelain (Rörstrand, n.d.). During 1741, this porcelain was still imported from China by Swedish trade ships (Murphy-Gnatz, n.d.) and it took 131 years before Rörstrand started creating its own porcelain. This porcelain was a type of bone-porcelain, a mix consisting of bone ashes, feldspar, quartz and kaolin (Rörstrand, n.d.). Today porcelain has an importance to our society in different ways, it is used for many reasons such as electrical fuses, which are surrounded in an unglazed porcelain, used by many geologists to test minerals in a streak test (SGU, n.d.). Porcelain is also a component that is used on some common household items such as toilets and sinks (USGS, 2016).

This study will focus on the Swedish porcelain industry and how it has evolved throughout history. In my research, I will focus on the material that has been and are used to create porcelain and its development throughout history. I will also discuss where the Swedish porcelain industries get their raw material from to create their porcelain, specifically Rörstrand. My research is based on scientific literature and a short field trip; thus, this is in essence a literature review about the porcelain industry. The field study has been conducted from a visit to the Rörstrand museum in Lidköping, Sweden to answer questions regarding their history and manufacturing of porcelain. During this research, I will be considering how the porcelain industry in Stockholm led to the discovery of the 8 elements found at Ytterby and how these have changed industries and developments in society. My research might be partly limited due to literature accessibility of the subject in hand, as much of the necessary historical comparisons are in foreign languages.

2 Geological setting

Stockholm, Sweden where Rörstrand porcelain industry were originally located in 1726, has a bedrock consisting of mainly a thin layered quartzite, granite-bearing gneiss, greywacke gneiss, meta-argillite and migmatite gneiss towards the south-eastern region of Stockholm with small portions of leptite-gneiss and gneiss granite. Towards the northern region of Stockholm, the bedrock consists of young granites, pegmatites, and porphyritic gneiss-granite. Stockholm also have a few breccia and mylonitic fault zones throughout the archipelago, (Stålhös, 1968) see figure 1.

