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Jet artifacts from two Neolithic sites on the Dutch coast: An experimental approach

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1) Introduction

Jet is a glossy black material that was used in the past primarily with the purpose of ornamental display. In the Neolithic period in the Netherlands, finished artifacts of jet are found mostly in grave contexts often together with stone, amber and bone ornaments. Ornaments are capable of conveying symbolic messages and are seen as humanities earliest use of material objects as media for communicating social identity (Kuhn *et al* 2001, 7645). As such, they reflect an important step in human behavioral evolution.

The onset of the earliest shell ornaments of the Upper Paleolithic is associated with critical demographic thresholds; the ornaments are characterized as part of a system of communication, functioning as signals for strangers: efficient visual communication, especially at a distance, is beneficial only when it is likely to encounter someone less familiar (Kuhn *et al* 2001, *ibid.*).

From early Neolithic times onwards ornaments visualize social identities and trade networks and the wider range of raw materials used for ornaments of increasingly varied color and shape reflect the increasing importance of new social and economic needs created by a sedentary way of life (Wright and Garrard 2003, 282).

This thesis focusses mainly on Neolithic ornaments made of jet and seeks to interpret these finds by addressing two objectives.

First, geological sources of jet have not been identified in the Netherlands; therefore it is relevant to questions regarding provenance and patterns of mobility in the past. X-Ray Fluorescence techniques have been successful in the characterization of the inorganic elemental composition of various materials and their respective geographic sources and the application of XRF has been important in the scientific definition of jet and non-jet material in the United Kingdom (Pollard *et al* 1981; Hunter *et al* 1993; Allason-Jones and Jones 2001; Sheridan *et al* 2002; Hunter 2008; Penton 2008). The first objective of this thesis will be concerned with characterizing the black shiny ornaments of Schipluiden and Ypenburg which have preliminarily been termed jets and to further investigate the possibilities of provenance studies for Dutch Neolithic jet ornaments with the use of XRF.

Second, the material properties of jet that allow its surface to take a high polish are usually seen as indicative of its use as a raw material for ornaments. However, the relationship between these properties and their ornamental value are complicated: processes of prolonged wear are capable of polishing jet ornaments to a seemingly decorative shine. Shiny surfaces may be the result of wearing these ornaments rather than being the initial cause of wearing them. While the analysis of a polished surface seeks to answer questions of technology, processes of wear point to the use-life of an object and answers questions of functionality. This thesis will investigate the possibility of distinguishing between an intentional polish and use-wear related shine on the basis of macroscopic analysis. For this purpose a series of experiments has been designed involving experimentally made ornamental beads and a rock tumbler.

The research questions that this thesis seeks to answer are as follows: Are the black shiny ornaments from Ypenburg and Schipluiden derived from true jet, which is geologically restricted to locations outside the region? And if so, can questions concerning the geological origin of these materials and the patterns of mobility in the past be answered with the use of XRF? Is it possible to distinguish between an intentional polish and a polish resulting from prolonged wear with the use of macroscopic analysis? How can these differences be defined and recognized?

2) Jet; physical properties, geochemical composition and genesis

Jet is a carboniferous rock that develops static electricity when rubbed on wool or silk (Muller and Muller 2013, 5). When jet is worked it produces a brown powder, when it is rubbed on unglazed porcelain it produces a brown streak and it fluoresces when exposed to blue light (Wilson 2003, 2). Jet is very light in weight and has a specific gravity ranging from 1.18-1.30 (Pollard et al 1981, 141; Muller and Muller 2013, 6). It has a Mohs hardness of 3-4, it breaks with a conchoidal fracture and it burns with the smell of coal. Its blackness is so intense that it produced the phrase "*as black as jet*", originated in Britannia in the 12^{th} century and it takes such a high polish that mirror-use is possible (Muller and Muller 2013, 6).

Geochemically, jet is a glassy compact variety of coal relatively free of shrinkage cracks (Blanco et al 2008, 877). Coals are carboniferous rocks that are formed by the compaction and induration of altered plant remains. Coal rank is used to describe the degree to which various coals have undergone the process of coalification, the degree and duration of heating received during burial of the original plant material. A coals rank is reflected by its fixed carbon percentage and the energy that is released upon combustion: this type of analysis is mainly used by oil companies with the specific aim of testing the calorific content of possible fossil fuels. Jet is essentially a very pure organic carbon source and consists mainly of organic compounds, 12% mineral oil and traces of aluminum, silica and sulfur (Pollard 1981, 139). When defined by its fixed carbon percentage, it can be classified as an abnormally high volatile B-bituminous coal (Traverse and Kolvoort 1968, 302).

Table 1 Composition of Whitby jet, shales, lignites and cannel coals (Pollard *et al* 1981, table 1).

	Whitby jet*	Kimmeridge** 'Blackstone'	Kimmeridge** Shale on top of 'Blackstone'	Lignite** Bovey Tracey	Cannel coal** Durham	Cannel coal** Yorks
C	81.64	37.94	8.71	66.31	75.98	
H	7.37	4.19	1.39	5.63	5.07	
O	6.09	3.88	4.16	22.86	8.06	
N	1.03	1.03	0.50	0.57	1.17	
S	1.28	4.51	2.09	2.36	0.59	
Water	2.12				0.57	
Ash	0.47	48.45	83.15	2.27	8.56	10–20

Table 2 Rank and calorific content of Utah jet and other coals (Traverse and Kolvoort 1968, table 1).

Content	Utah jet	Ohio high volatile B bituminous (8)	Wyoming subbituminous B (8)	Kentucky bituminous cannel coal (9)
Proximate analysis (moisture on as-received basis; all others on moisture-free basis)				
Moisture (%)	5.79	5.9	22.2	2.36
Ash (%)	1.85	4.1	5.6	10.7
Volatile matter (%)	61.82	46.5	41.9	49.6
Fixed carbon (%)	36.33	49.4	52.5	39.7
B.T.U.	14,308	13,980	12,510	13,770
Ultimate analysis (moisture-free basis)				
Carbon	76.21	76.7	69.3	71.98
Hydrogen	6.33	5.4	5.7	6.47
Nitrogen	0.63	1.4	1.3	1.16
Chlorine	0.04			
Sulfur	3.10	3.3	0.6	1.20
Oxygen	11.84	9.2	17.6	8.70

All coals contain macerals, which are essentially vegetable tissues that determine the material qualities of coal-like material. This term was proposed as an organic analogue to minerals. Microscopic organic tissues in coals can be sub-defined in vitrinites, huminites and inertinites (Allason-Jones 2001, 234). *Huminite* and *vitrinite* macerals derive from woody structures such as lignin, cellulose, tannins and colloidal humic gels. These wood tissues have decomposed in an anaerobic, water saturated environment into a humic gel that is termed *huminite*. These are only identified in brittle, low grade coals, and will have hardened into *vitrinite* in higher graded coals. *Vitrinite* is black and glassy and makes up the dominant component of coals, which are usually too brittle to be worked. Vitrinite tends to have a high oxygen content and is made up of aromatic chains surrounded by aliphatic functional groups (Watts and Pollard 1996, 39). *Liptinites* are the optically distinct parts of the original plant such as the resin, spores, cuticles, suberines, and algae and these show the highest content in hydrogen, H^2. They create aliphatic carbon-hydrogen bonds (Watts and Pollard 1996, ibid.). A high ratio of *liptinites* will give graded coals the ability to take a high polish, and these materials fluoresce when exposed to ultra-violet or blue light, as is the case with jet. *Inertinites* consist of parts of the original plant material that were strongly altered or degraded in the presence of oxygen before they were deposited, for instance by forest fires. They exhibit a high degree of aromatization and condensation and are chemically similar to charcoal.

Table 3 Vitrinite reflectance corresponding to coal ranks (Allason-Jones 2001, table 1).

Coal Rank Stage	% RO
Bog oak	0.2
Lignite	0.2–0.4
Sub-bituminous	0.4–0.7
Bituminous	0.7–1.5
Sub-anthracite	1.5–2.5
Anthracite	2.5–5

In nature, different heterogeneous mixtures of macerals, along with mineral impurities, determine the material qualities of coal-like material (Allason-Jones 2001, 235). Another way of classifying coal-like material is by the amount of vitrinite grading, that is the mean reflection of a vitrinite particle in oil, % RO (Allason-Jones 2001, 235). Vitrinite reflectance measurements differ slightly for different sources, ranging from about 0,15-0,30 % RO (Allason-Jones and Jones 2001, 241). Jet has a very low vitrinite reflectance with regard to its fixed carbon percentage, therefore it is usually thought of as a special type of very dense lignite (Pollard *et al* 1981, 139).

The nature of jet, which proved difficult to determine geochemically, was a considerable debate in the 19th century and some scholars interpreted jet as a solidified bituminous resin (Muller 1987, 7). In its geological formation, however, jet is fossilized wood of Araucarioxylon, a family of conifers similar to but much larger then present day Araucaria –the monkey puzzle tree (Baker *et al* 2003, 91; Muller and Muller 2013, 5). This type of tree flourished in the Jurassic period, around 180 million years ago. An analysis of the organic matrix of Whitby jet, using pyrolysis gas chromatography mass spectrometry (Watts *et al* 1999), showed that jets are made mainly of multiphenols that are also present in lignites, which reflect their woody origin. An enrichment with aliphatic hydrocarbons was also evident (Watts *et al* 1999, 929). The annual rings of the original wood can be seen when cored jet is studied under a microscope, and sometimes even with the naked eye in fine specimens. Thin section samples of jet viewed under an electron microscope will clearly reveal the xylum vessels of the original woody structure (Pollard *et al* 1981, 141; Muller and Muller 2013, 6).

The process of fossilizing is facilitated by deposition in an aqueous anaerobic context and subsequent transportation to its final deposition setting. Muller (1987) advocated a process of *jetonization*, based on the work of Hemingway (1933). His thesis states that when the original trees died, they would dry up and crack and become wedged by rocks and minerals in the surrounding sediment. The logs would be carried to the Upper Lias Sea by the floodwaters of surrounding rivers, whose violent action would round and abrade them. When the pieces of wood reached the Yorkshire basin they would float until they were completely waterlogged and sank to bottom of the sea where they would be covered by detritus and mud for millions of years (Hemmingway 1933, 111; Muller 1987, 9). *Jetonization* is the anaerobic decomposition process that attacks the wood along its modular lines from the outside to the inside. During this process, the lignins are removed and the wood cells collapse. Amorphinite and algae generate hydrocarbons that would soak into the wood, impregnating it and allowing the wood to be preserved as a more resilient form than the usual brittle vitrinite form of lignites, although the materials grade into each other (Allason-Jones and Jones 2001, 237).

An interesting discovery was done when Peruvian uncompressed mummified wood from coarse sand facies preserved in an anoxic environment were exposed to humic, light, aerobic conditions: they rapidly gained a glassy black appearance (Verkool *et al* 2009, 700). Consequent pyrolysis-GCMS analysis showed that the process of "*jetification*", the turning from mummified wood into a glassy coal variety, can be a very rapid process (less than a year) that is very similar to the synthesis of bakelite (Kool *et al* 2009, 705). They proposed an adaptation of the *jetonization* model in which mummified conifer wood *Araucarioxylon* gains its jet-like appearance when it is exposed to aerobic conditions and sunlight prior to its final deposition. Subsequent burial processes compress and preserve this jet-like material (Fig. 1). It seems that after more than 150 years there is still no consensus on the genesis of jet.

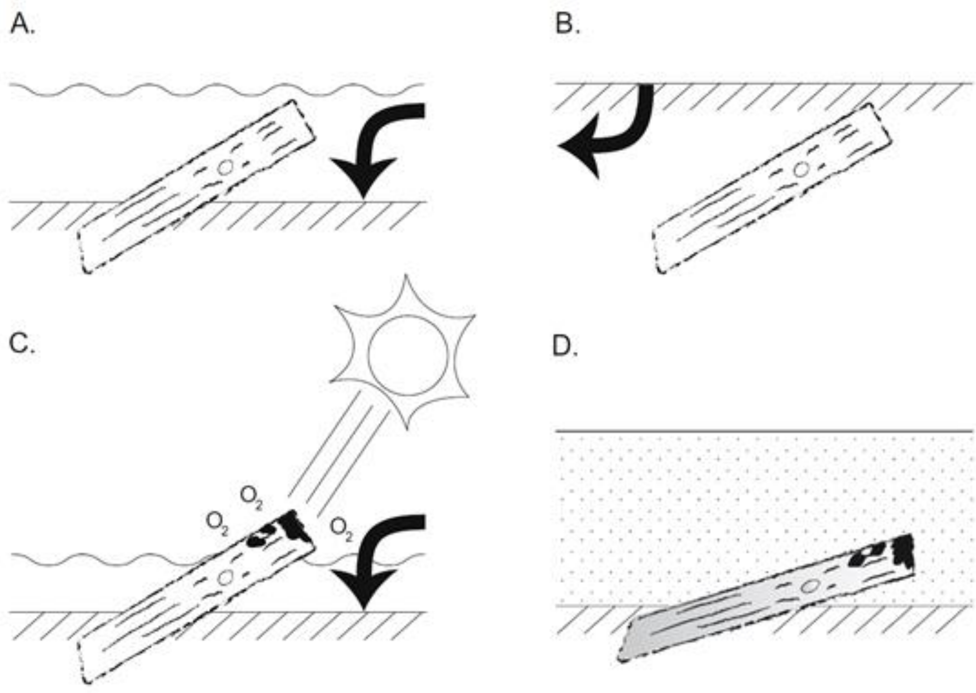

Figure 1 Schematic depiction of the formation of jet (Verkoot *et al* 2009, fig 4).

Jet is found as either plank or core form (Muller 1987, 9). In plank jet the wood is compressed and its shape is lost; it is the most common variety and occurs in thin plano-convex shaped seams, only 25-50 mm in thick. In some wood the core was silicified before *jetonization* could take place and in this way the other variety, cored jet, is formed.

Jet is further divided in soft and hard jet. Hard jet is much more tough and durable, was formed in sea water and can be polished to a brilliant sheen (Muller and Muller 2013, 5; Sheridan *et al* 2002, 823). It is also called “true jet” and it is distinguished from resembling materials primarily in its durability: A skillfully crafted and polished specimen, 4000 years in age, will still look like it was made yesterday (Muller and Muller 2013, 8). Soft jet was probably formed in fresh water (Muller and Muller 2013, 5). It is brittle and tends to disintegrate when subjected to heat, and due to the layering property of the material it tends to break along its many horizontal fracturing planes when worked (Muller 1987, 4; van Gijn 2006, 197). It has been remarked that soft jet has been used in the past along with hard jet, and that workers were not always aware of its low durability (Sheridan *et al* 2002, 823). The depth of color of the brown streak of jet on unglazed porcelain gives an indication of quality: The harder the jet, the lighter the color (Muller 1987, 3). A nuclear magnetic resonance analysis of the relative intensity of hydrogen atoms (^{1}H-NMR) in jet samples has shown an excellent relationship between the working quality of a jet and the length of the aliphatic chains in it: A jet of good working quality exhibits shorter, less branched out aliphatic chains (Blanco *et al* 2008, 884).

Jet is by its nature and formation history confined to specific geological locations. As jet occurs embedded in Jurassic oil shale, it can be found in the Jurassic strata of Western Europe, such as the Posidonia shales of Southern Germany (Fig 3), and the Upper Lias of Yorkshire (Figures 4 and 5; Allason-Jones 1996, 6; Wilson 2002, 3) and near Cseustochan in Poland (Blanco et al 2008, 877). Upper Lias jet is found in discreet seams in the jet rock, underneath the top jet dogger, which is basically a hard limestone band around 200 mm thick that contains calcareous and pyritous concretions (figure 2; Hemingway 1933, 26).

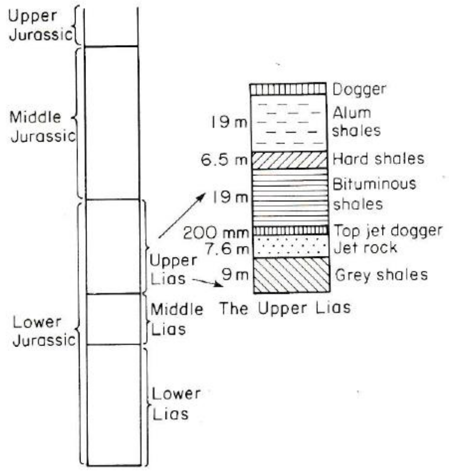

Figure 2 Upper Lias geological succession in North Yorkshire (Muller 1987, Fig 2.6).

In Spain and France it is said to also occur in the Greensand of the Cretaceous formation (Hemingway 1933, 98), cretaceous jet also occurs near Stockholm, in Sweden (Poole *et al* 2008, 701). Jet sources in Spain occur along the north coast in Asturias (Fig 4), in the North-Western province of Gallicia and in the North-Eastern province of Aragon (Allason-Jones 2001, 243; Muller and Muller 2013, 9). In France, jet occurs in thin seam similar to the plank jet of Yorkshire in the departments of Aude, Languedoc (Muller 1987, 113). Other French sources can be found near Marseilles, in the Pyrenees near Chalabre and Belestat and probably in Nord-Pas-de-Calais (Figure 5; Muller and Muller 2013, 9; Van Gijn, personal communication October 2014). There are known but unexploited sources of jet in Norway, on the island of Andoya and in Beitstadfjorden, Trondelag, (Resi 2005, 91).

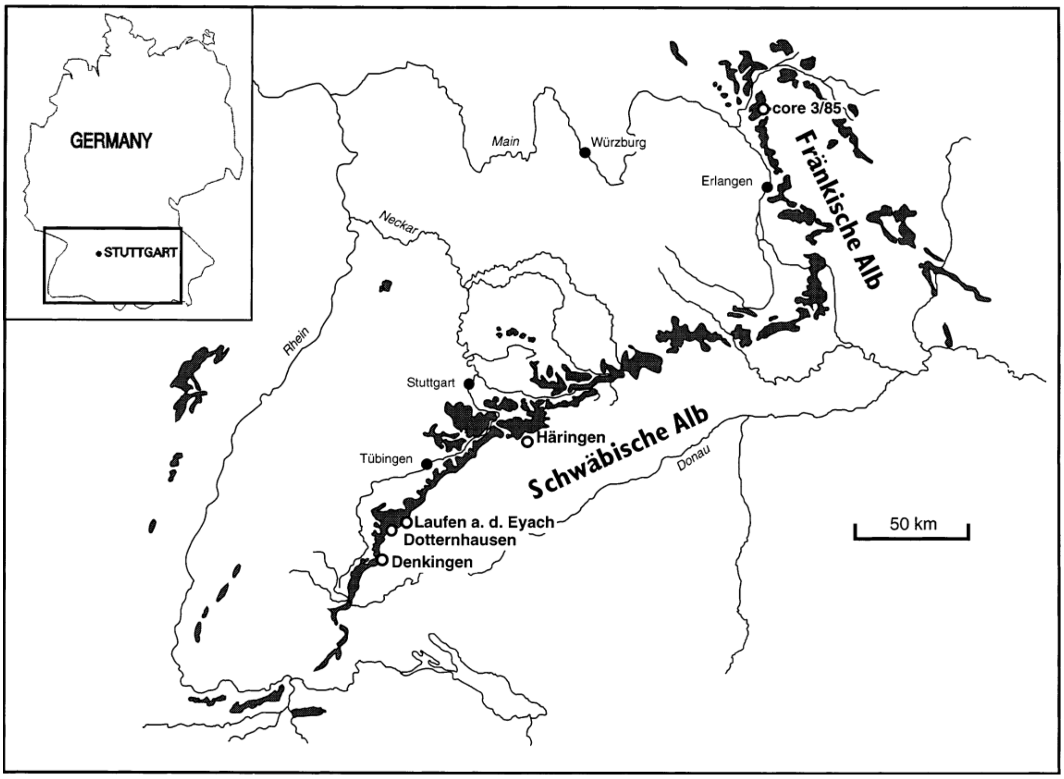

Figure 3 Location of the southern posidonia shales of Germany (Röhl et al 2001, Fig 1).