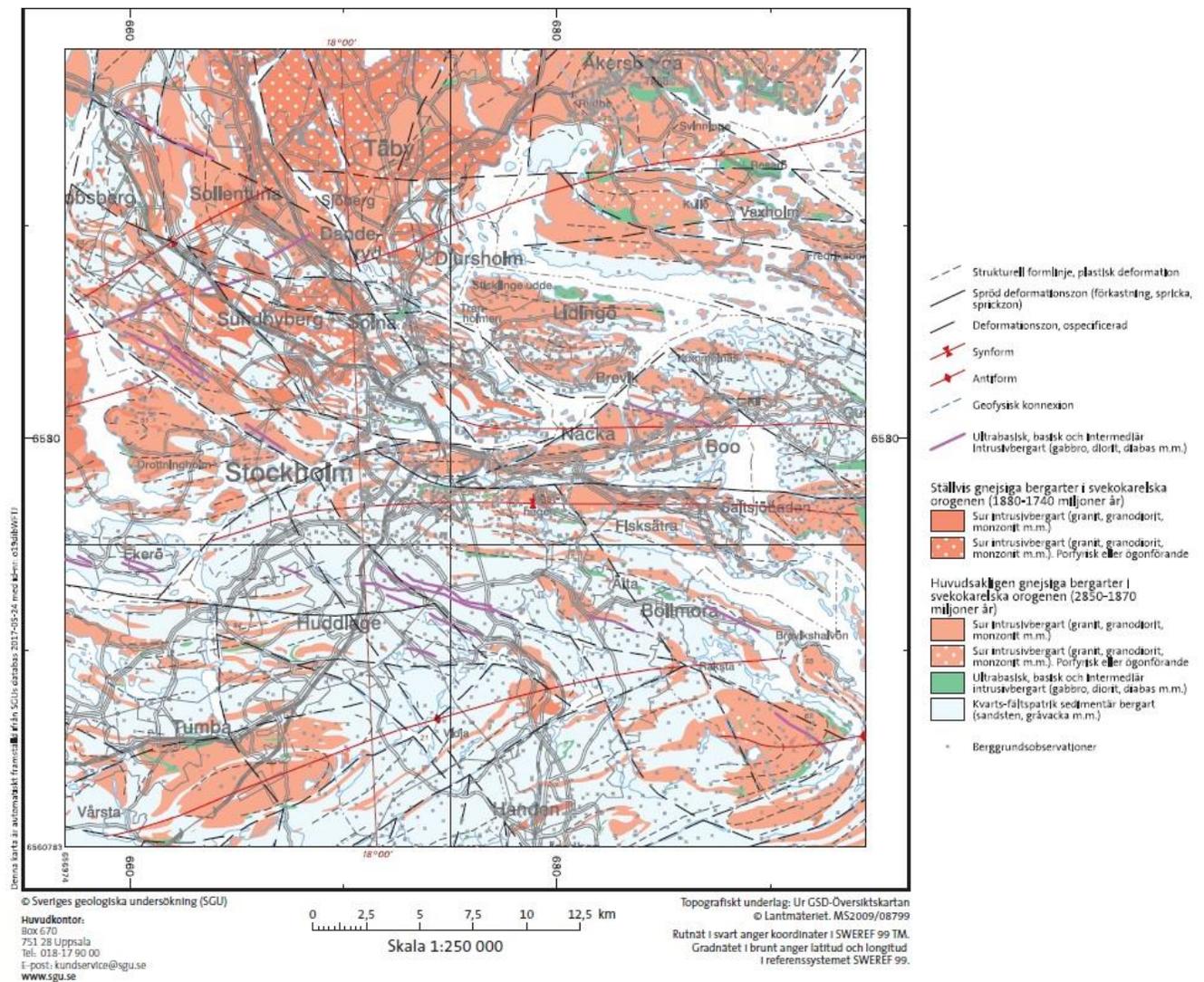


Figure 1. Bedrock map of Stockholm, where Orange represents acid intrusive bedrock (granite, granodiorite, monzonite), Orange with white dots represents porphyritic acid intrusive bedrock, Green represent ultrabasic, basic, and intermediate intrusive bedrock (gabbro, diorite, diabase), and white represents quartz-feldspathic sedimentary bedrock. Taken from SGU kartgenerator (available at http://apps.sgu.se/kartgenerator/maporder_sv.html)

North east in Stockholm where Ytterby Mine is located on Resarö in Stockholm's archipelago the bedrock consists of 1.9-1.8 billion years old metamorphic granitoid and syenitoid rocks and is a part of the Svecofennian province (SGU, n.d.). There is also a substantial proportion of gabbro, diorite, amphiboles, and pyroxenite-hornblendite stretching throughout the island, as well as semi-acid gneiss-granite (Stålhös, 1968). The Svecokarelian domain which Ytterby mine is located on is one of the largest in Sweden and covers most of the northern and central parts, it stretches from Västervik to Kiruna.

Greenstone belts has been found in the metamorphized volcanic and sedimentary bedrocks (Andréasson, 2013, p. 391); (Stålhös, 1968).

The Svecocarelian domain is divided into two bigger sub-provinces; Karelian-Lapponiska and the Svecofennian the first named stretches throughout the northern parts of Sweden to the Finnish Lapplands, and the Svecofennian_sub-province is made up of shallow rock deposits that is not visible today, which has a more intrusive deformation than the Karelian-Lapponiska (Lindström, et al., 1991, p. 26). The metamorphized sedimentary rocks that can be found in the Svecocarelian orogeny is generally grey wacke and shale stone, and the metamorphized volcanic rocks is generally of silica-rich types, such as rhyolite and gneiss (Sveriges Nationalatlas, 2009, pp. 17-18).

the Ytterby pegmatite; a coarse-grained granite-pegmatite that is composed of quartz, oligoclase and red microcline with biotite (Enhag, 2004, p. 433); (Wik, et al., 2004, p. 11). The Ytterby Pegmatite is a Rare-element class pegmatite in the NYF-pegmatite family (enriched in Niobium, Yttrium, and Fluorine) with the gadolinite subtype. This subtype is enriched in Heavy Rare earth elements (HREE), Yttrium (Y), Niobium (Nb), and Gadolinium (Gd). According to Ercit (2005) these pegmatites usually do not undergo any obvious regional zoning. This could be due to a less volatile composition of the parent rock as it melted at a relatively shallow depth of the crust. This is however not known (Ercit, 2005, pp. 176-179). Resarö also a high proportion of red leptite with a fine-grained composition (Stålhös, 1969, pp. 81-83) See figure 2.

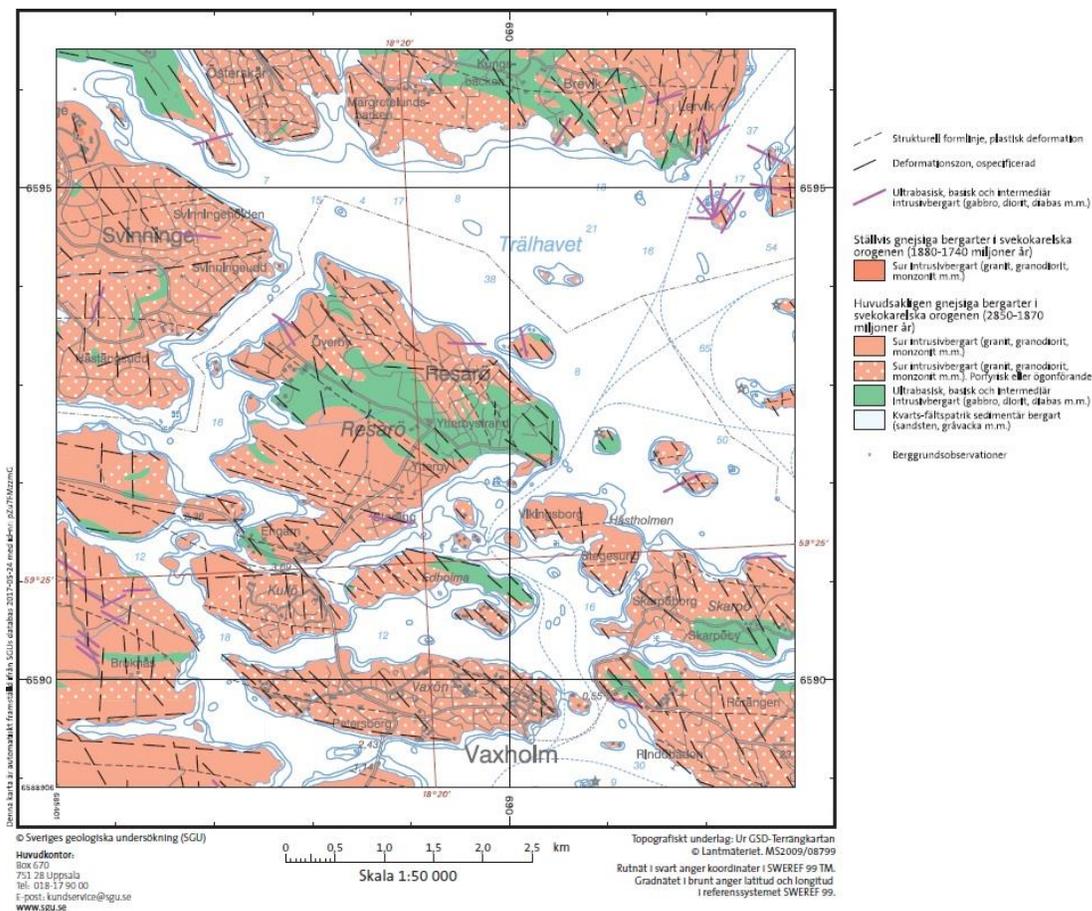


Figure 2 . Bedrock map of Resarö, where Orange represents acid intrusive bedrock (granite, granodiorite, monzonite), Orange with white dots represents porphyritic acid intrusive bedrock, Green represent ultrabasic, basic, and intermediate intrusive bedrock (gabbro, diorite, diabase), and white represents quartz-feldspathic sedimentary bedrock. Taken from SGU kartgenerator (available at http://apps.sgu.se/kartgenerator/maporder_sv.html)

3 Method

In my research, I will be collecting and reviewing literature, both from a historical and geological perspective, this will be collected from libraries and reliable internet sources with the focus in finding books and text about yttrium, Rörstrand and the Swedish porcelain development at the geological, mineralogy, and historical sections. I will be expecting to encounter difficulties around collecting and gathering the right material for my purpose, as the geological part about yttrium and Swedish porcelain at my nearest library is limited and difficult to collect. Thus, I used books collected at the library in combination with reliable and trustworthy internet documents and articles.