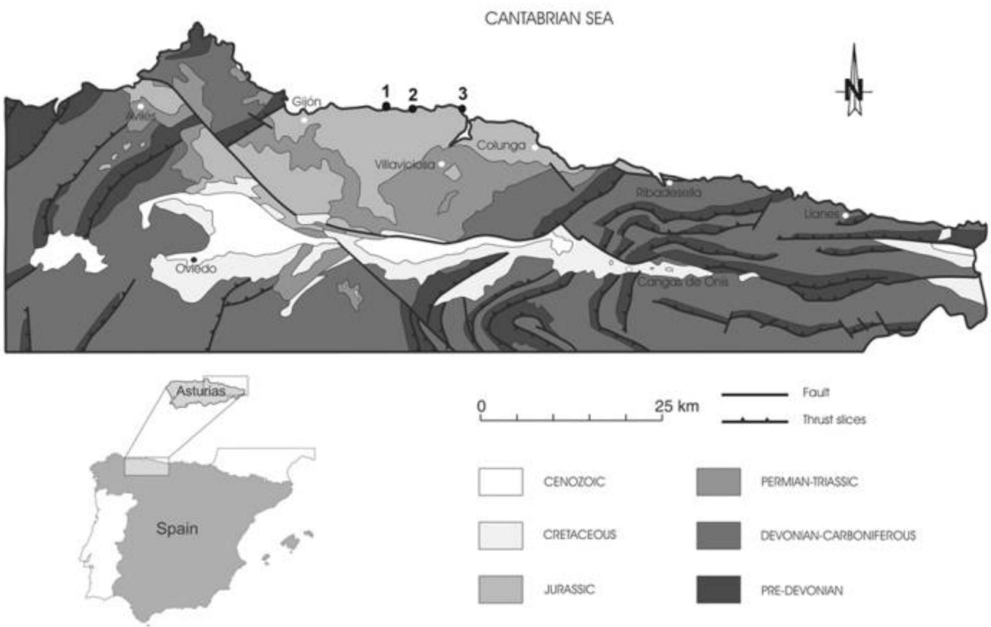

Figure 4 Possible jet locations in Asturias, Spain. Jet should be present in the cretaceous formation (Avanzini et al 2010, fig 1).

Figure 5 Outcrops of late Jurassic rocks in Great Britain, Normandy and around Calais (Fürsich 1977, Text-Fig. 2).

3) The archaeology of jet

The use of jet for ornamental display goes back quite a long way in human prehistory. The oldest archaeological evidence comes from Las Caldas cave in Asturias, Northern Spain, and is ascribed to an Upper Solutrean occupation layer dated to +/- 24250-22300 calBC (Corchón *et al* 2008, 312). Five ornaments of jet were found (Figure 6) together with three pieces of amber, all locally produced. Jet, like amber, is very light in weight, amorphous, and may develop static electricity that allows it to attract pieces of paper or straw when rubbed on wool or silk (Allison-Jones 1996, 7; Muller and Muller 2013, 5). The original Greek name for amber provided our word for electricity and the Romans sometimes named jet 'black amber'. Jet and amber's interesting electrostatic properties may have been assigned a supernatural status in the past and as such may have aided in the popularity of these materials, which are very often found together; questions concerning magic and superstition are rarely answered by archaeological evidence, however (Allason-Jones 1996, 17).

Figure 6 Jet and lignite finds from las Caldas cave, Asturias, Spain (Corchón et al, Fig. 12).

The next evidence for prehistoric use of jet was found in the area around the Swabian alps. Stone Age settlers between 15000- 10000 BC in this area in Switzerland and South Germany used jet to fabricate animal figures, Venus figurines, and drilled geometric figures that were possibly worn as pendants (Muller and Muller 2013, 7). One talisman is thought to represent the larva of the dassel fly (Figure 7), which parasite on reindeer, an important source of food, antlers and skin to these people (Muller 1987, 94).

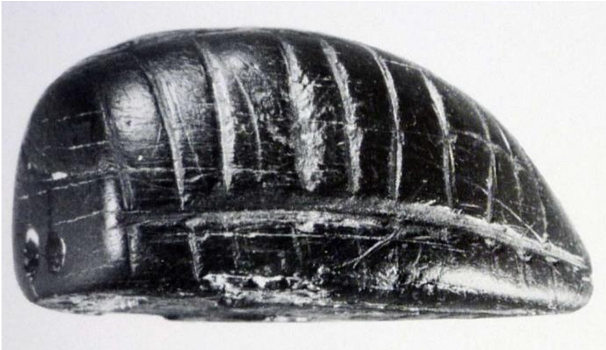

Figure 7 Dassel fly larva carved in jet (Muller 1987, fig 6.1).

In the middle and late Neolithic periods in the Netherlands we find ornamental beads, necklaces and pendants made from jet, together with amber, bone and stone equivalents (van Gijn 2006, 2008; Devriendt 2012). In Britain, the use of jet is archaeologically known from the first half of the fourth millennium onwards, with the use of elliptical beads and belt sliders (Sheridan *et al* 2002, 815).

In France jet was known to have been used from prehistoric times onward, but not many artifacts have been attested until the Neolithic: a burial from this period was found in Couriac, near Saint-Affrique in Aveyron, that contained a necklace of jet and chalk beads (Muller 1987, 112).

In Britain, jet is known to have been used in the Neolithic, between the fourth to the second millennium BC, but it did not become extensively exploited until the subsequent Bronze Age (Allason-Jones 1996, 8). In this period it is used to create beads for spacer necklaces and V-perforated buttons, often in combination with cannel coal and shale (Figure 8). These artisan pieces of jewelry are predominately found in burial mounds in this period, although sites have been identified where crafting took place, attested by half-products and waste production (Muller and Muller 2013, 7). Bronze Age jet was shaped using grooved sandstone slabs to create the barrel shape of beads, chips of flint mounted on simple bow-drills were used for drilling and the brilliant sheen was obtained by polishing with oil and jet-dust (Muller and Muller 2013, 8).

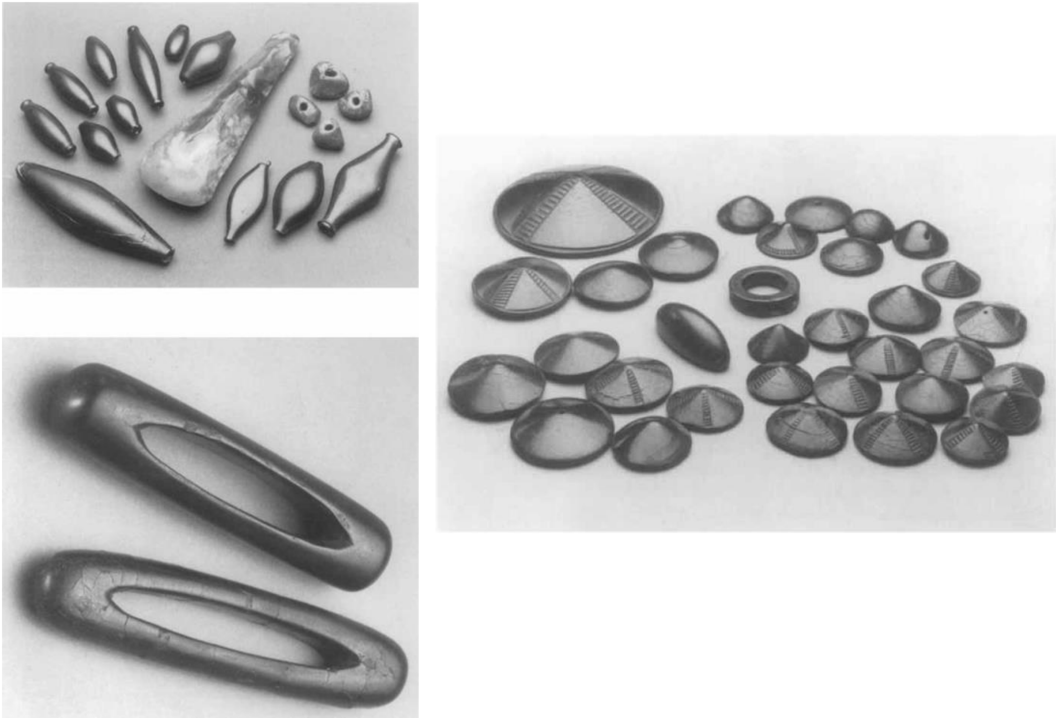

Figure 8 Jet finds from Scotland. Above-left: elliptical jet beads together with a flint axe head and four amber beads. Below-left: Two jet belt sliders. Right: V-perforated buttons (Sheridan *et al* 2002, Fig 2-4).

Jet was the preferred material for beads for a long time as it is relatively simple to carve, but in later Bronze Age Britain, around 1800 BC, jet began to lose its popularity to shale and throughout the Iron Age jet artifacts are very sparse: shale was worked more often than jet and other prestige items such as faience began to appear, possibly related to technological progress (Allason-Jones 1996, 8; Sheridan *et al* 2002, 819).

In sharp contrast to the developments in Britain, jet appears to be common in Iron Age continental Europe. A large amount of Celtic jet jewelry is found in the region around Schwäbisch Gmund, Southern Germany, ascribed to the Hallstatt and the later la Tène periods, ca 800-0 BC (Muller 1987, 95; Muller and Muller 2013, 9). Jewelry finds include armlets, which can be flattened, ribbed, triangular or hexagonal in cross-section; but also pins and numerous beads, mounted on necklaces, armlets, belts and ankle bands (Muller 1987, 95).

The use of jet became highly popular again in Britain somewhere around the later third century AD, as by this time the Romans were utilizing it on an industrial scale, producing rings, bracelets, hairpins, necklaces, pendants and dagger handles (Fig 9; Muller and Muller 2013, 7). The Roman jet artifacts are most commonly found in the Rhineland and in Britain, and show a similarity in artefacts that strongly suggests a trade route of either finished products or raw material with craftsman flourishing between York, South Shields and Cologne (Graham 2002, 214). Raw material for Roman black jewelry was not confined to jet but includes cannel coal, lignite and bog oak. These materials are derived not just from York, but from all available sources in the empire, which includes the Rhineland and Spain. However, the sparse Spanish jet finds in York are probably individual items: personal keepsakes rather than indicators of imperial trade routes (Allason-Jones 2001, 242).

Figure 9 Roman grave group from York (Allison-Jones 1996, fig 7).

It is difficult to explain why jet became so popular in Britain and the Rhineland and failed to catch on in other provinces, but it is probably related to existing trade routes and the movement of troops (Allason-Jones 1996, 14). It is a bit unclear when the Romans started using jet for their jewelry industry: There is a passage from the first century AD on the medicinal purposes of jet by the author Pliny, but it is very rare to find an actual jet artifact anywhere in the Roman Empire before the third century AD and jet artifacts do not appear in the Mediterranean basin in any numbers throughout the period (Allason-Jones 1996, 8). Archaeological evidence suggests that jet may have been worked in York as early as the second century AD, and if the empress Julia Domna was introduced to jet during her visit in York in 208-211 AD, than she may have started a trend in the same way Queen Victoria would do centuries later (Allason-Jones 1996, 9). It is probable that the Romans only started fabricating jet jewelry after the invasion of Britain, impressed by and following an existing Yorkshire tradition, and since the industry declined after they lost the British Isles, it was probably their primary center where crafting took place (Allason-Jones 1996, 8; Muller and Muller 2013, 9).

Alternatively the resurgence of Whitby jet in a Roman context may imply the introduction of a new cult in the area: jet as a material seems to be surrounded by mysticism and religion in the Roman world, attestable to medusa pendants and cantarus-headed pins. Objects such as these can be related historically to the 3rd century AD, when a revival of Eastern mystery cults occurred, such as the cult of Bacchus (Allason-Jones 1996, 15). Jet jewelry in this period is found especially in women's graves, a general significance for women can also be assigned through the artifact types, which seem to be predominately female (Allason-Jones 1996 in Graham 2002, 215). The archaeological tendency of jet to occur primarily in grave contexts in this period may be related to the Romano-Celtic believe of the capacity of personally worn objects to imbue the spirit of the owner, giving it the capacity to inflict harm onto new wearers (Allason-Jones 1996, 16).

In the Viking and Saxon periods, black jewelry was used only intermittently in Britain (Allason-Jones 1996, 9). The Vikings did not just use jet in Yorkshire, however, but also in Scandinavia. A small number of jet finds occurs in Norwegian Viking graves, mostly women's. Continuous trade networks with York throughout the Viking era well into the medieval period have been suggested, but care must be taken, as many of the Viking objects, such as 'bangles', (or ´arm rings', a type of arm braces), are most often made of less rare materials such as shale, cannel coal and lignite (Hunter 2008, 103). These materials are not as geographically confined as true jet. Furthermore, there are known but unexploited sources of jet in Norway and the provenance of the raw material used remains unknown (Resi 2005, 91). Finds include rings, beads, small figures of animals, dice and chess-pieces (Muller 1987, 26).

In the Middle Ages jet acquires a popular status once again, and remains a commodity throughout the period. Artifacts include mostly Christian religious objects such as pilgrim badges, rosary beads, crucifixes, amulets and figurines of saints (Allason-Jones 1996, 10), but gaming pieces have also been found, such as dice and chess pieces (Resi 2005, 94). Medicinal and magical properties are ascribed to the combination of jet with the symbolism of the cross which provided a potent protection against all forms of evil (Muller 1987, 27). Yorkshire was one of the medieval production places of jet, but especially Asturias in Spain is worth mentioning here: The Galician town of Santiago de Compostella became an important center of pilgrimage in the 12th century, and started giving jet souvenirs to pilgrims as a certificate of their journey. This gave rise to a sizable jet industry that flourished between the 13th and the 17th century (Muller 1987, 103). In Germany, during the same time period, a flourishing jet trade centered on the town of Schwäbisch Gmund in the Rhineland.

In France, a jet industry centered on Saint Colombe and Labastide-sur-l'Hers that was particularly well- known for its rosaries and exported finished goods to Spain, Germany, Italy and Turkey (Muller 1987, 113). It was on its height in the 18th century but by the early 19th century it had declined, possibly because the supply of raw jet had run out.

The jet industry around Yorkshire achieved some significance again around the beginning of 19th century, centering on the town of Whitby, where several craftsmen were working jet at that time. When her husband prince Albert died in 1861, Queen Victoria set in a fashion for jet jewelry as suitable for mourning purposes (Allason-Jones 1996, 10). When the jet sources around Whitby started to deplete around the end of the nineteenth century, jet lost a large part of its popularity due to inferior materials being passed off in its stead. This trend continued largely until today, now that there is a renewed interest in the material.

4) The jet ornaments of Ypenburg and Schipluiden; manufacture and use

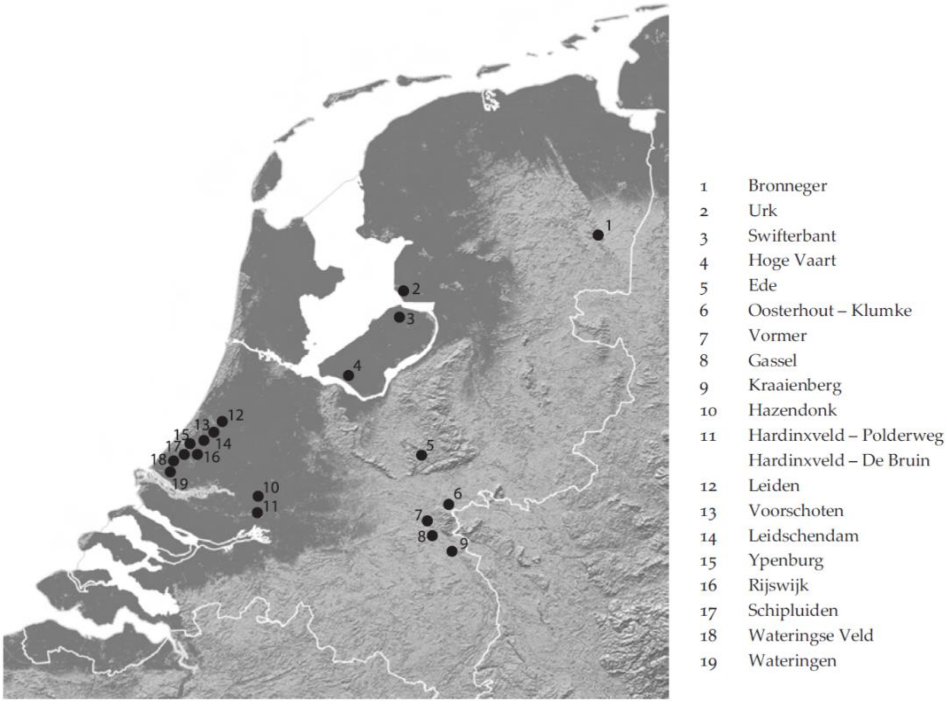

Figure 10 Map that shows the locations of Neolithic sites (Louwe-Kooijmans 2009, Fig 1).

Ypenburg and Schipluiden are among the oldest Neolithic sites of the Western coast of the Netherlands (Fig 10), located in a coastal geographical area where prehistoric occupation remained unknown until the 90's of the previous century. Schipluiden is part of a gradual Neolithisation process, preceded by the Mesolithic period and the Swifterbant culture. It has three permanent occupation phases, ranging between approximately 3630-3380 BC (Louwe-Kooijmans *et al* 2006, 490). Ypenburg was occupied relatively intensively for about 400 years, ranging between 3860 – 3435 BC. It gained special attention for its burial ground, unique in size for the Middle Neolithic period in North-Western Europe: 42 individuals were buried here, divided over 31 Burial pits (Koot, Bruning and Houkes 2008, 6).

Ypenburg and Schipluiden can be assigned to the Hazendonk group (Louwe-Kooijmans *et al* 2006, 491; Koot *et al* 2008, 456). This archaeological culture is contemporaneous with the Michelsberg culture in the south and the late Swifterbant group in the central parts of the Netherlands. These cultural groupings are generally referred to as the Middle Neolithic A, ranging between approximately 4900 – 3400 BC (Louwe Kooijmans 2009, 249).

At Schipluiden, 37 jet artefacts were found, including raw materials, blanks and unfinished products (Fig 11; van Gijn 2006, 195). Seven finished beads were found, three of tubular shape and four that are flat and cylindrical (Fig 12). The large amount of unfinished products points to on-site manufacturing with a rather careless treatment and probable abundance of raw material (van Gijn 2006, 203).

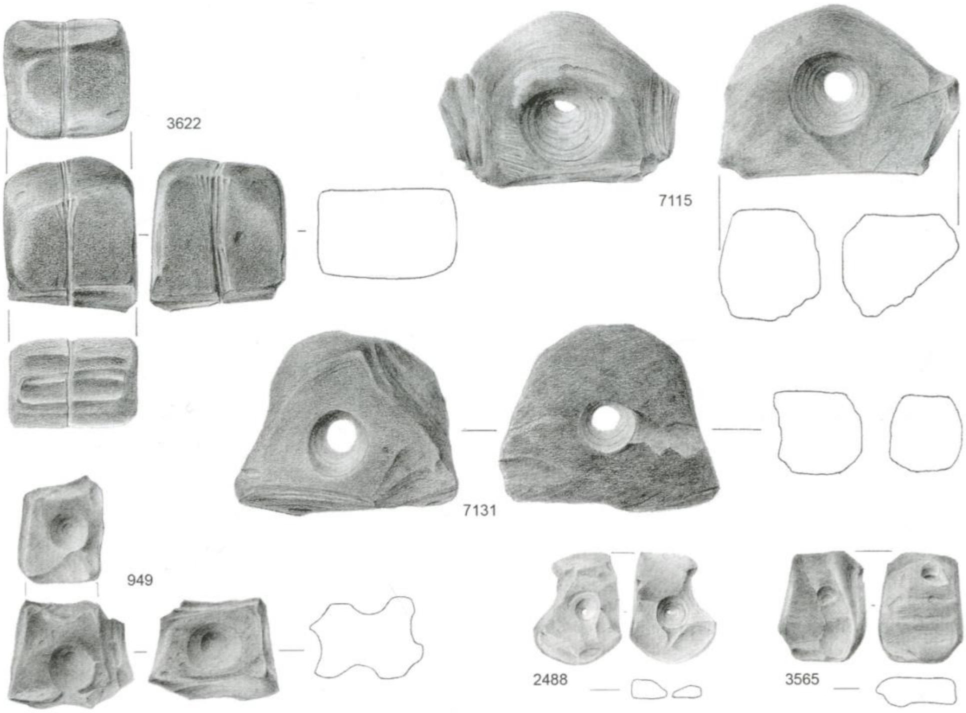

Figure 11 Blanks and half-products from Schipluiden (van Gijn et al 2006, Figure 9.3).