3.1 LITERATURE SURVEY

While searching for literature I have visited several libraries. These includes the Kungsbacka city library here I found literature regarding the history of Rörstrand. The second library I have visited is Gothenburg biomedicine university library, this is where they keep their earth science collection and thus where I collected the majority of documents regarding earth science and geology. The way I approached the problem of finding literature is to visit several libraries in Gothenburg both the city library and the Gothenburg's biomedical university library as they state this is where they keep their earth science collection (Göteborg's Universitet, 2016).

To describe the discoveries of the elements found at Ytterby mine I will be looking through historical and mineralogical books about Ytterby, rörstrand and earth science at Gothenburg's university library as well as going through reliable documents on the internet.

3.2 SITE VISITS

My goals in this research will be to describe the history of the porcelain industry, how and why it started, I will research about the raw materials needed for manufacturing porcelain and its predecessors and where these were sourced. by doing this I have visited the Rörstrand's porcelain industry in Lidköping, Sweden. To find information about Sweden's porcelain industry history and look for a connection to what role Rörstrand had on the discovery of yttrium at Ytterby mine in as much detail I can to and describe the discoveries of each of the elements; yttrium, erbium, terbium, ytterbium, holmium, thulium and gadolinium and what these meant for society.

4 Results

In this chapter I present the results of my literature review.

4.1 HISTORY OF THE SWEDISH PORCELAIN INDUSTRY

Porcelain is a material that has been desired and wanted ever since its discovery, Sweden had a limited knowledge of how to make porcelain until around 1766-88 where marieberg created the first true porcelain, Rörstrand has at this time creating an earthenware due to their limited knowledge in porcelain manufacturing (Lutteman, 1980, p. 9).

Sweden started with manufacturing earthenware is the 1730's at rörstrand, by using domestic clay from Uppsala's plain, this clay was a yellow-brown chalky clay transported by boat to rörstrand. The chalky yellow-brown clay made the earthenware red and white-yellow in appearance. To create the right firmness in the earthenware the domestic clay was mixed with a siliceous sand (Lutteman, 1980, pp. 13-14); (Nyström & Brunius, 2007, p. 15). Earthenware created from this yellow-brown clay required a lower temperature when heated than the porcelain we have today porcelain. Earthenware is a very porous material, so it requires an extra layering to prevent liquids from leaking through the material and create a useable porosity, at rörstrand a pewter material was used for this final layering (Finley, 2010, p. 81); (Lutteman, 1980, p. 16).

In the 1770's rörstrand started producing stoneware, which was a method they had adopted from England and in 1790 rörstrand had abandoned earthenware production and focused singularly on stoneware production, this stoneware was made with clay, feldspar and flint (Nyström & Brunius, 2007, p. 25). This Stoneware is heated to a temperature between porcelain and earthenware and has a strength that is higher than the previous earthenware but still lower than the porcelain we know today, stoneware usually have a grayish colour and is very close to nonporous (Finley, 2010, p. 81). In the 1850's rörstrand also owned mines at Ytterby, Resarö in Stockholms archipelago for mining feldspar and silica as their raw material in creating this Stoneware (Udd & Leek, 2012, p. 5). In the 1870 rörstrand started manufacturing their first feldspar porcelains, this consisted of kaolin, feldspar and quartz (Lutteman, 1980, p. 143) this material was nonporous and semitransparent with good durability and strength, however fragile to drops (Finley, 2010, p. 81).