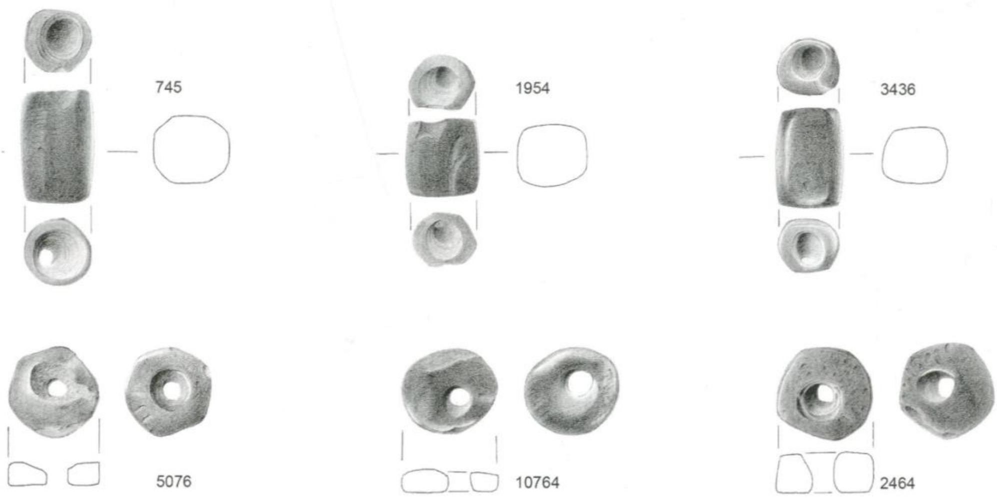

Figure 12 Finished ornaments from Schipluiden (van Gijn et al 2006, Figure 9.4).

Ypenburg yielded 24 jet artefacts, again both finished goods and production waste. Five unfinished products, one large chunk and several smaller pieces of unworked jet allow a reconstruction of the production sequence (van Gijn 2008, 283). Four finished ornaments were found (Fig 13), all of them in burial contexts:

three jet pendants, two in a single female burial[1], both placed on the left shoulder (vnr 467, vnr 468) and one in a single child's grave (vnr 385). One smaller specimen, a bead, was also found in a single child's grave (Baetsen 2008, 151-181).

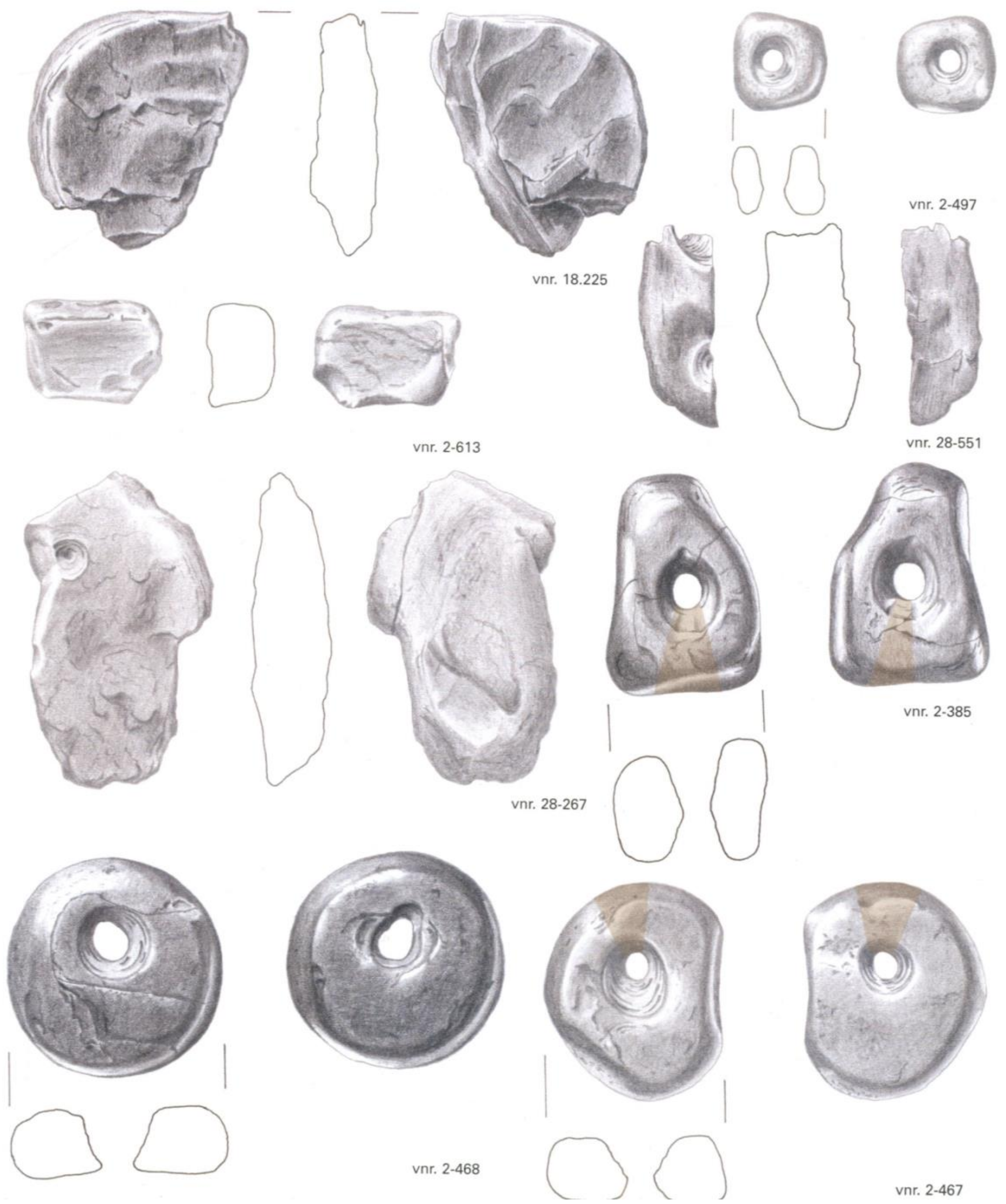

Figure 13 Jet ornaments and half-products from Ypenburg (van Gijn 2008, Fig 14.2).

The shape of Dutch Neolithic ornaments can be broadly divided in pendants and beads. Pendants are generally larger than beads and exhibit a decentralized perforated, use wear analysis further indicates that they were asymmetrically worn (van Gijn 2008, 285). Beads are smaller, can be either flat or tubular in shape and are characterized by a centralized perforation; traces of wear around

[1] This woman's face was reconstructed and named "*Ypje*".

the circumference of the holes indicate that they were part of a string of beads (van Gijn 2006, 204; Devriendt 2008, 385).

Beads and pendants were roughly cut, probably along the horizontal fracture planes, after which they were perforated with a solid flint drill in a biconical fashion from both sides, creating a hourglass-shaped hole (van Gijn 2008, 283). After this the bead or pendant could be roughly shaped with sandstone and further polished. This could have been done using a piece of leather and sand or flint-dust (van Gijn 2008, 285). Plant material, such as horse tail, E*quisetum hyemale,* would also have been available to people at the time (van Gijn 2008, 199).

Jet ornaments are not uncommon at Neolithic sites in the Netherlands, although these finds represent the earliest examples, together with an unfinished piece found at Wateringen-4[2] and a single jet bead from Swifterbant[3]. They become more abundant in the later Vlaardingen and Funnelbeaker culture and the subsequent Bronze Age (van Gijn 2008, 287). Sources of raw jet have not been determined in the Netherlands, implying that either raw material or manufactured goods were derived from elsewhere. It is known from Schipluiden and Ypenburg that manufacturing took place on site (van Gijn 2006, 203; van Gijn 2008, 281), but the question remains whether this accounts for all finished products. Amber ornaments were probably not locally manufactured at Schipluiden and Ypenburg but rather acquired as end-products; a case can be made that they were acquired by means of an exchange network with the northern parts of the Netherlands where there is an abundance of amber: it is much more commonly found here and manufactured on site (van Gijn 2008, 278).

A possible hypothesis for the availability of raw material is related to North-Sea ocean currents. The fact that most jet finds occur at sites close to the southern part of the Dutch coastline and become much scarcer to the North may be attributed to the North Sea transporting the material from Yorkshire in Britain or from Pas de Calais in France, as the specific gravity of jet is very small (van Gijn 2006, 204). To further investigate questions related to provenance, it is important to chemically characterize the assemblage and the jet sources existing in close proximity to the archaeological sites under investigation.

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[2] A bead with two incomplete conical perforations, Wateringen-4 is dated around 3500 (Raemaekers *et al* 1997).

[3] The jet ornament is about 3 cm in diameter and has a decentralized perforation. It was found in an occupation layer dated between 5200-4200 BC (Devriendt 2008, 391).

5) XRF – Spectrometry

5.1) Characterization

Even for those experienced in identifying geological specimens it is no easy matter to identify the small and often fragile archaeological samples (Pollard *et al* 1981, 139) and 19th century archaeologists made the mistake of calling numerous carboniferous rock -made artefacts jet (Muller and Muller 2013, 8). Neolithic, Bronze Age and Roman craftsmen alike used different kinds of very similar black stones for their jewelry, jet, but also shale, lignite, and cannel coal (Allason-jones 1996; Sheridan *et al* 2002; Muller and Muller 2013).

Shales are composed of clay minerals in the form of hydrated aluminum silicates. Oil and gas are created by bacterial action that breaks down organic constituents in shale (Allason-Jones and Jones 2001, 235). The type of shale that is most easily confused with jet is Kimmeridge shale. It is formed in anaerobic sediments at the bottom of shallow marine deposits and contains grains of quartz and calcite (Watts and Pollard 1996, 41). It shows the same conchoidal fracture and has excellent polishing qualities that can make it visually indistinguishable from jet. It also fluoresces under blue or ultraviolet light. The name Kimmeridge can misleadingly mean occurring in the United Kingdom only, but this type of material spans a geological horizon and might be collected from many locations in Europe (Allison-Jones and Jones 2001, 236). Shale has been a separate industry in the past, often used for different end-products, and it would be wrong to say that shale objects were made to imitate jet (Muller 1987, 117). Shales appear opaque in an x-radiograph whereas other jet-like materials are translucent (Hunter *et al* 1993, 84).

Lignite is an immature brownish coal-like deposit ranked in between peat and bituminous coal, and it is black lignite that is thought to have been worked in the past along with jet[4] (Watts and Pollard 1996, 40). Under a microscope the original plant structure is less compacted and distorted than in jet (Muller 1987, 119). Lignite, like jet, is also derived from logs that are washed into sediments, but it lacks the hydrogen impregnation that protects jet from becoming brittle (Allason-Jones 2001, 237). It is therefore less durable than jet and lacks the deep black color and shine. It is known that lignite and jet grade into each other (Allason-Jones and Jones 2001, 237) and soft jet may lay closer to lignite in this grading spectrum, although soft jet is presumably formed in fresh water (Muller 2013, 5)

Cannel coal is a sapropelic coal that consist of finely comminuted plant debris and it lacks the woody structure of jet and lignite (Allason-Jones and Jones 2001,

[4] See chapter 3, The archaeology of jet.

235). It is formed in stagnant water near coal swamps and contains almost no *vitrinite*. It also breaks with a conchoidal fracture, but the color is not as black as jet and the surface does not take such a high polish (Muller 1987, 120). It leaves a black mark on a streak plate.

Other materials that may resemble jet, but are less important in archaeological contexts include asphalt, torbanite, anthracite and bog oak (Muller 1987; Allason-Jones and Jones 2001). The confusion of visual resemblance in these materials is reflected in the Latin word for jet, *gagates,* which was also used for asphalt; a name derived from a source of arguably solely the latter material, the river Gages in Lycia (Allason-Jones 1996, 5; Muller and Muller 2013, 5). The need to distinguish true jet from other materials inspired a range of analytical techniques. The first chemical techniques that were used on jet were inorganic and based on trace elements. They include neutron activation analysis, X-Ray Fluorescence, X-ray radiography and scanning electron microscopy (Pollard et al 1981; Hunter et al 1993).

Organic techniques are much more apt to characterize and provenance highly organic materials, such as jet. An obvious use of organic techniques on coal-like material is coal petrology. There are several difficulties involved with this type of analysis, however. First of all, the application of reflected light microscopy requires thin slides and the relatively large sample size usually associated with thin slides restricts this type of analysis to small artifacts such as beads (Watts *et al* 1999, 923). In the case of jet white and blue incident light causes fluorescence, which often results in only mm's of sample requirement. Another difficulty that arises is the degree of expertise that is required for this analysis, which has traditionally been reserved to oil companies, although the field has been opening up in recent years (Allason-Jones 2001, 239). A cheap and simple archaeological application of coal petrology is determining coal rank by the reflectance in oil (% RO) of a vitrinite particle. Although this still requires a sample, it is micro – invasive: only a ballpoint-sized hole is left in the artifact. Jet has much lower % RO than other carboniferous materials like lignite and different jet sources have different RO values; jet in Britain ranges from 0.17-0.25 % RO, jet from Holzmaden on the Rhine in Germany ranges between 0.19 - 0.2 % RO, jet from Asturias in Spain is consistent with 0,35-0,37 % RO (Allason-Jones and Jones 2001, 241).

Another highly successful technique that has been recently applied on archaeological artifacts (Watts *et al* 1996) is Fourier Transform Infrared Spectrometry (FTIR). In the study of amber this method has already successfully characterized European sources (Pollard *et al* 2007, 89). The Infrared spectrum produced by jet-like materials is a function of their compound macerals (Pollard and Watts 1996, 39). The downside of this technique is that a sample is required.

The most successful organic technique for characterization and possibly provenance of jet is probably pyrolysis Gas Chromatography Mass Specrometry (py GC-MS). The organic materials that reside in organic-rich sediments, such as whitby jet, are usually present in an insoluble kerogen matrix (Watts *et al* 1999, 924). This matrix consists of complex macromolecules and varies according to precursor organic material and depositional environment: A specific kerogen matrix is therefore characteristic of a specific geological source (Watts *et al* 1999, 943). Py-GCMS allows the Kerogen matrix to be partially cut up into pyrolithically volatile smaller components and subsequent analysis of those volatile pyrolysis products produces a characteristic fingerprint of a given kerogen matrix. To apply this technique, a sample is required.

To conclude, the scientific identification of jet is not an easy matter and the most reliable methods of identification above will alarm museum curators (Pollard 1981, 141). In distinguishing archaeological artifacts, XRF and X-radiography still have many advantages over organic techniques: they are inexpensive, quick, accessible and non-destructive (Watts and Pollard 1996, 38).

Several attempts to identify jet using XRF-spectrometry have been made in the past, taking different approaches to this kind of analysis. Pollard *et al* (1981) and Hunter *et al* (1993) established elemental discriminants between geological Whitby jet and non-jets in the form of shale, cannel coal and lignite. Hunter et al (1993) established an effective methodology for distinguishing archaeological material and recommended an approach that is a combination of XRF and X-radiography. With these techniques Sheridan *et al* (2002), Hunter (2008) and Penton (2008) have succeeded in distinguishing Whitby jet from inferior materials in Great Britain.

In this investigation a handheld X-ray fluorescence *Bruker Tracer III-SD* was used for the determining the chemical composition of the various jet artifacts from Schipluiden and Ypenburg. The instrument is equipped with an Rh anode X-ray tube and a Peltier-cooled Silicon Drift Detector (~150 eV), the spot size is approximately 2 by 3 mm. This XRF-investigation is divided into two sets of measurements; first, a qualitative distinction of jet and non-jet material based on iron and some heavier elements; second, a qualitative characterization of the assemblage based on the lighter elements to investigate patterns useful for provenance.

Because jet, like lignite, and as opposed to cannel coals and oil shale, is naturally derived from wood, its main essence is very pure and contains little inorganic material (Pollard *et al* 1981, 140). Minerals that are present in jet and detected by XRF include quartz, pyroxene, zircon and microcline (Figure 14; Hemingway 1933, 101).

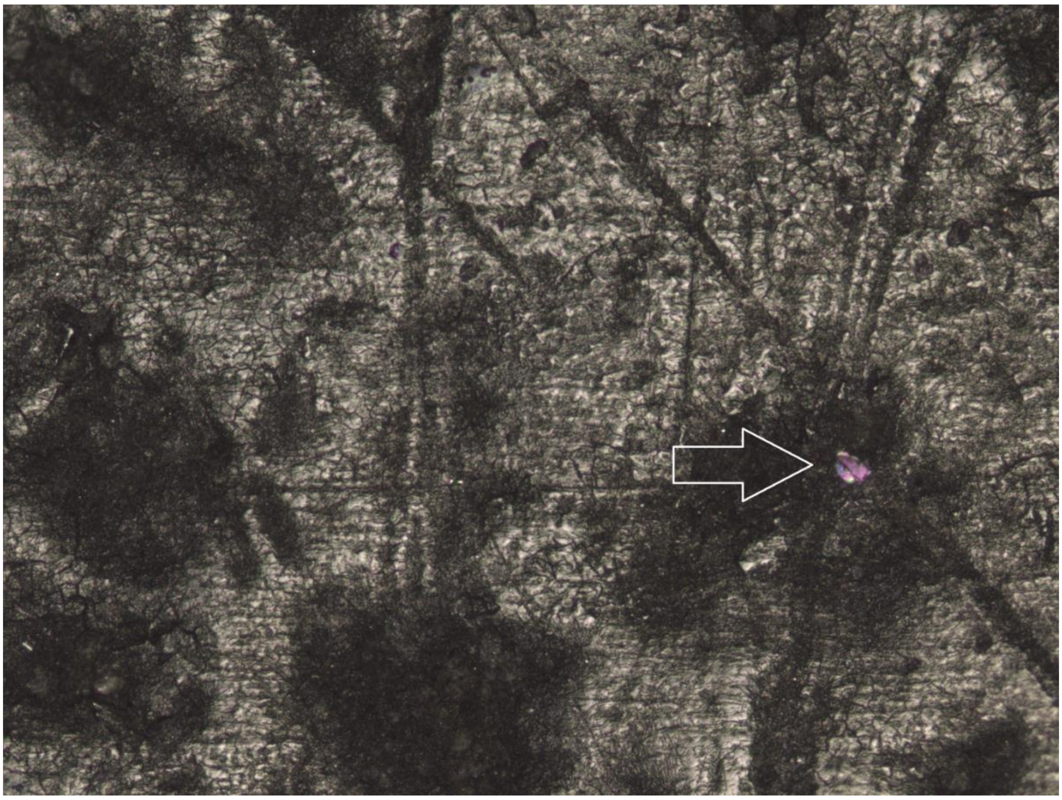

Figure 14 Instance of a mineral inclusion in jet as seen by the author on a 200 X magnification of the surface. This is possibly quartz or zircon.

Trace elements are probably derived from mineral inclusions that were part of the original wood and include sulfides and sulfates. Especially Iron-sulfide seems predominant, which is probably an organic fraction of the matrix of the wood structure or is present in grains that are very homogenously distributed in jet, as iron (Fe) shows much less elemental variation in jet as compared to other elements (Hunter 1993, 84). Iron in very low densities is discriminative of jet as compared to much higher mineral densities in non-jet coal material while the presence of a high silicon (Si) or aluminum (Al) ratio clearly defines shale (Pollard *et al* 1981, 160). High values of vanadium (V) and zinc (Zn) occur in some jets; qualitatively high values of Zirconium (Zr) are associated with jets; Shales have a higher Rayleigh : Compton peak ratio (Hunter *et al* 1993, 79). Calcium (Ca) seems to be too variable in archaeological samples for analytic purposes, possibly due to burial conditions or limestone polishing in the manufacture process of jet artifacts in the past (Hunter *et al* 1993, 109). To be conclusive, jet is distinguished from related materials on the basis of XRF –Readings by a clean spectrum and the notable presence of distinctive elements such as titanium, vanadium, zinc and zirconium (Table 4; Hunter 2008, 109).

Table 4 Criteria of jet distinction by Pollard *et al* 1981 and Hunter *et al* 1993 synthesized into a table (Penton 2008, table 1).

element	ppm	material
Fe	< 600	Jet
	1600-1800	Lignite
	>5000	Shale and Cannel coal
K	<600	Jet and lignite
	400-1000	Cannel coal
	> 1000	Shale
Ti	> 1000	Jet
Sr	<50	Jet and cannel coal
Cr	< 40	Possible Jet
V	presence	Possible jet
Zr	presence	Possible jet
Zn	Presence	Possible jet
Pb	Presence	Possible shale
Rb	Presence	Possible shale
Al	High	Shale
Si	High	Shale
Ca /Cu	variable	Too variable for archaeological material

Jet can be identified qualitatively by focusing on the ratio of the Iron Kα-peak at 6,40 KeV as compared to the tubes Compton Kα peak and the presence of Ti, Cr, V, Zr and Zn. If the Iron peak is much smaller than the Compton peak the sample is jet, if it is much higher the sample is a non-jet (Hunter 1993, 84).

For the first set measurements were taken in air for 300 seconds, on two locations for some objects to check the consistency of the matrices. A yellow (Ti-Al) filter was used with beam conditions of 40 keV and 10.24µA, which provides optimal excitation of elements from 12 to 40 keV. These qualitative measurements will be used to determine whether the objects agree with the afore mentioned characteristics of geological Whitby jet as established by Pollard *et al* (1981) and Hunter *et al* (1993). This qualitative analysis will be visualized by XRF spectrum software with element-peak-identification (S1pXRF) and normalized to the Compton α-peak. All spectra can be found in the appendix 1 included at the end of this thesis.

5.2) Provenance

To successfully link a specific jet artifact to a specific source one needs a measurable characteristic value of both the material and the source. In the use of XRF ideally trends in the elemental composition of artifacts are analyzed, grouped and linked to specific geographic samples of known sources. A main problem associated with XRF on mostly organic jet samples is the considerable variation in element values in a given sample of jet. Furthermore, XRF spectrometry and other non-destructive methods have to date not proved sufficient at pinning down individual jet sources due to intra-source variation and the abundance of possible sources (Pollard *et al* 1981, 161; Hunter 2008, 109).

To further investigate questions related to provenance, it is important to attain a clearer picture of all possible European jet sources and their trace elements, especially those existing in close proximity to the archaeological sites under investigation. The only available XRF data that distinguishes between sources comes from Muller (1987) who performed X-ray emission spectrometry on two objects and noted that jet from Whitby had a higher proportion of aluminum whilst jet from Asturias in Spain contained more sulfur (Muller 1987, 2). Penton (2008) also noted high aluminum content in a confirmed Whitby jet artifact. Jets are likely to show large variations in the values of certain elements, however (pollard *et al* 1981, 161).

The reference samples include 13 pebbles that were collected from beaches around Whitby and have been weathered to some extend by the oceans waves and beach sand. Most collected pebbles were thought to represent true jet and were collected with that purpose, although none of the pebbles have been chemically tested prior to this investigation.

The second set of measurements was taken in a vacuum without a filter for 300 seconds. Soil and oil shale reference samples have been used to check for machine drifting. Single measurements were taken of the lighter elements. Beam conditions of 15 keV and 24µA were used, which means that Cl and Ar are overlapped by the Rh-L lines. This qualitative analysis will be visualized by XRF spectrum software with element-peak-identification (S1pXRF) and values are normalized to the RhLα Rayleigh-peak.

5.3) Results

5.3.1) Iron and the heavier elements

All the relevant XRF-spectra can be found in the appendix 1. Table 1 shows the initial distinction of jets and non-jets, categorized in reference pebbles, artifacts, and blanks or half-products. The finished artifacts are the objects that are recognizable as deep black ornaments of high quality that have retained a degree of shine in over 6000 years of burial. They include four ornaments from Ypenburg (385, 467, 468, 497) and three from Schipluiden (1954, 5076, 10764). We might expect these objects to reflect true jet in XRF-readings as true jet is distinguished from resembling materials primarily by its durability (Muller and Muller 2013, 8), although the effect of burial conditions on jet is not well known (Penton 2008, 9).

Blanks or half-products include those raw materials that failed to become actual ornaments either because they were abandoned (blanks) or due to manufacturing errors (half-products). We may speculate, therefore, that a fair portion of these raw materials include lower quality jets, soft jets and other materials of lower durability such as shale, cannel coal and lignite. Soft jet and other lower quality materials are known to crack when worked and thus should include especially the worked material that cracked or blanks that were deselected prior to manufacture. They include 10 objects from Schipluiden (7115,7131, 2488, 3565, 3622, 29450, 29431, 29428, 29422, 29454) and 5 from Ypenburg (145, 225, 267, 427, 613).

A striking feature that is apparent from table 5 is that nearly all objects from Schipluiden do not qualify as a jet according to this method. All artifacts from Ypenburg qualify as jets as well as two half-products. It appears that half products are indeed more often made of non-jet materials than the artifacts. One of the collected reference samples appears to be a non-jet.

Table 5 Overview of the XRF-distinction of the assemblage

object	distinction	Double measured
Whitby reference pebbles		
1	intermediate	no
2	unknown	yes
3	jet	no
4	jet	no
5	non-jet	yes
artifacts		
Yp 385	jet	yes
Yp 467	jet	yes
Yp 468	jet	yes
Yp 497	jet	yes
Schip 1954	non-jet	no
Schip 5067	non-jet	no
Schip 10764	non-jet	no
halfproducts and blancs		
yp 145	non-jet	yes
yp 225	non-jet	no
yp 267	jet	no
yp 427	non-jet	yes
Yp 551	non-jet	no
Yp 613	jet	yes
Schip 2488	non-jet	no
Schip 3622	non-jet	no
Schip 3565	non-jet	no
Schip 7113A	non-jet	no
Schip 7113 B	non-jet	no
Schip 29428	non-jet	no
Schip 29431	non-jet	no
Schip 29454	intermediate	no

5.3.2) Lighter elements

All the relevant XRF-spectra can be found in the appendix 2. Spectra of the reference samples differ considerably: the fact that they were picked up on the beach and were not chemically tested for being true jets underlines the difficulty of visually distinguishing between these materials, although pebble 3 and 4 are clearly true jets. Hunter *et al* (1993) have noted a high degree of intra-source variation. Interestingly, there is virtually no aluminum attested in either the samples or the archaeological objects, which questions Muller's (1980) distinction between Spanish jets and Yorkshire jets. Sulfur content is generally high. All iron measurements are highly consistent with the yellow filter measurements, strengthening the initial differentiation. This means that only 7 of the 21 measured archaeological objects are possibly true jets, with a single border case, which is a blank (29454). Unfortunately, no other patterns in elemental distribution emerge, nor any finger print that matches the Whitby reference samples. For now the provenance of these materials remains a guess.

5.4) Discussion

When we consider the reliability of the qualitative XRF data that have been obtained there are several issues that should be addressed. First of all, there are considerable problems related with the inorganic analysis of jet: The matrix of the material is organic in nature and the few trace elements that are present show some internal variation, as apparent from the double measurements that were taken. However, overall the individual objects showed remarkable consistency even between yellow filter and vacuum measurements. Whitby reference pebble 2 is the only object that showed high inconsistency and was probably contaminated.

According to Hunter *et al* (1993), iron is the most reliable element as a discriminating agent because it is more homogenously distributed in Whitby jet than other elements. This is probably related to very small grains of iron sulfide that are evenly distributed in the organic matrix (Hunter *et al* 1993, 84). The definition of a true jet by Pollard et al (1981) and Hunter *et al* (1993) was based on geological samples from Whitby, which were derived from specific Upper Lias strata. Information on the trace elements of Cretaceous sources is not available. If these grains are absorbed from the soil by the original tree, they reflect the growth environment and may therefore be source-specific. Obviously more research on trace elements is required for a better understanding of elemental distributions in other jet sources.

Another problem relates to the Whitby reference samples that are used in this analysis: They are not geological samples that are categorized as jets by petrographic analysis, such as the ones analyzed by Pollard et al (1981) and

Hunter et al (1993), but rather pebbles collected from beaches around the Whitby area. One of the samples actually proved to be a non-jet in the XRF analysis of the heavier elements.

The 3mm point area of measurement (point-analysis) that is covered by XRF is not highly surface penetrating and so it is the surface that is analyzed rather than the main body of these artifacts. Artifacts from museum collections usually pose problems related to contamination and surface texture (Pollard *et al* 1981, 146), but there is also the fact that it is unclear what the effects of a burial environment are on the deterioration of jet artifacts (Penton 2008, 9), especially prolonged periods of time such as is the case with this Neolithic assemblage that has been buried over 6000 years. It has been noted that the surfaces of many jet artifacts have probably been oxidized to an extent by their burial environment (Watts and Pollard 1996, 49).

6) Microscopic use- wear analysis

6.1) Experiment: introduction

The research question that this chapter will seek to resolve is whether it is possible to distinguish between an intentional polish and a polish resulting from prolonged wear with the use of macroscopic analysis. The following surface investigation will focus primarily on the finished jet beads of Ypenburg and Schipluiden and an attempt will be made to characterize the development of polish on jet and to microscopically investigate the difference between intentional craft related polish and use-wear using experimentally made jet beads. How can these differences be defined and recognized?

The material properties of jet allow it to be polished to a preferable extent quite easily, resulting in a shine that can be strong enough to resemble a mirror-like sheen. A craftsman intentionally creates the conditions that allow a polish to develop on a jet surface and it is this act that is archaeologically relevant. Therefore care must be taken, as the conditions that are required for a polish to develop on a jet surface are poorly understood and a polish may also result from weathering or a process of wear resulting from long-term use.

The fact that a polish has developed on a human artifact, in this case on a crafted bead or pendant, is no direct evidence that the polish was also intentionally applied. In the assemblages from Ypenburg and Schipluiden, jet ornaments surfaces have developed different extents of shine. It is often assumed that an extended period of use, which means a continues process of wearing down against human skin or clothing, is responsible for these differences and can even by itself be largely responsible for the objects polish (van Gijn 2006, 199). The question here is how much the perceived polish on archaeological artifacts resembles the originally manufactured product. Therefore it is worthwhile to investigate the effect of use-wear on jet surfaces. Confirmation of the polish effect of use-wear hints at extensive personal use of jet ornaments, and provides insight in their social importance.

6.2) Experiment: Methods

To investigate the process of use-wear on a jet surface a series of experiments have been designed that aim to empirically test the effect of use-wear by centrifuging six pieces of jet pouched in leather, linen or pigskin in a rock tumbler. In this way it is perhaps possible to mimic the long –term use of beads and at least show that a polish can indeed develop in such a way. A comparison of surfaces will be made by a metallographic microscope with a 100-500 x magnification, to see in which way tumbled surfaces relate to the surfaces of the artifacts. Fundamental for the reliability of this experiment is the assumption that the process of tumbling with leather, linen and pigskin is comparable with the slow wearing against human clothing and skin in the past.

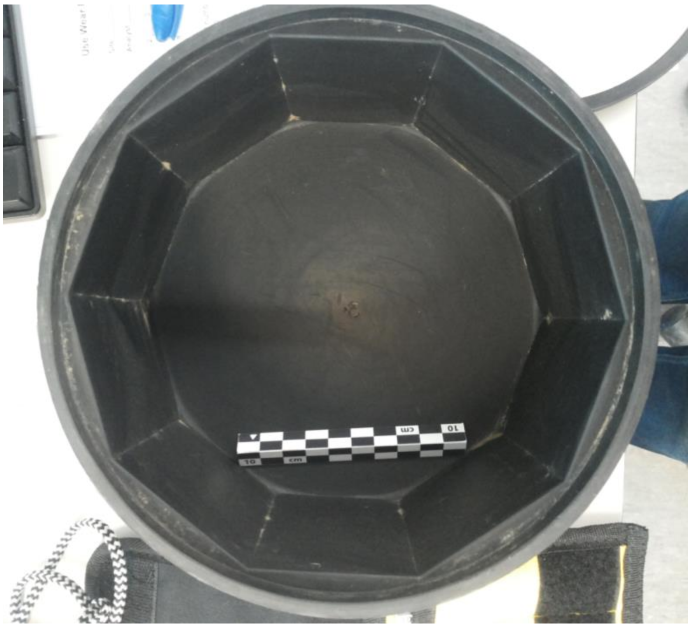

Figure 15 Inner chamber of the tumbler

For the centrifuging, a Lortone rotary rock tumbler model QT12 will be used (Figure 15), which is a machine that is used primarily to polish gemstones. The best results for polishing in this way are achieved by using tumble barrels that are filled for about 66 percent; the source material is polished by a mixture of water and grit which is allowed to tumble on for about seven days.

The barrel of this particular tumbler has a diameter of 17.10 cm, and an effective rotary radius of 8.55 cm. The breadth of the chamber is 9 cm. The inner space of the barrel is not round, but rather a decagonal so movement is forced upon the objects it contains. It has a volume of 2,08 L or 2,08 dm^3. Rotation speed is a steady 25.95 rpm, which is a steady 1557.09 rounds per hour. To achieve a relatively "filled" or "saturated" barrel, all beads are tumbled simultaneously. The reason that a relatively filled barrel is desirable is that friction is facilitated by multiple objects, or put differently: a nearly empty barrel will not be expected to achieve a significant polish. Surfaces are microscopically investigated before the initiation of the tumbling and then after a duration of 1 hour (1557.09 tumbles), 11 hours (15570.90 tumbles) and 50 hours (77854.67 tumbles), per bead. The resulting polish on the experimental beads will be microscopically studied and compared to the polish that is seen on archaeological artifacts. Microscopic images are made with a Leica DM6000 M incident light using a 100x magnification.

Figure 16 The used raw hard whitby jet materials, set against a background of buckskin

The beads for the experiment were made by Diederik Pomstra, a Stone Age craftsman. All beads were made of three specimens of hard Whitby jet (Figure 16) that was shaped using sandstone and flint. Six beads were procured, five flat and one tubular form, using the Schipluiden beads as an example. The material was split, drilled and subsequently ground to its final shape.

In order to make maximum use of the material properties of jet, which is naturally layered, incisions were made. A sawing motion was applied on the edges of the material with a very thin flint blade from which the jet could be split along its conchoidal fracturing planes. The blades would often break during this exercise. Splitting was not accomplished by hand, as the material would not fracture along straight lines in this manner. A wooden hammer and 33% incision depth were required to split the material with a predictable outcome along the fracturing plane. A straight flint blade with a broad cutting angle was used as a wedge as the jet was softly hammered from the other side (personal info, D. Pomstra).

The drilling was facilitated by the use of a small drill with flint drill bit, the holes were widened by hand using a flint borer. Drilling in jet using flint is fast and efficient and only took a few minutes at most. The long borehole in the tubular shaped bead made work more difficult, however, as the risk of fracture was high. Therefore, only on the tubular shaped bead, and only for the purpose of drilling, iron tools were used, which was necessary in order not to waste the material. All traces from iron tools were subsequently removed by secondary use of a flint drill.

For the final touch the half fabricates were ground using finely grained sandstone and sand. This was easy and fast. Three out of the six beads received a basic polishing prior to tumbling using three different polishing tools, namely wood, leather and plant fiber in the form of horsetail, *Equisetum hyemale*. This plant is known to have been used as an abrasive material in the past and the genus *Equisetum* was indeed attested for in the pollen samples of both Ypenburg and Schipluiden, be it in small quantities (Bakels 2006, 313; van Beurden 2008, 340). The polishing process of beads nr 2417, 2418 and 2419 took several minutes at the most.

All in all the fabrication of the six beads took four hours and twenty minutes, most of this time was spent on the tubular shaped bead, which is by far the most difficult form to achieve. This shows that a tubular shaped bead would have required more skill, time and energy to manufacture in the past than a disc-shaped one, although more disc-shaped beads are required to fill the string of a necklace.

The different pouches in which the beads were tumbled were chosen to resemble either human clothing appropriate to the period (buckskin, linen) or human skin (pigskin). The average bead size approximates 1 cm^3. The pouches were manufactured by the author and approximate four times the size of the beads, so that every bead has some freedom of movement.

In order to make a full comparison, 12 beads are required, as shown in table 7. The current experiment only works with 6 beads (table 6) and the differences in development of polish due to tumbling cannot be ascertained because it is unclear what the result of a comparable treatment is in the different pouches. This is partly related to the availability and cost of raw material and the time and energy required for the manufacture of the beads and their consequential microscopic analysis. Expansion of this experiment in the future is therefore desirable.

Table 6 Experimentally made beads and their respective treatment

Bead nr	**tumble-pouch**	**prior treatment**
2414	Buckskin	None
2415	Pigskin	None
2416	Linen	None
2417	Buckskin	Wood polish
2418	Pigskin	Leather polish
2419	Linen	*Equisetum* polish

Table 7 Variable table that shows the lacking beads required for a full comparison

Treatmen / Tumble-pouch	**Unpolished**	**Line-wood**	**Leather**	**Rough Horsetail**
Buckskin	2414	2417	-	-
Pigskin	2415	-	2418	-
Linen	2416	-	-	2419

Rotation speed is a steady 25.95 rpm, or 1557.09 rounds per hour. Surfaces are microscopically investigated before the initiation of the tumbling and consequently after a duration of 1 hour (1557.09 tumbles), 10 hours (15570.90 tumbles) and 50 hours (77854.67 tumbles). After this investigation an attempt can be made to characterize different sorts of polishes on jet and to compare these experimental specimens with archaeological ones.

Before the tumbling is initiated, each bead is measured and documented to be recognizable, using drawings, a digital scanner and photography. This documentation involves making a map of the surface of each bead, allowing the viewer to retrace the microscopic locations with the aim of creating microscopic pictures of the same area.

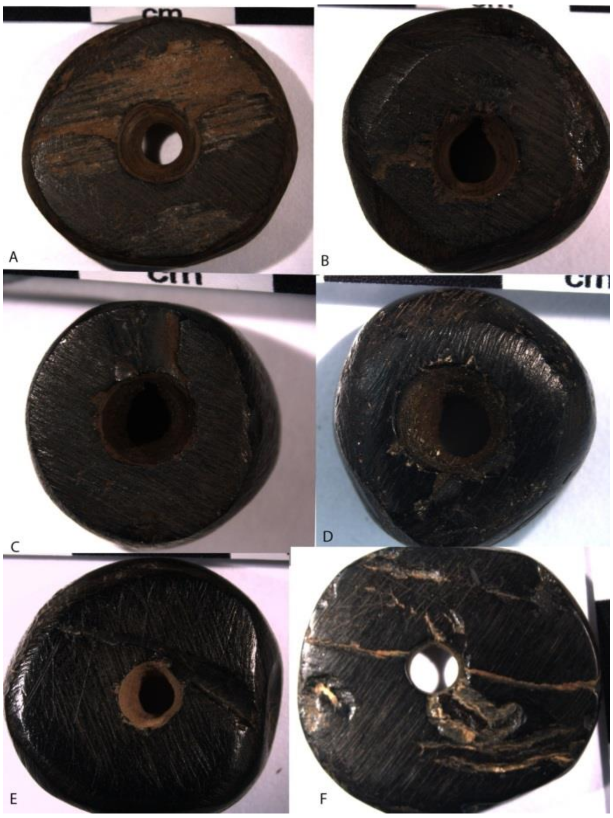

Figure 17 Experimental beads 2414 (A), 2415 (B), 2416 (C), 2417 (D), 2418 (E) and 2419 (F), scale 2:1

Table 8 Order and subdivision of the tumble experiment in seperate chambers

1st chamber	Contains six pouched beads, emptied after approximately 1 hour
2nd chamber	Contains six pouched beads, emptied approximately 10 hours after initiation
3rd chamber	Contains six pouched beads, emptied approximately 39 hours after initiation

Rotations per minute and total tumbles give an estimate of total rotations required for a polish to develop and a means of quantifying data. Expectation is that a large amount of total rotations will create a better developed polish on the surface of the object, and thus prove that a well-developed polish can be an indication of long term use. Polishing by tumbling should create a polish which is visibly distinct from a purposeful polish by sandstone, plant fiber, wood or leather.