Before marieberg and rörstrand's porcelain manufacturing Sweden imported the porcelain from china in heavy quantities, especially during the 16th century (Lutteman, 1980, p. 9). It was a naturalist by the name of Johann Ehrenfried Walter Von Tschirnhausen together with what Lutteman (1980) called a "gold maker" by the name of Johann Friedrich Böttger that first created a feldspar porcelain in Europe. This was done by mixing kaolin with quartz and feldspar in 1708 that had a Chinese appearance (Lutteman, 1980, pp. 9-10). Johann Böttger had made false claims that he could create gold which had led to his

imprisonment in Dresden, Germany. He attempted to flee to Austria but failed. In 1704 Tschirenhausen had been told to direct Böttgers work, together they created a red stoneware in the ancient fortress of the Wettins. In 1707 Böttger was placed in a research laboratory in Dresden and managed to create a white porcelain by mixing kaolin, alabaster and quartz (Watanabe-O'Kelly, 2002, pp. 223-224). This discovery revealed how essential kaolin is when creating porcelain.

4.2 RÖRSTRAND'S HISTORY

Rörstrand porcelain industry was situated at Rörstrands castle in 1726 and was used to experiment on the making and burning of stoneware. In 1709, a mercenary by the name of Valentine Sabbath had bought the south-eastern parts of the Rörstrand area, which are today known as Sabbatsberg. From around the 1200 – 1600's there was a brickyard located in the areas that Sabbath purchased, this area had a large amount of mud and clay which Rörstrand used in their experiments of porcelain making (Byggnadsinvertering Stockholms Stadsmuseum, 1987, pp. 10-12).

Before Rörstrand's time at Rörstrands castle this building was used for several other purposes. In the start, it was owned by a wealthy citizen by the name of Mårten Wewitzers which he gave to his wife in 1635. When he died, it was owned by the Queen Kristina around 1640 to 1650 which she gave to Karl X Gustav. She also formed a Knight academy situated in the castle. A couple years later a fire destroyed the Royal Palace, after the destruction of the Royal Palace they used Rörstrands castle to house the Royals. In the early 1700's, during the Nordic wars it was used as a jail for Russian war criminals (Rörstrands slott AB, n.d.).

In 1898, Gothenburg created their first porcelain at an industry based in Hisingen, Gothenburg, however, Rörstrand porcelain was looking for a new place to settle their industry around this time, and in 1914, Rörstrand porcelain industry bought the Gothenburg porcelain industry, which they moved to in 1926, abandoning their Stockholm industry. In 1922 Rörstrand started working together with ALP, AB Lidköpings porcelain industry which was, at the time a top-notch feldspar industry where they produced ceramics. In 1934-36 Rörstrand built a new, modern stoneware factory in Lidköping which led to the whole company moving there in 1936-39.

The porcelain factory that Rörstrand started working together with in 1922 ALP, AB Lidköping porcelain industry was later close down around 1943. This however did not affect Rörstrand much at the time and during 1952-53 they built a new feldspar industry in Lidköping where around 1500 people worked. This was at the time one in ten of Lidköping's population that worked for Rörstrand. In more recent years Rörstrand was bought by a company called Iitala AB in 2003-04. This led to economic problems for

rörstrand branded products and in 2004 rörstrand porcelain industry in Lidköping was forced to close down, just after firing over 100 employees a secret donation was given to Rörstrand which kept it going for the time. It was however moved abroad in 2005 (Field trip to Rörstrand Museum, 2017).

4.3 RAW MATERIALS IN PORCELAIN

Porcelain consists of feldspar, quartz and kaolin, that is first molded into the desired form, then heated to a temperature of around 1250 °C until it starts to partially melt. It is then cooled down quickly to create a thermal metamorphic change within the mineral assemblage, as the quartz within the material is heated it will start to slowly convert into cristobalite having the same chemical formula (SiO_2) this is called quartz inversion (Cuff, 1996, pp. 92-93), this creates a glass-type appearance making the porcelain semitransparent (Marshak, 2012, p. 229).

Kaolin is a weathered product of feldspathic rocks such as gneiss & granite with high abundance of kaolinite; a hydrated aluminum silicate. (Sveriges Nationalatlas, 2009, p. 71); (Murray, 2007, p. 85). When contacting rörstrands museum through an email with the following question; where did rörstrand get its kaolin from. I got an answer from a staff member at rörstrands museum, This person wrote that she had asked a proficient co-worker which got back to her with the answer that rörstrand got its kaolin imported from England/Cornwall during the 18th century and very likely later from France (Rörstrands Museum, 2017).

Around the 1790's rörstrand got its feldspars and quartz from the Ytterby mine that was located at Resarö in Stockholm's archipelago making the raw material somewhat easy to access (Udd & Leek, 2012, p. 5). Before the feldspar quarry started at the Ytterby mine, rörstrand obtained their raw material from uppsalaslätten (Lutteman, 1980, p. 13). According to Udd & Leek (2012) rörstrand owned the mine in the 1850's to 1926 (Udd & Leek, 2012, p. 5).

Feldspar has throughout time been quarried at several places in Sweden, mainly for ceramic products and porcelain. Today however, Sweden has only two active feldspar quarries that are both located in Riddarhyttan, Bergslagen, Sweden (Sveriges Nationalatlas, 2009, p. 69), even though feldspar deposits appear plentiful in Sweden according to Sweden's geological survey's website tool *Kartvisaren* there is still only two quarries active today (SGU *Kartvisaren*, n.d.). SGU also mentions that kaolin clay has previously been quarried in Skåne, Sweden, for firebrick, floor tiles and porcelain (Sveriges Nationalatlas, 2009, p. 71), however, No record was found that the kaolin from Skåne was being transported to the rörstrand porcelain industry. The quartz that has been used for manufacturing porcelain, glass, computer chips and solar cells, are plentiful in Sweden. It

has also been quarried west of Lidköping where the porcelain was manufactured under the rörstrand brand (Sveriges Nationalatlas, 2009, p. 71). Thus, this indicates that the Swedish bedrock have a large availability of all raw materials needed for manufacturing porcelain of all types.

4.4 HISTORY OF THE YTTERBY MINE

Ytterby Mine, in Stockholm's archipelago has a conflicting history as to when it started its quarry, both reliable texts, one by Stockholms county administration board that implies the mine to open in the 17th century, and the other source from the Swedish fortification government agency suggest the opening to be in the 16th century. This makes it hard to determine when the Ytterby mine started its quarrying, what is clear however is that it opened between the 16th -17th century. It is also clear that they initially mined for quartz. This quartz was sold to ironworks in northern Uppland initially, and later the mine added feldspar for quarrying due to its increasing value for glassworks and porcelain industries (Hallnäs, 2005, p. 131); (Udd & Leek, 2012, p. 16).

The Ytterby mine was closed and abandoned in 1933, and in 1953 it was rebuilt and designed to store oil, which continued to be stored there until around 1978 when it became a storage for diesel. It was later decommissioned in 1995 where it got emptied of all diesels and sanitized (Udd & Leek, 2012, p. 6)

4.5 ELEMENTS FOUND AT YTTERBY

At Ytterby mine, Rörstrand's porcelain industry in Stockholm was part in the discovery of a new unusual material called Yttrium (Nyström & Brunius, 2007, p. 229), Ytterby mine started production around the 16th - 17th century, mainly for quarrying silica and feldspars and stopped its production in 1933. During the years it was active, a geologist by the name of Carl Axel Arrhenius, discovered an unusual black mineral in the quarry ore which was later discovered to be gadolinium (Gd). This later lead to the discovery of eight new elements yttrium (Y), erbium (Er), terbium (Tb), ytterbium (Yb), holmium (Ho), gadolinium (Gd), scandium (Sc) and thulium (Tm) (Hallnäs, 2005, p. 9).