6.3) Experiment: results

The first observation on all beads is that while a distinguishable polish is visible after 50 hours, 1 or even 11 hours is generally not enough to show a marked difference on a 100x magnification of the surface. Therefore I will focus on the visual differences between freshly manufactured beads and beads that have been tumbled for a period of 50 hours. Pictures show approximately fixed microscopic locations before and after 50 hours of tumbling. All microscopic locations are shown in the same magnification (100x), and have been scaled down to fit the document. Unfortunately some scale-bars have failed to appear due to software problems.

6.2.1) Unpolished beads

Unpolished surfaces generally look rougher and show micro craters. The obvious deep, parallel longitudinal grooves are the traces from grinding with sandstone. The micro scratches result from the use of sand.

2414

Figure 18 bead 2414, scale 3:1

The pictures below show approximately the same locations before (left) and after (right) 50 hours of tumbling in a leather pouch.

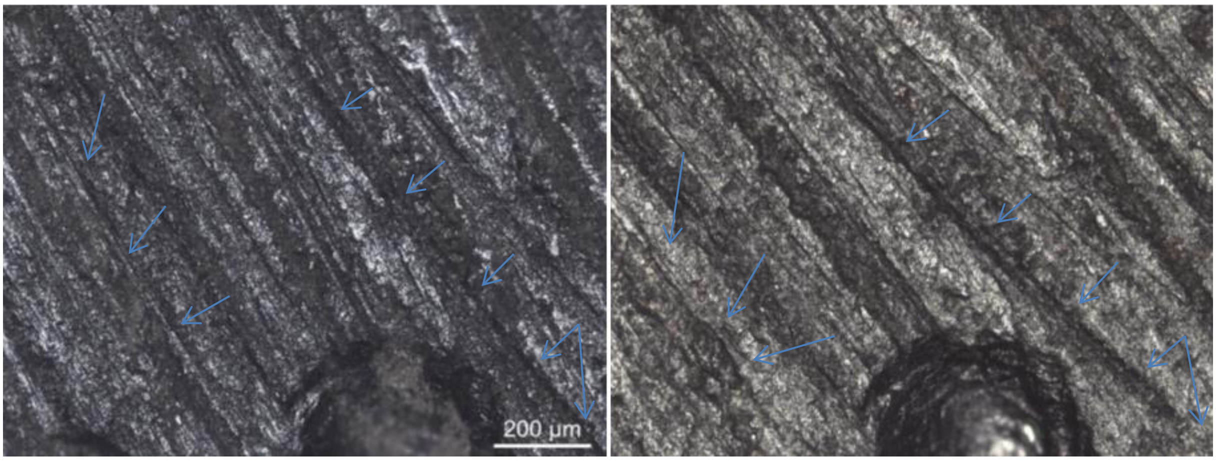

Figure 19 bead 2414, location 2(100x), scale 1:1.5

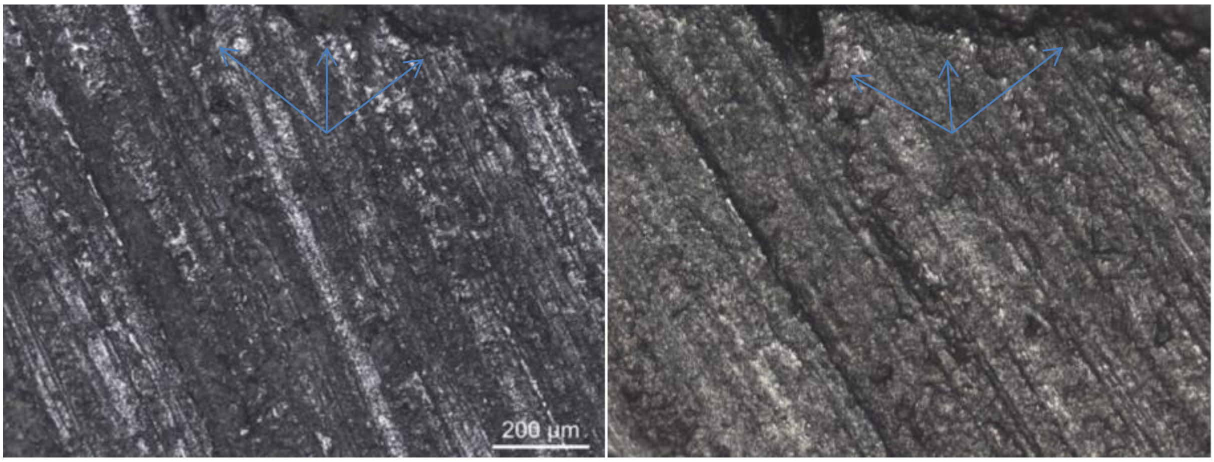

Figure 20 bead 2414, location 3(100x), scale 1:1.5

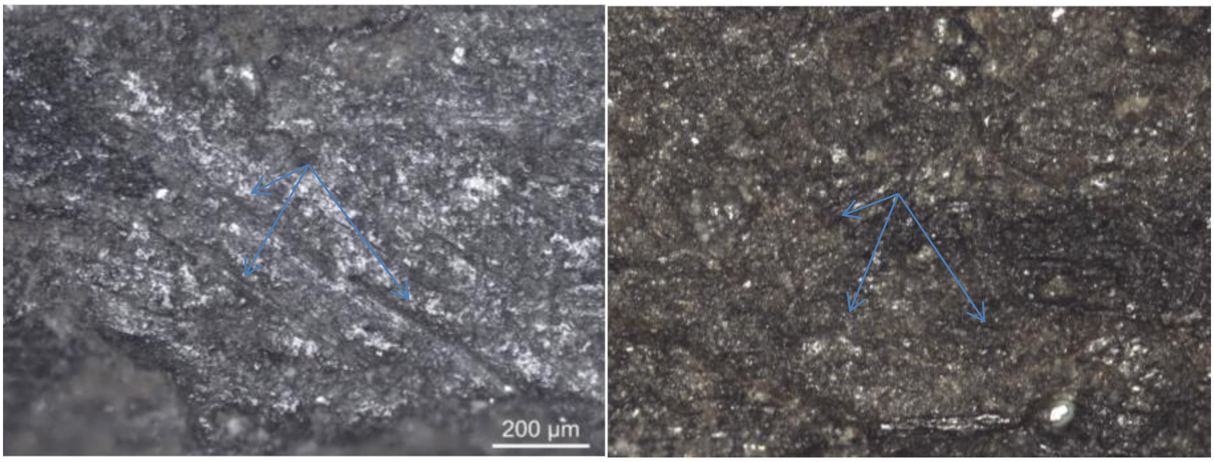

Figure 21 bead 2414, location 4 (100x), scale 1:1.5

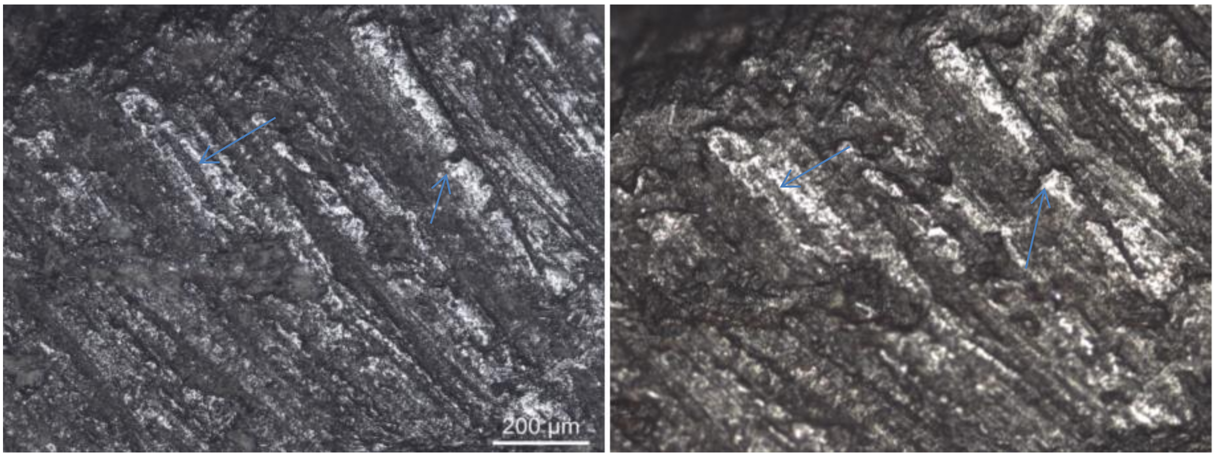

Figure 22 bead 2414, location 5 (100x), scale 1:1.5

Bead 2414 shows some surface transformation after 50 hours of tumbling in a buckskin pouch. A dull, equally distributed gloss is overlapping the production traces. The micro scratches seem to have faded away and the ridges of the deep sandstone grooves have become smoother (Fig 19). Some of the protrusions appear to have flattened, as have the rims of the craters, broadening them (Fig 20, 22). There are instances in which the sandstone grooves have been hollowed to some extent (Fig 21). Overall the picture localities are visually similar and microscopically retraceable.

2415

Figure 23 bead 2415, scale 4:1

The pictures below show approximately the same locations before (left) and after (right) 50 hours of tumbling in a pigskin pouch.

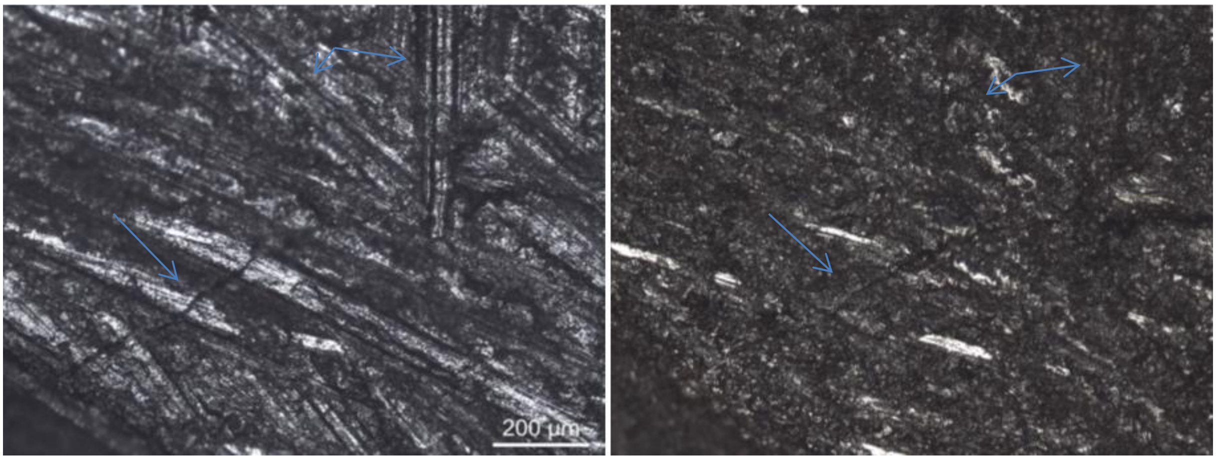

Figure 24 bead 2415, location 5 (100x), scale 1:1.5

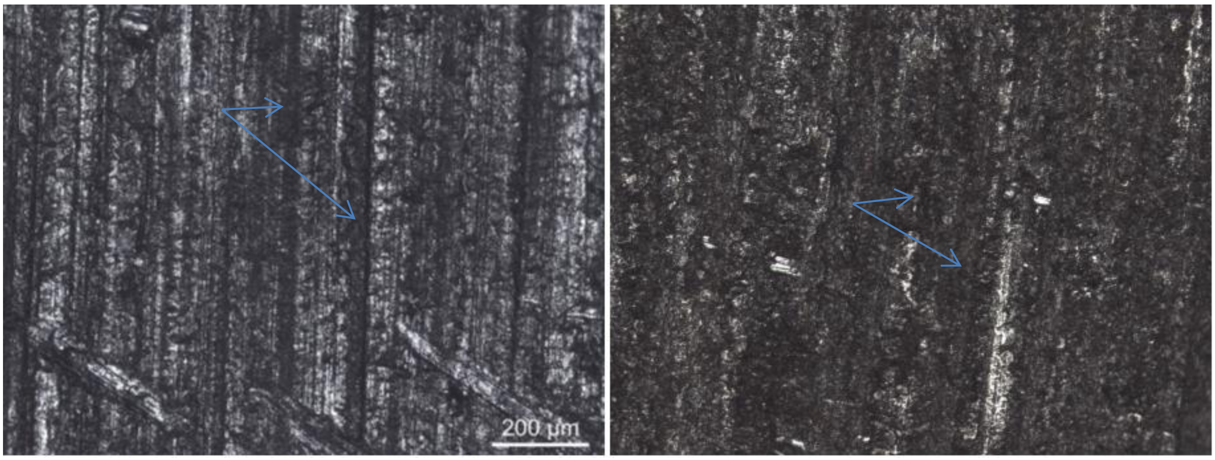

Figure 25 bead 2415, location 6 (100x), scale 1:1.5

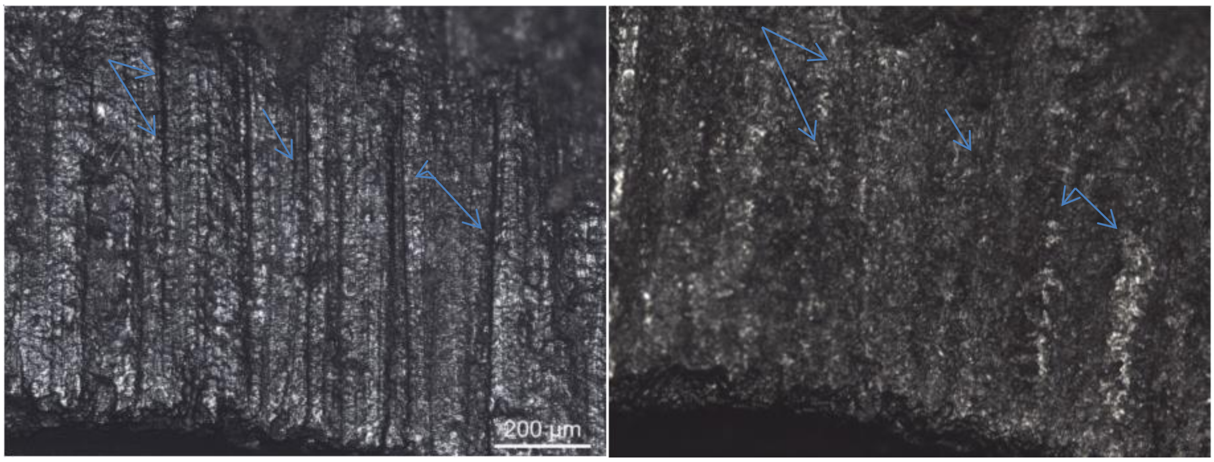

Figure 26 bead 2415, location 7 (100x), scale 1:1.5

Bead 2015 shows a high degree of surface transformation after 50 hours of tumbling in pigskin. Cracks that were present in the surface from the start have smoothed out and the material has lost much of the initially present longitudinal parallel grooves, derived from grinding with sandstone (Fig 24, 25, 26). Overall the surface appears smoother due to wear of especially the protruding elements of the surface. Due to the pigskin, the bead became rather greasy and still appeared so even after the bead was given an ultrasonic treatment and was subsequently cleaned with alcohol and detergent. A rough, amorphous gloss overlaid and obliterated much of the manufacturing wear. The smoothing of the surface also gives a dulling effect microscopically as the light is reflected back more equally. Picture localities were very difficult to retrace as characteristic spots had considerably changed appearance (see Fig 24 and 25).

2416

Figure 27 bead 2416, scale 4:1

The pictures below show approximately the same locations before (left) and after (right) 50 hours of tumbling in a linen pouch.

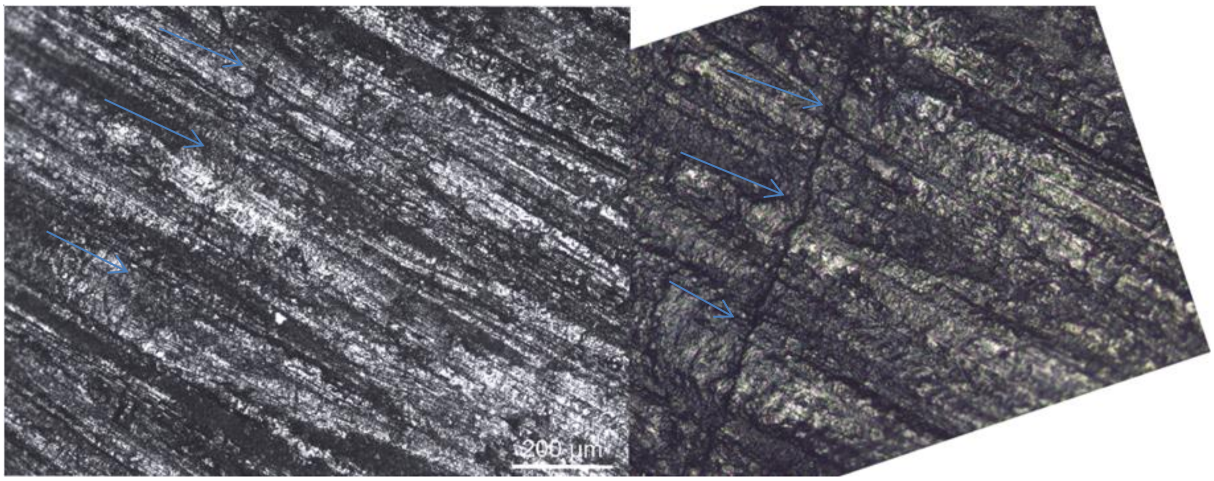

Figure 28 bead 2416, location 4 (100x) (the picture on the right has been rotated to match the angle of the picture on the left to indicate from where the crack originated), scale 1:1.5

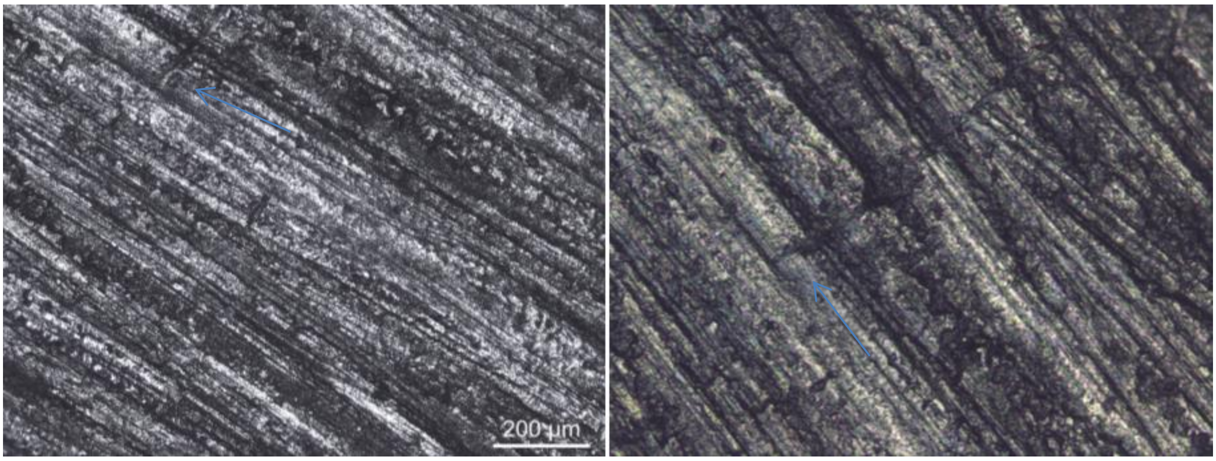

Figure 29 bead 2416, location 5 (100x), scale 1:1.5

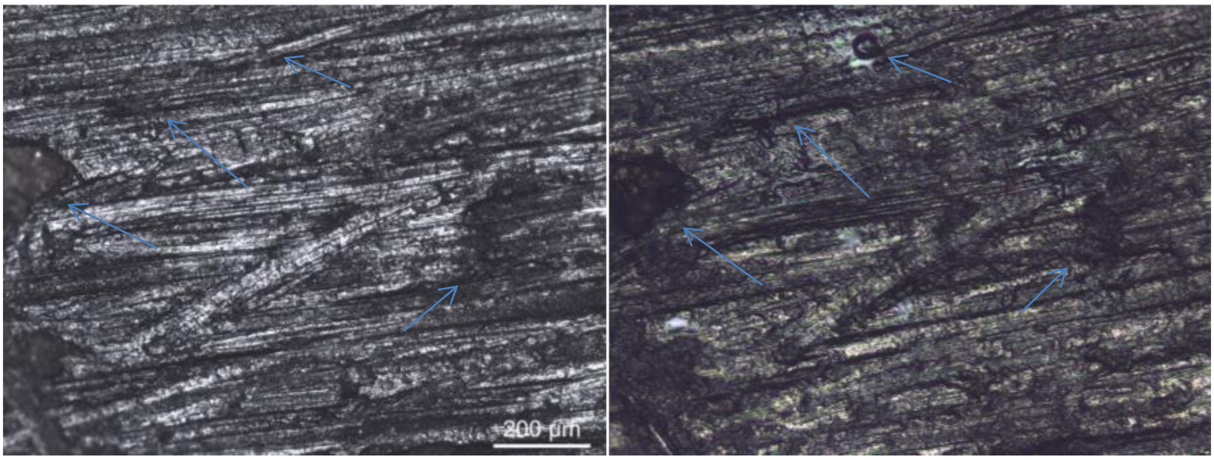

Figure 30 bead 2416, location 10 (100x), scale 1:1.5

After 50 hours the surface became smoother with less angular shapes: note the Z-shape in Fig. 30 that has faded considerably. A dull polish has appeared in which ridges of grooves and craters are rounded due to wear. Some of the craters have disappeared (Fig 29). Deeper grooves and craters are more pronounced while some new craters have appeared (Fig 30), as well as a large crack in the surface where previously only a surface irregularity was present (Fig 28). All in all the surfaces are highly recognizable and were easily traced back with the microscope.

6.2.2) Polished beads

Intentionally polished surfaces look very different in a 100x magnification compared to the surfaces of bead 2414-2416 that were not intentionally polished after manufacture. Effects of tumbling are largely comparable and only effects after 50 hours of tumbling will be shown here, as with the previous beads.

2417

Figure 31 bead 2417, scale 4:1

Bead 2417 received a polish with lime wood before tumbling initiated. The pictures below show approximately the same locations on the same scale before (left) and after (right) 50 hours of tumbling in a buckskin pouch. The line-wood polish is characterized by scratches that overlap the grooves that result from the use of sandstone and seems to have had the same effect as an eraser on pencil stripes. The grooves are still visible, but the scratches that result from the lime wood run parallel in a different angle, cut through and have to some extent smoothed them out. Some organic residue (blue arrows on Fig 32, 33) is also present, resulting from the wooden tissues.

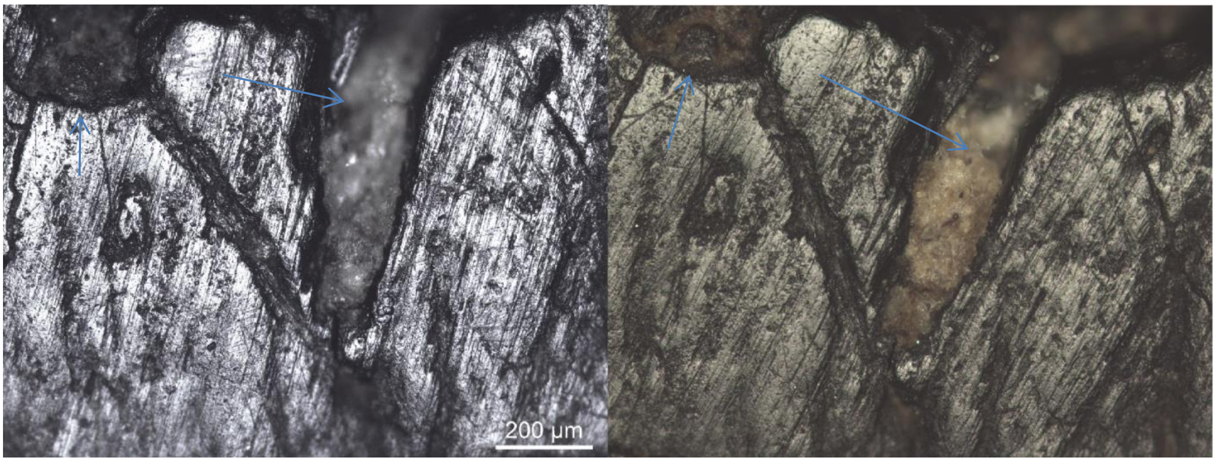

Figure 32 bead 2417, location 2 (100x), scale 1:1.5

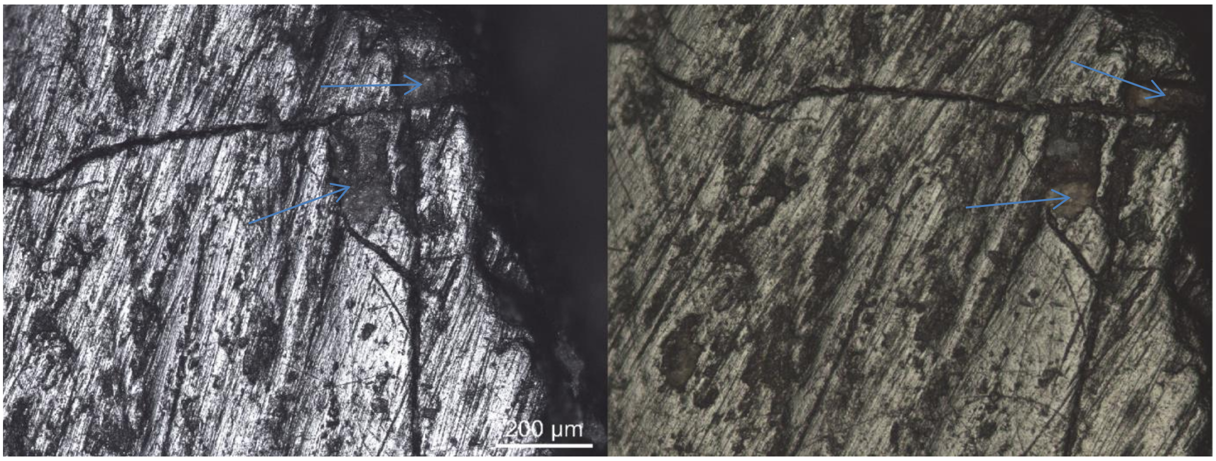

Figure 33 bead 2417, location 3 (100x), scale 1:1.5

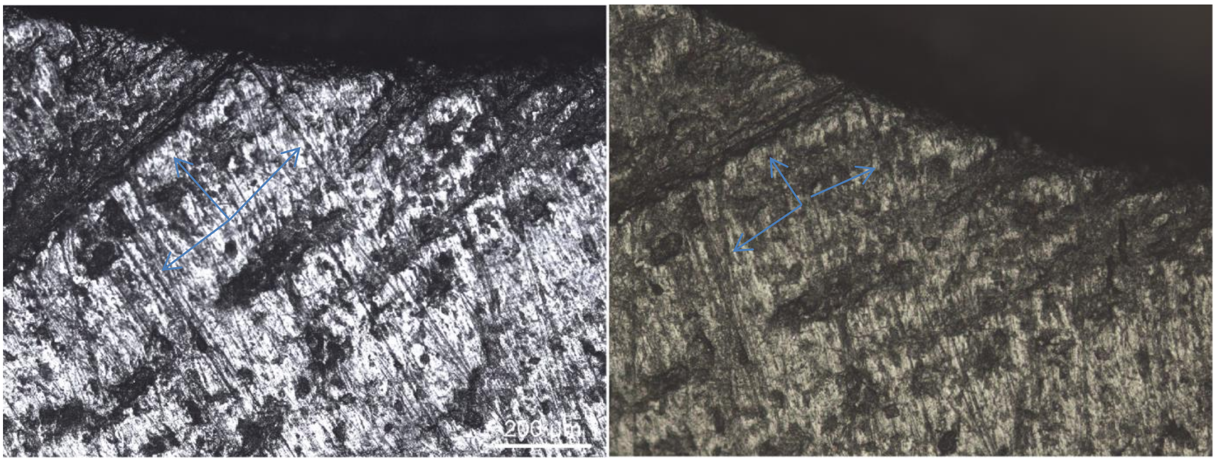

Figure 34 bead 2417, location 6 (100x), scale 1:1.5

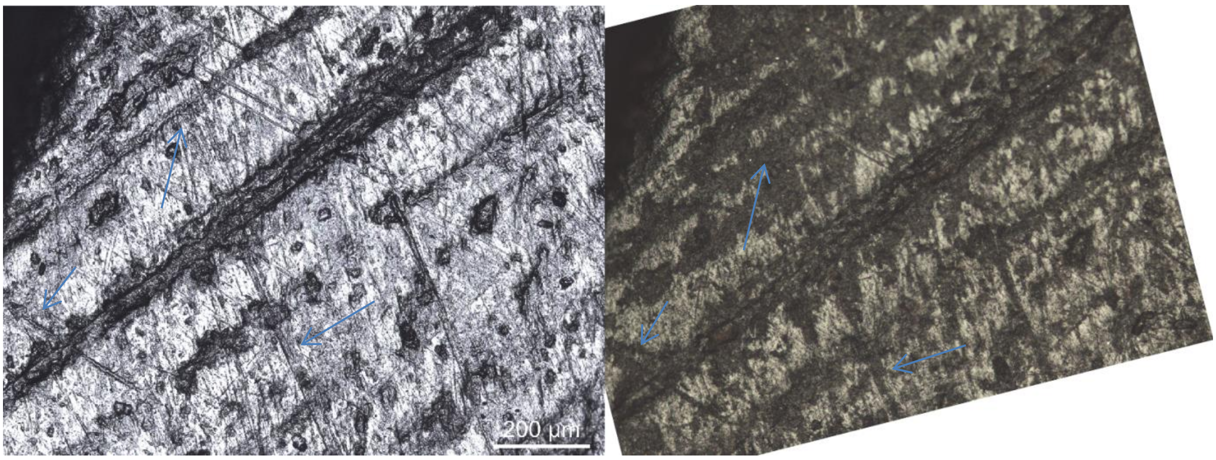

Figure 35 bead 2417, location 9 (100x) (the picture on the right has been rotated to match the angle of the picture on the left), scale scale 1:1.5

After 50 hours of tumbling in a buckskin pouch, the surface alteration is moderately attestable. The surface appears duller. The scratches that result from line-wood are not as sharply visible and have been smoothed out to some extent (Fig 35). The sharp attestable difference between the grooves resulting from sandstone and the scratches derived from the line-wood have been somewhat blurred (Fig 34). Overall, surfaces are highly recognizable and were easily traced back with the microscope.

2418

Figure 36 bead 2418, scale 4:1

Prior to tumbling, bead 2418 received a polish with leather. This polish is characterized by a high gloss on the elevated parts of the surface that overlays the manufacturing traces and that has smoothed out the more superficial grooves from the sandstone. Traces of the leather treatment are sharp, short, angular scratches that lack the regular parallel patterning characteristic of lime wood -polishing. This relates to the motion applied with leather, which is much more malleable and allows for a more dynamic surface movement than lime wood does. Some organic residue is present (see Fig 37).

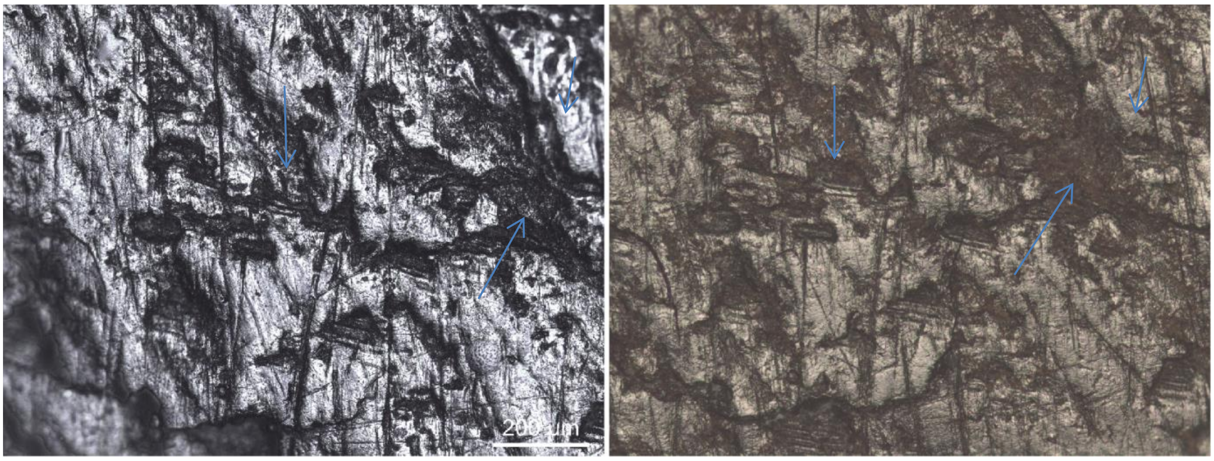

Figure 37 bead 2418 (100x), location 2, scale 1:1.5

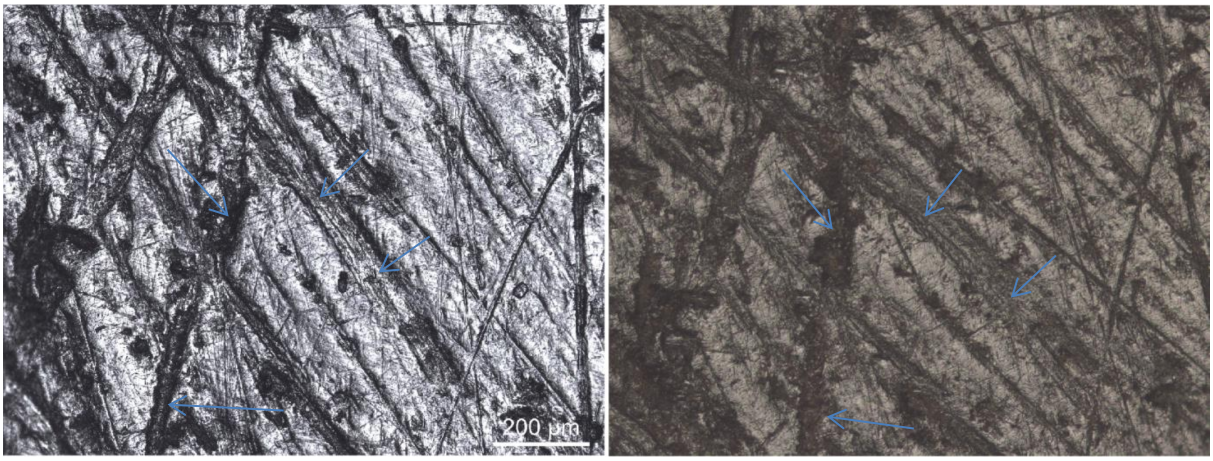

Figure 38 bead 2418, location 4 (100x), scale 1:1.5

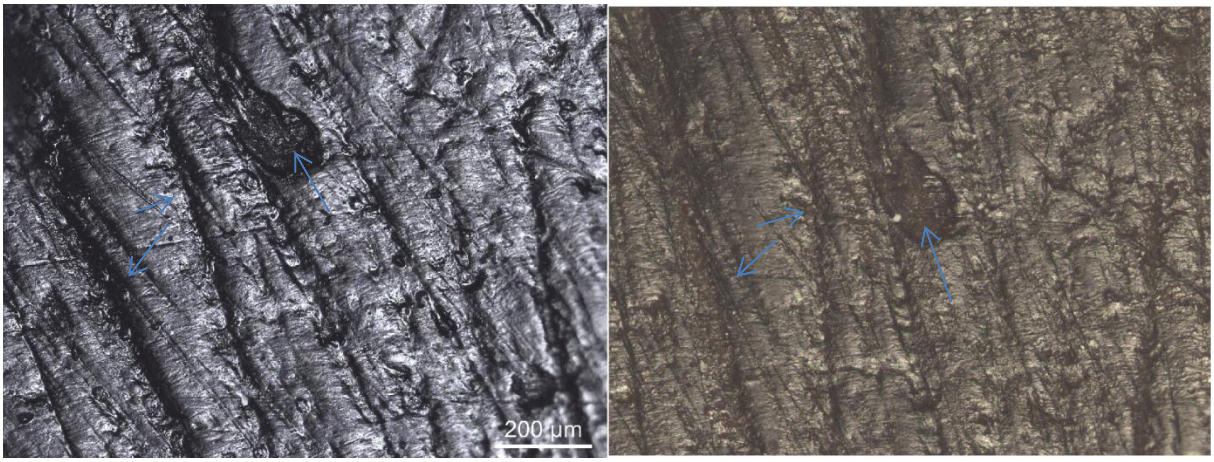

Figure 39 bead 2418, location 7 (100x), scale 1:1.5

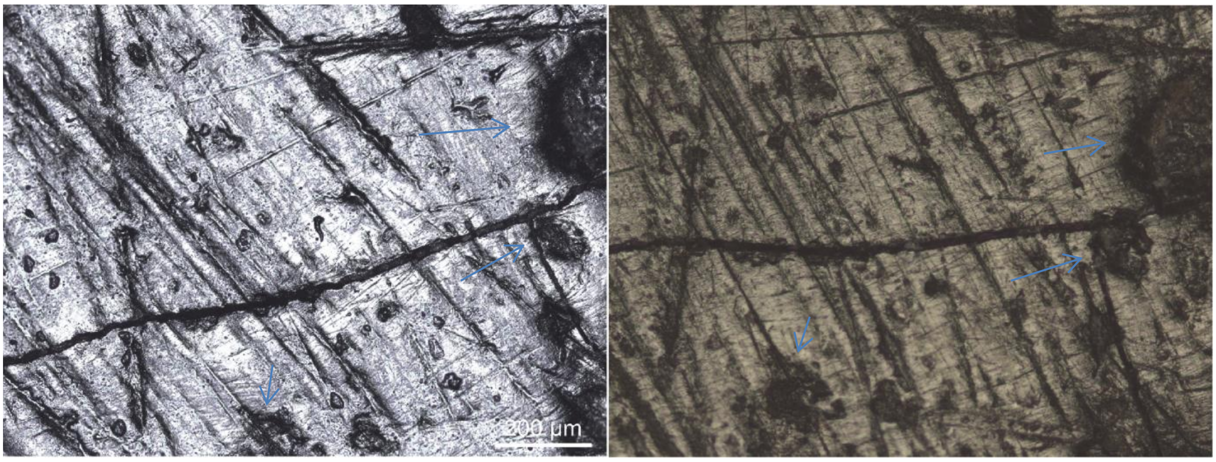

Figure 40 bead 2418, location 9 (100x), scale 1:1.5

After 50 hours of tumbling in a pigskin pouch, the surface appears duller. Scratches and craters have broadened (Fig 37, 38, 39, 40), relating to the eroding effect of the pigskin pouch. The sharp angles and clear lines have been blurred out to some extent by this effect. The surface is equally eroded by a dull, rough looking gloss. A comparable greasy effect as attested with bead 2415 lingers over the surface relating to the pigskin pouch that again did not disappear after the bead was given an ultrasonic treatment and was subsequently cleaned with alcohol and detergent. Overall the surfaces were microscopically easy to retrace.

2419

Figure 41 bead 2419, scale 3:1

Bead 2419 received a polish prior to tumbling with horsetail, *Equisetum hyemale*. This polish is quite subtle, characterized by a myriad of cross-hatched scratches, tightly concentrated all over the surface. The pattern of scratches overlaps and penetrates the sandstone-grooves, of which the deepest are still visible, although the plant-fiber has clearly eroded some of the superficial grooves of which only vague outlines remain (see Fig 43, 44).