Gadolinium was first discovered by an amateur geologist by the name of Carl Axel Arrhenius in 1787 who also was a lieutenant in the Swedish army. Arrhenius sent a sample of his findings to a chemistry professor by the name of Johan Gadolin, a Finnish chemistry professor at the Royal Academy of Turku this was also noted and described by Reinhold Geijer in 1788 who was the first to see the mineral after Arrhenius. Geijer was

at the time the owner of the Rörstrand's porcelain industry and a mineralogist, He wrote a letter that described a black unusual mineral that was not magnetic found at Ytterby. After some time, it was discovered that Gadolin had underestimated the amount of silica and aluminum content of the black unusual mineral. This was discovered by a Swedish chemist in uppsala by the name of Anders Gustaf Ekeberg who analyzed a purer sample of this mineral, he found 9.5 more oxides than Gadolin previously had, he also noted a strange taste to the mineral (Skelton & Thornton, 2017); (Dinér, 2016).

it took however 56 years before this could be analyzed closely, and shortly after the analysis, two new rare earth elements (REE) was discovered within the gadolinite by the Swedish Chemist Carl Gustaf Mosander who discovered that yttria had a mixture of different metal oxides which he separated into different parts. This led to the discovery of two new REEs these were; Yttrium (Y) and terbium (Tb) (Dinér, 2016). Thirty-five years later ytterbium was discovered within the gadolinium by a Swiss named Marginac, the following year the two Swedes Cleve & Nilsson discovered erbium (Er), holmium (Ho), scandium (Sc), and thulium (Tm) within the original Gadolinium, thus completing the discovering of elements at Ytterby (Hallnäs, 2005, p. 131) according to SNA (2009) "*The original gadolinium itself was surrounded by a 1800Ma pegmatite*" (Sveriges Nationalatlas, 2009, p. 19). Ytterby mine did not quarry these REE commercially, since the market of the time had a higher profit within feldspar and quartz (Udd & Leek, 2012, p. 5).

4.6 ELEMENTS DESCRIPTION

Several of the REE found at the ytterby mine are lanthanides; they have atomic numbers between 57-71 on the periodic table and are today essential in producing lasers, magnets, X-ray tubes, night-vision goggles, camera lenses and high tech-lamps (Marshak, 2012, p. 517). Thus, are quite necessary for today's society in many ways. The gadolinium has been theorized to be of importance in multi-modal imaging and cancer therapy (Park, et al., 2015, p. 569). Gadolinium is also a component used to create television colour and has a high conductive property with unique magnetic properties (Los Alamos National Laboratory, n.d.). Due to the magnetic properties of gadolinium it has a very important part in magnetic cooling which makes it possible to put a magnet under more external magnetic fields. The ^{155}Gd & ^{157}Gd nuclei have shown to be great for absorbing neutron cross sections, and are today used in nuclear reactor control rods (Pyykkö, 2015).

Yttrium has several uses today such as; create red colour in televisions, importance when used as microwave filters, creating effective transducers and transmitters in acoustic instruments, and it can also be used to reduce the grain size in specific elements, which will improve their strength (Los Alamos National Laboratory, n.d.). The isotopic 90 yttrium is furthermore used in cancer treatment due to its high-energy, short half-life

(Wilkes & Ades, 2004, p. 6). Dinér, P. also states that the “*most important of yttrium has been its role in the discovery of high temperature superconductors*” (Dinér, 2016) where yttrium-based conductors could go to a temperature of 93 K. This has led to an increasing effort in finding even higher temperature superconductors (Dinér, 2016).

Ytterbium has not been extensively researched and therefore most of its potentials are unknown. It was for a very brief period of time subdivided into neo-ytterbium and lutecium, these have an atomic weight of around 172 and 174 g mol⁻¹ but is today known as ytterbium. It is used to increase grain refinement and strength in materials and can be used as a semi-conductor at pressure. Which makes it possible to use for stress gauges but is also used for portable X-ray machines (Los Alamos National Laboratory, n.d.); (Skelton & Thornton, 2017).

Erbium is a REE that consists of 6 different isotopes and the most stable radioactive isotope within erbium is the ¹⁶⁹Er with a half-life of 9.4 days (Voncken, 2016, pp. 63-64). Erbium has a very excessive and large amount of regular spacing in its excited-state that was used in a theoretical infrared detection experiment where photons would be detected and countered in a logical sequence of absorption to a specific ion in a solid state and use superexcitation as a photon detector, this theoretical test failed. In 1966 Francois, Auzel established that a superexcitation had the capability to benefit from collecting what Piguet, C. describes “*light harvesting carried out by partner ions*” (Piguet, 2014) today this method is used in lasers in skin treatment and dentistry. Erbium is also used in infrared greenlights and solar cell technologies (Piguet, 2014).