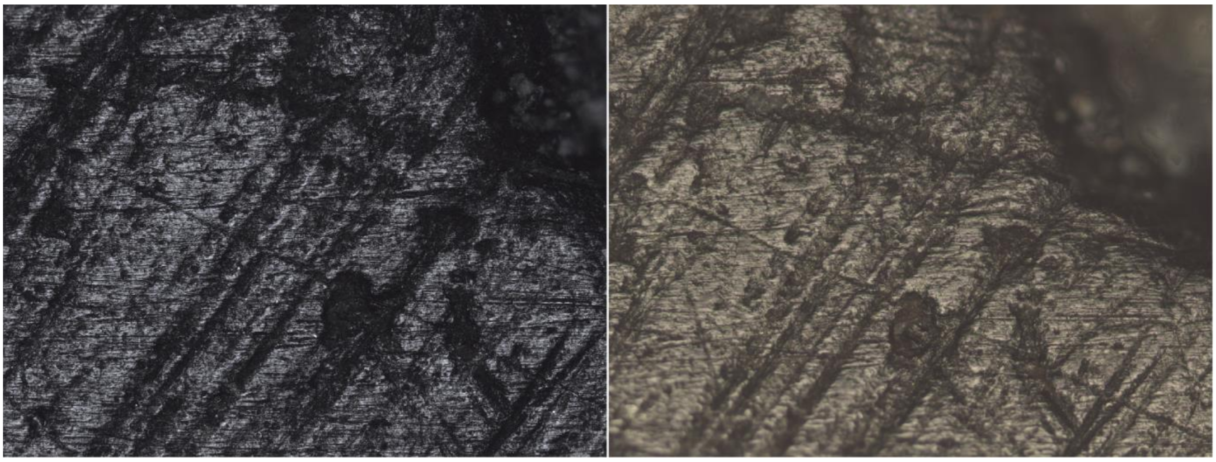

Figure 42 bead 2419, location 2 (100x), scale 1:1.5

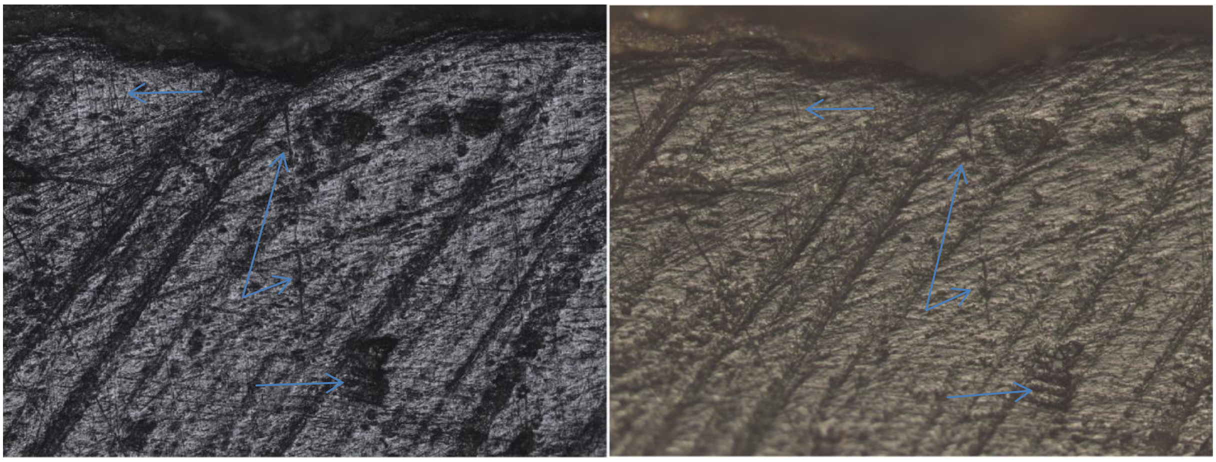

Figure 43 bead 2419, location 3 (100x), scale 1:1.5

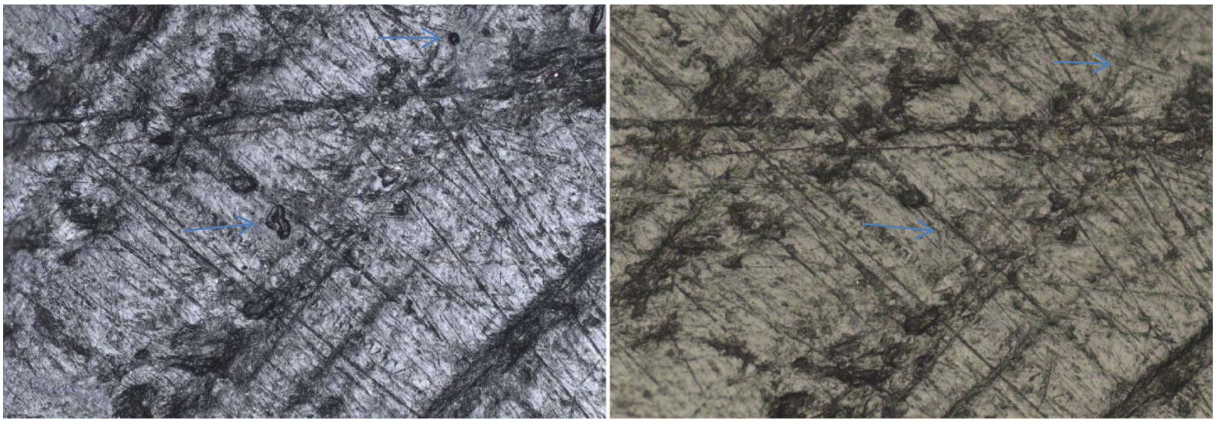

Figure 44 bead 2419, location 6 (100x), scale 1:1.5

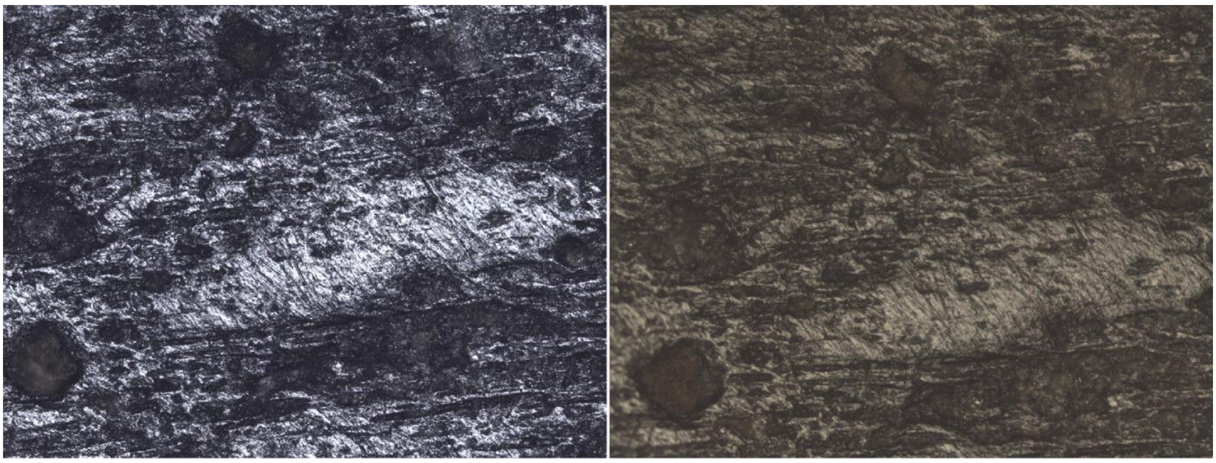

Figure 45 bead 2419, location 9 (100x), scale 1:1.5

After 50 hours of tumbling in a linen pouch the surface has undergone minimal amounts of transformation. Some minor protruding surface elements have disappeared (Fig 44), indicating that surface wear did indeed take place, be it in very small quantities.

6.4) Discussion of the experiment

Unpolished experimental objects look very rough and the surfaces show a lot of microcraters. Manufacturing traces are still clearly attestable and include deep parallel grooves that result from grinding with sandstone and also much smaller scratches that result from the use of sand. Polished experimental objects are much smoother and brighter and show scratches that cut through and overlap the sandstone grooves. In the case of lime wood these scratches are long and parallel strokes that affect the sandstone grooves in the same way that an eraser affects pencil stripes. Line wood does not affect the deeper parts of the surface.

Leather is more subtle than line wood and does not penetrate the surface as deeply as lime wood does. But leather is also more malleable than wood and affects the deeper parts of the surface that lime wood would have skipped. Although it affects the higher parts of the surface more strongly, which display a more intense gloss. Finally, leather allows a more dynamic motion than wood and traces of leather-polishing are characterized by sharp short angular scratches that lack the regular patterning of wood.

Horsetail, *Equisetum hyemale,* is the most subtle of the abrasive materials used for polishing. Because it is so malleable, it affects the entire surface, following the contours of the original surface and sandstone grooves, slowly eroding it. It leaves a myriad of cross-hedged scratches all over the surface.

Tumbling, with any of the used pouches, does not leave specific marks of its own in the way that polishing materials did with longer or smaller scratches in the surface. Rather, it is much more subtle. It dulls the polishing effect and further flattens the surface, but to a much lesser degree than an intentional polish does. Especially pigskin was effective in doing this. It also left a greasy overlay on the beads that could not be washed away with either alcohol or detergent. Leather only slightly affected the surfaces and linen did nearly nothing visible on a 100x magnification. If tumbling in pouches remotely imitates the effects of wearing down against skin or clothing, we can assume, or conclude tentatively, that a prolonged period of using (wearing) an ornament can do either one of two things: It can create a matte gloss without leaving distinct microscopic traces, or it can cover the effects of an intentional bright polish, dulling and greasing the surface.

6.5) Ornaments from Schipluiden and Ypenburg

Drawings were made in original size (1:1), but have been scaled to fit the document. Most scale-bars have failed to appear due to software problems; all pictures were made in a 100 x magnification and have been scaled to fit the document.

Ypenburg ornament 385, pendant

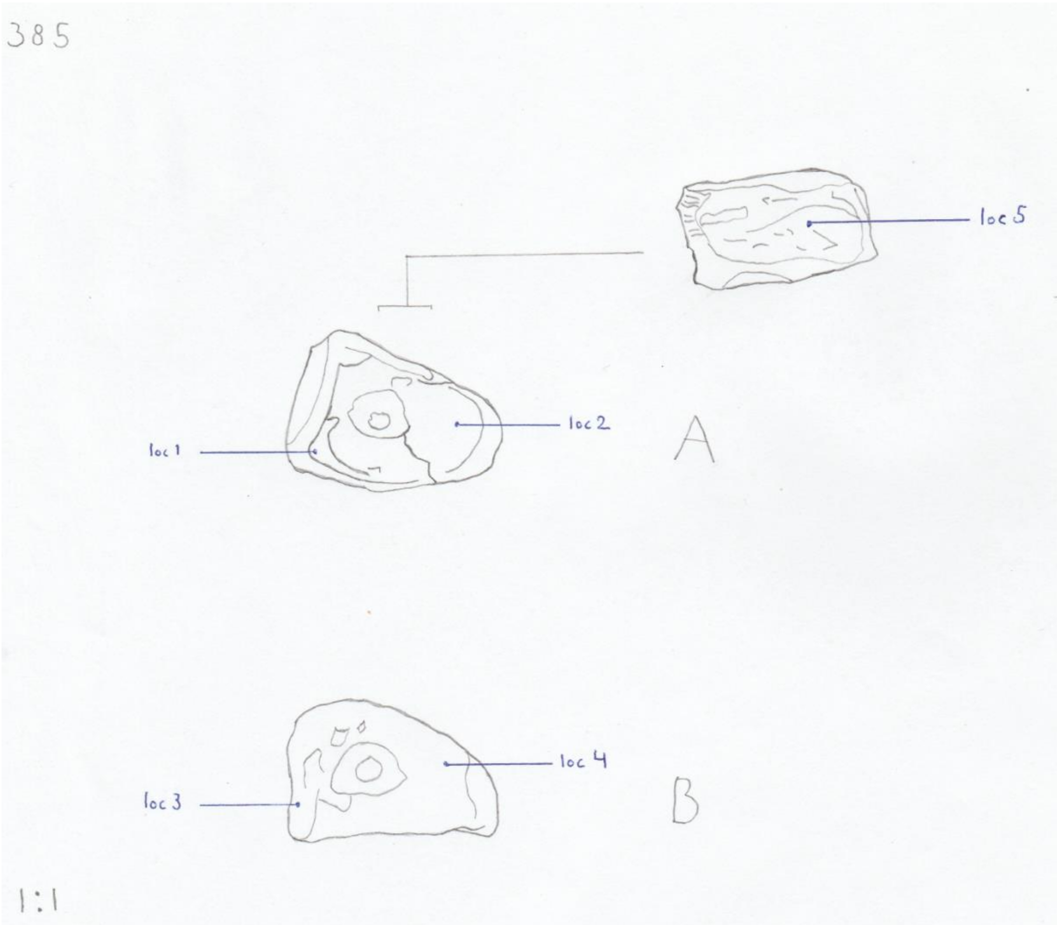

Figure 46 Drawing of vnr 385, scale 1:1.5

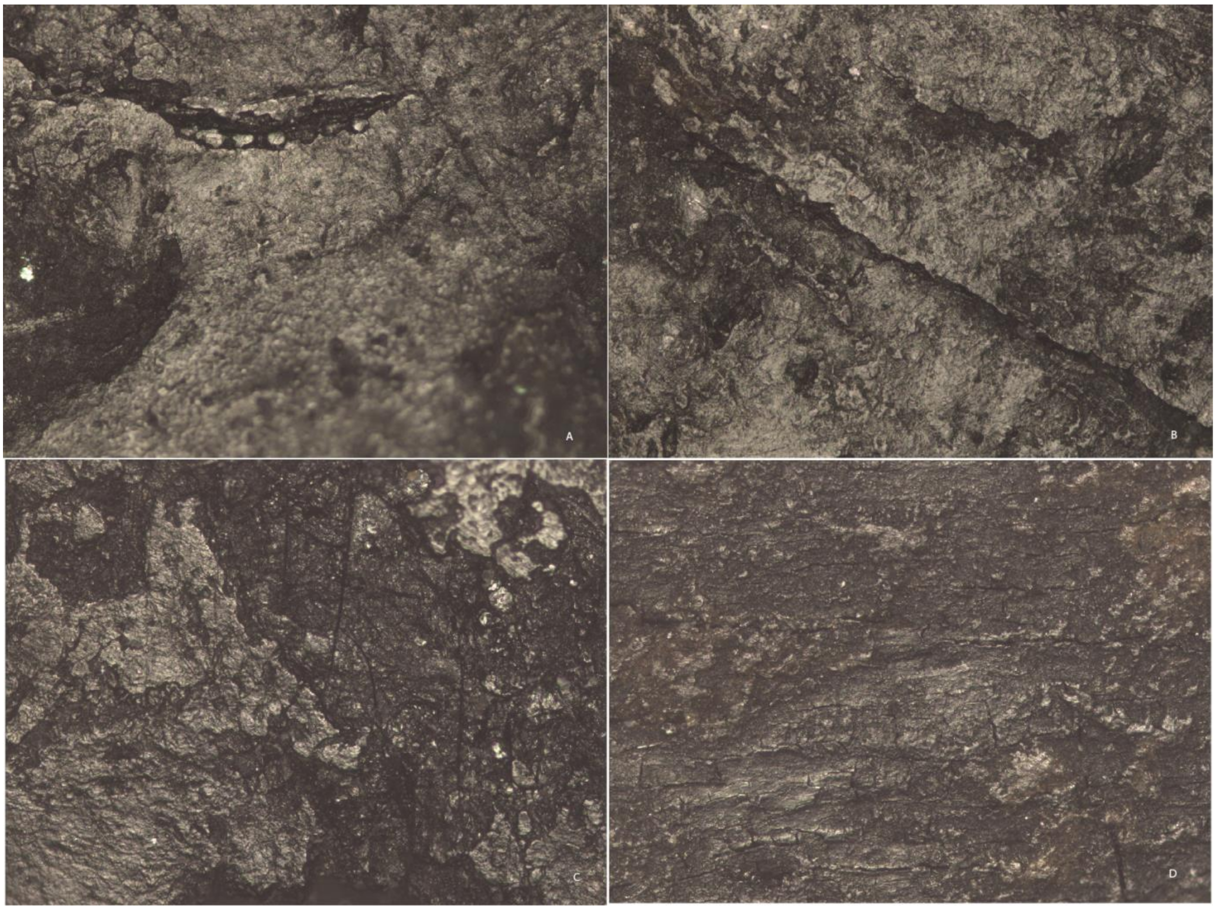

Figure 47 100x magnification of location 1 (A), 2 (B), 4 (C) and 5 (D), scale 1:1.5

A rough, dull, greasy polish is overlaying the abrasive surface of this relatively heavy jet pendant. It shows some layering, the outer surface skin appears to be crumbling and has many cracks in it. There are no attestable cutting grooves, nor any grinding traces. Micro scratches are also absent. In this respect it resembles the experimental beads that were tumbled in a pigskin pouch. This artifact appears to have worn down significantly, perhaps by human skin, signaling intensive use.