Holmium has one stable isotope called ¹⁶⁵Ho and 36 radioisotopes, the stable one being ¹⁶³Ho it has a half-life of around 4 and a half years (Voncken, 2016, pp. 63-64). It has a high magnetic sustainability, but these magnetic properties only present themselves at cryogenic temperatures. Holmium is today used in high-strength magnets and magnetic-flux concentrators, though they are more often used in surgical lasers by a holmium-doped aluminum garnet known as HO:YAG (Thornton & Burdette, 2015). Thulium is an element that consists of one stable isotope and 34 radioisotopes the most stable one being ¹⁷¹Tm which has a half-life or round two years (Voncken, 2016, pp. 63-64). Thulium is the least abundant naturally occurring REE. Both Holmium and Thulium was discovered by a Swedish chemist by the name of Per Theodor Cleve, he was looking at the impurities in the oxides of REE, he began by looking at Erbium and removed the contaminations he knew of. By doing this he discovered two different materials one brown oxide which was the thulium and a green oxide – the holmium (Thomas Jefferson National Accelerator Facility - Office of Science Education, n.d.); (Thornton & Burdette, 2015).

Terbium has one stable isotopes and 36 radioisotopes with the most stable one being ¹⁵⁸Tb, having a half-life of 180 years (Voncken, 2016, pp. 63-64).

5 Discussion

The purpose of this literature review was to research the porcelain's history in Sweden, how it came to be and what connection it had to the discovery of the REE yttrium, Gadolinium, Scandium, Terbium, Erbium, Ytterbium, and Holmium and if Rörstrand was instrumental in the discovery of these elements.

To determine whether Rörstrand was instrumental in the discovery of the REE found at Ytterby there's many perspectives to look at and there are many arguments for both perspectives surrounding Sweden's porcelain industries role in the discovery of the 8 new elements discovered in Ytterby.

The first perspective that I have looked at is; Would the mine have been active at the time the gadolinium was found if Rörstrand did not exist in Stockholm and needed feldspar for their production of porcelain or would the feldspar be thrown away. This is a very important question to look at since the Ytterby mine originally quarried quartz for ironworks in uppsala's plain, so would the production be as large as it was if not for the Rörstrands demand of feldspar and quartz.

Another thing to keep in mind is that Arrhenius first showed his sample to the CEO of Rörstrand who also was a mineralogist by the name of Reinhold Geijer, which makes this another question to consider. would Arrhenius have known to contact Johan Gadolin, the professor at Åbo academy in Finland who performed experiments on the gadolinium mineral, or was this suggested by the CEO of Rörstrand. The conversation between Arrhenius and Geijer could have been a key point in the discovery of Gadolinium, depending on what they conversed about.

However, the elements that were found at the Ytterby mine has been a series of coincidences which started in one small black mysterious mineral, and an amateur geologist, Arrhenius who initially found this mineral, That later turned out to be a very important mineral. It is hard to determine whether or not Rörstrand was instrumental in the discovery of the REE. The discovery was very circumstantial, like most scientific discoveries. If it wasn't for the demand from Rörstrand for quartz and feldspar, particularly for the substantial amount required, it is probable that the REE would not have been discovered until a much later date. I propose that the discovery, however, was inevitable.

6 Conclusion

The Rörstrand porcelain industry, has been the oldest recorded porcelain industry to exist in Sweden, it started in 1726 and continued their own manufacturing in Sweden up til 2005 where their last Swedish porcelain industry was closed and moved abroad (Field trip to Rörstrand Museum, 2017). During Rörstrands time in Sweden they owned the famous Ytterby mine in 1850's – 1926 (Udd & Leek, 2012, p. 5).

The Ytterby mine was originally a quartz quarry where quartz was of high demand for ironworks, they later added feldspar for quarrying since this became a valuable material for the increasing glassworks and ceramic industries. From one of the quartz pieces they discovered a black mineral, that led to the discovery of eight new REE. These all have been of significant use in our society, but it is possible we have not found their true potential within these elements and should do more research as they all have interesting properties.

7 References

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