Ypenburg ornament 467, pendant

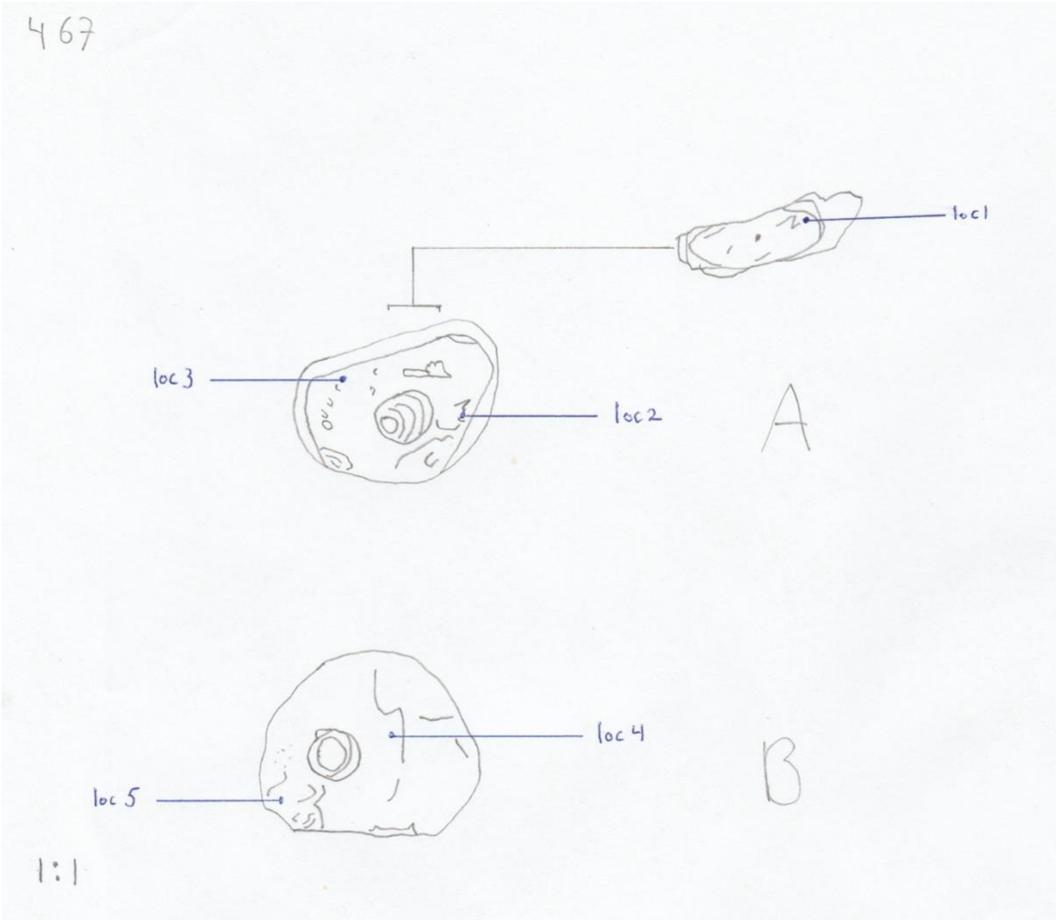

Figure 48 Drawing of vnr 467, scale 1:1.4

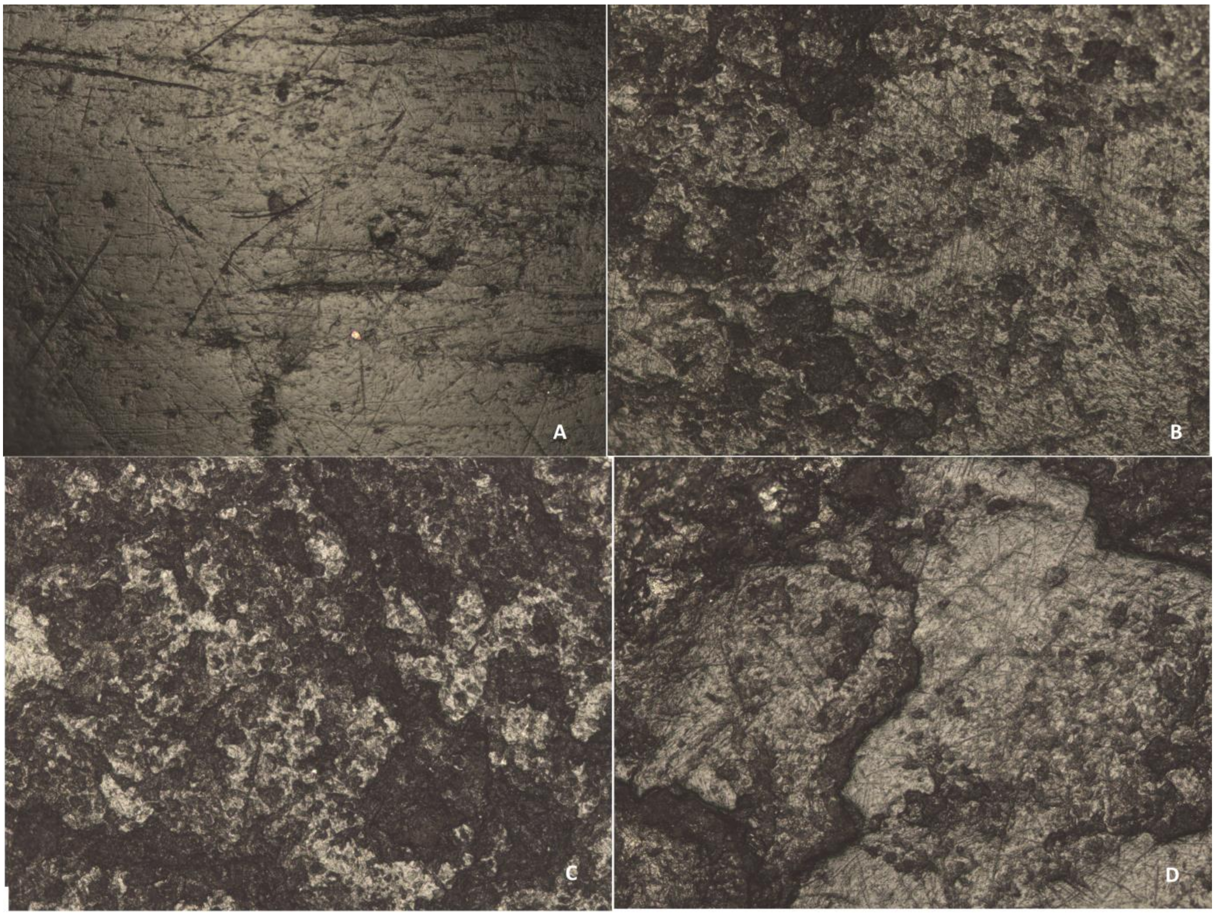

Figure 49 100x magnification of location 1 (A), 2 (B), 3 (C) and 4 (D), scale 1:1.5

Surface cracks are largely absent on this pendant. Some parts of the object show a high gloss that has almost completely smoothed out the surface (A). Some deep cuts, long and in single directions, are overlapped by smaller cross-hatched scratch patterns that spread out all over the surface, resembling the *Equisetum* polish from the experiments. The artifact does not the show same degree of wear as pendant 385, it is possible that it was not used as much.

Ypenburg ornament 468, pendant

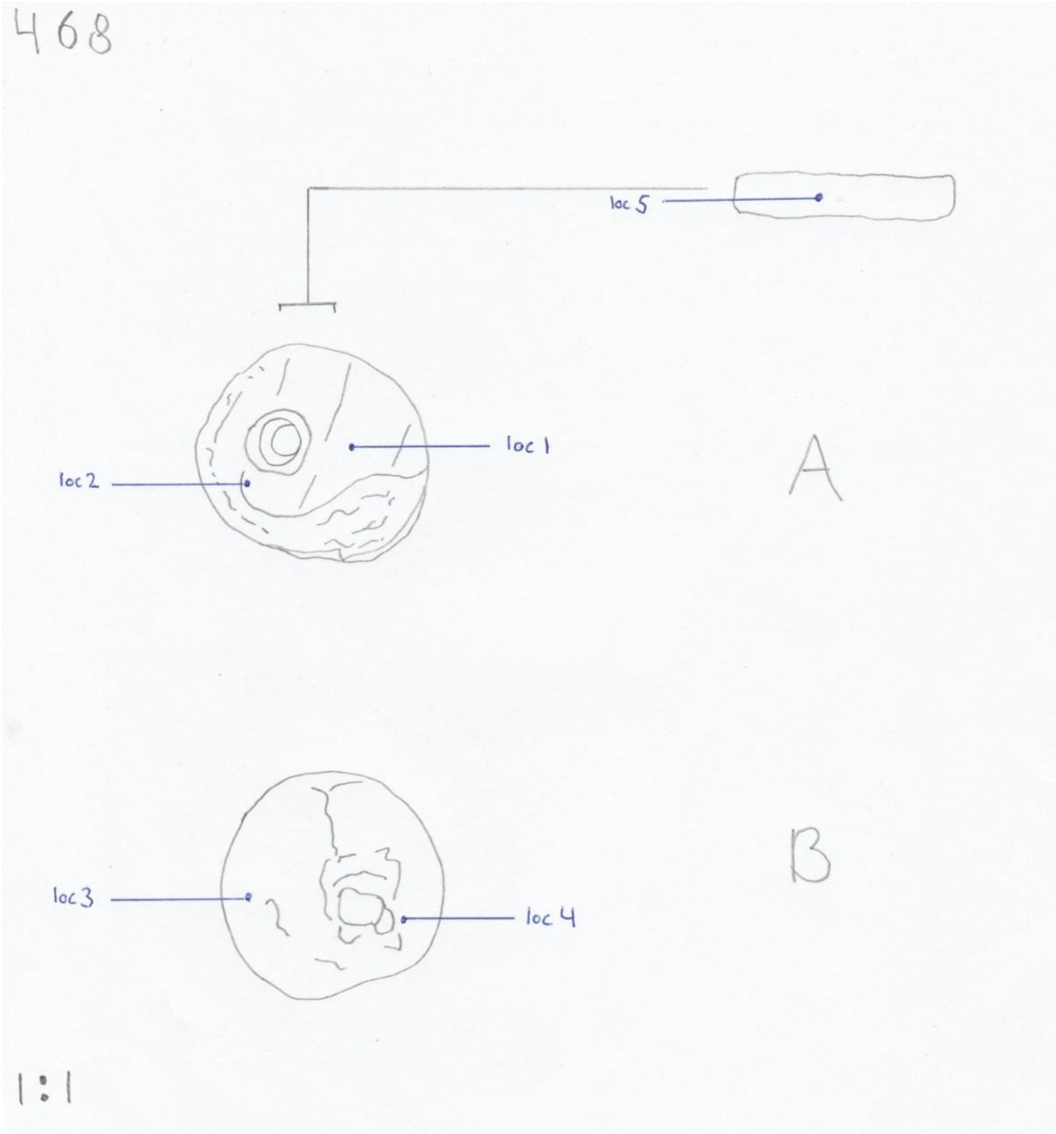

Figure 50 Drawing of ornament vnr 468, scale 1:1.3

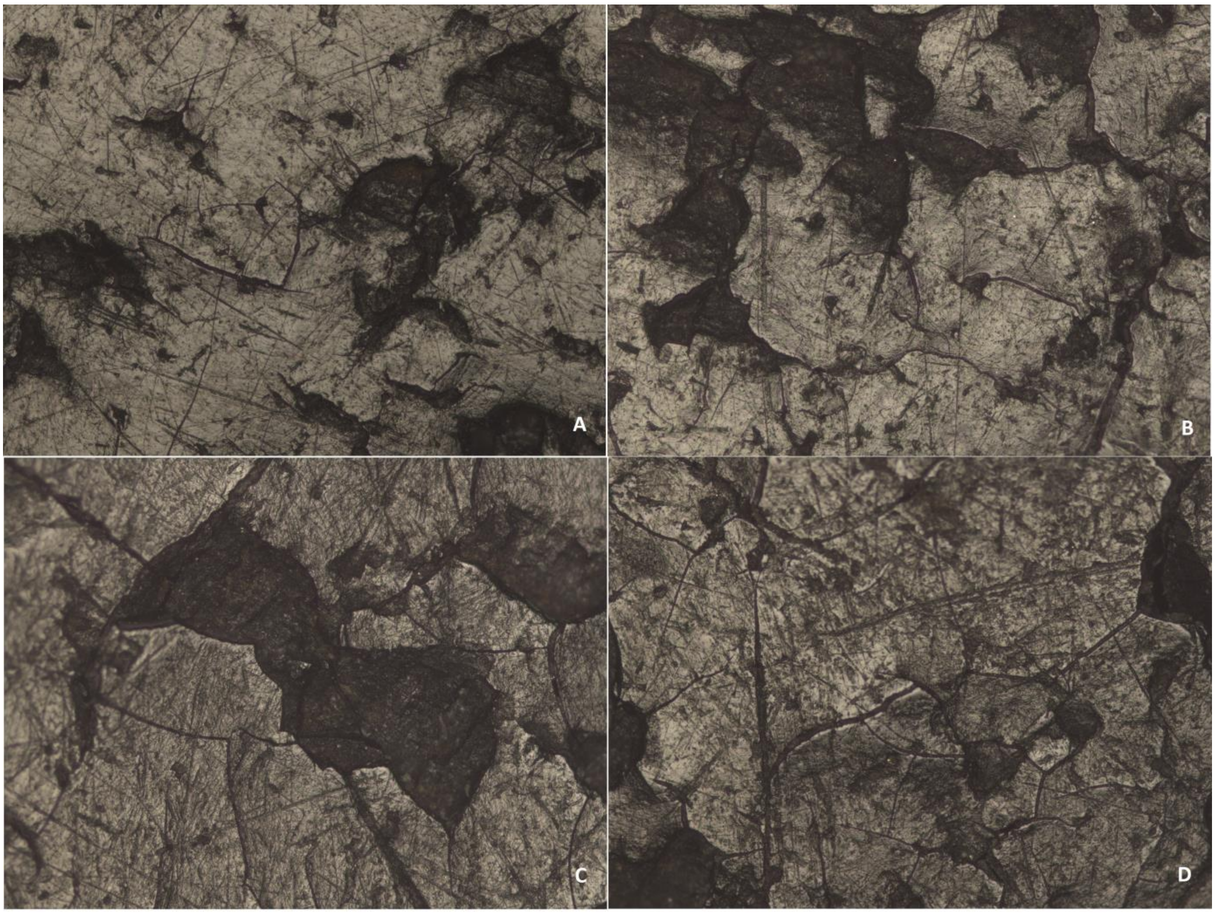

Figure 51 100x magnification of location 1 (A), 2 (B), 3 (C) and 4 (D), scale 1:1.5

This pendant shows a very high shine and the entire surface has been thoroughly polished. Cracks in the surface are deep and cut through manufacture traces that appear as long cuts and smaller cross-hedged scratches. The deep cuts appear more linear and often run parallel to each other. The smaller cross-hatched scratches are spread throughout the surface, again resembling the *Equisetum* pattern. Surface cracking is clearly attestable and small angular pieces of the polished surface layer have been chipped off, presumably due to burial conditions. The artifact shows a different type of wear as pendant 385: surface cracking is more severe and it lacks the glossy dullness that characterized pendant 385. Manufacturing traces are still clearly attestable.

Ypenburg ornament 497, bead

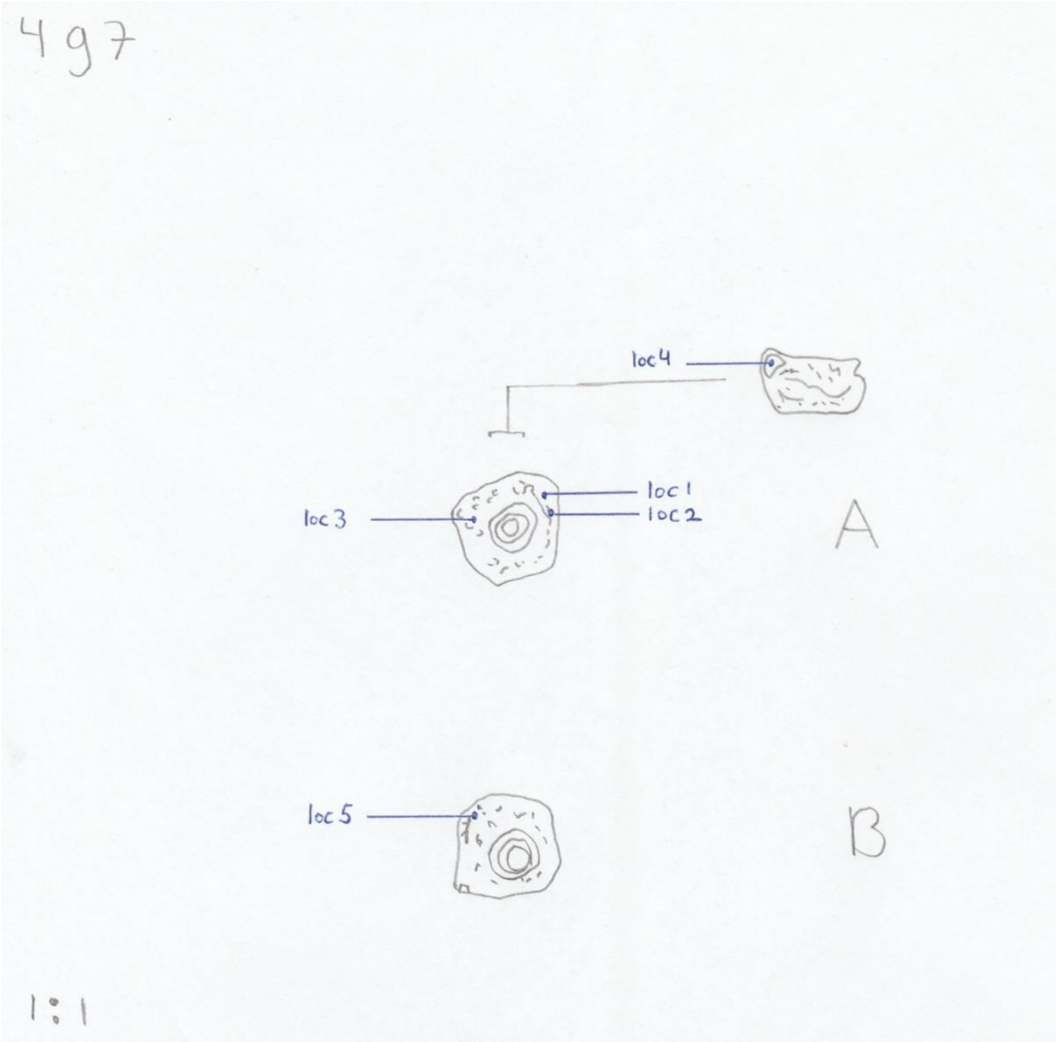

Figure 52 Drawing of ornament vnr 497, scale 1:1.3

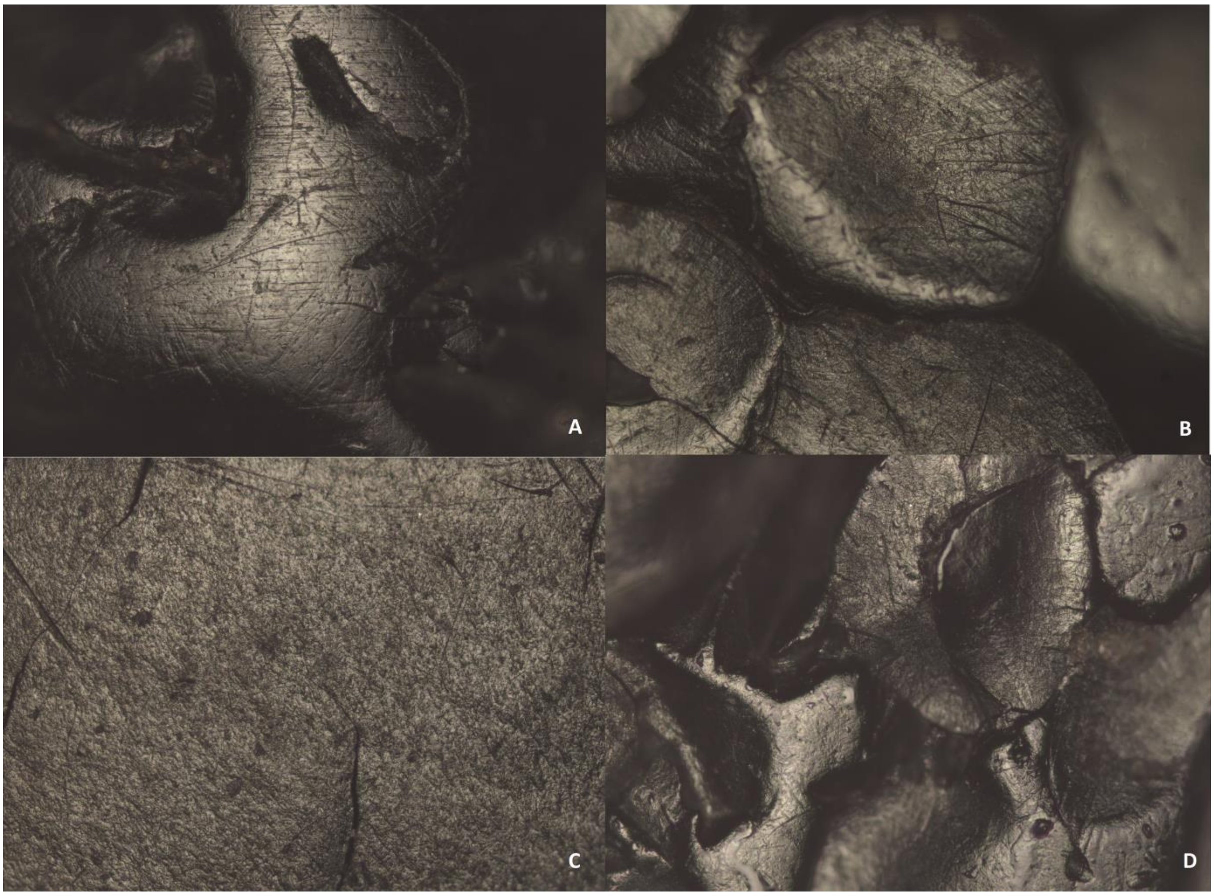

Figure 53 100x magnification of location 2 (A), 3 (B), 4 (C) and 5 (D), scale 1:1.5

This bead has a pocked surface with lots of protruding elements. It shows the highest polish of the samples under investigation. Some spots are completely smooth and appear metallic. Even quite deep depressions in the surface have been polished, indication the use of a malleable polish material. Compared to the cross-hatched micro scratch pattern of the previous ornaments, the scratches here are generally longer and appear more linear. They somewhat resemble the leather polish from the experiment. Picture A, B and D represent sides of the bead that would have made contact with other beads when worn on a necklace. The surface in picture C represents a part of the side of the bead that would have touched the skin or clothing when worn on a necklace. It has flattened out to an extent and shows cracks. The same matte gloss as attested in earlier ornaments overlays this surface and polish traces are less visible. This bead was found in a child's grave and the lesser degree of wear could be related to this fact.

Ypenburg ornament 551, half-product

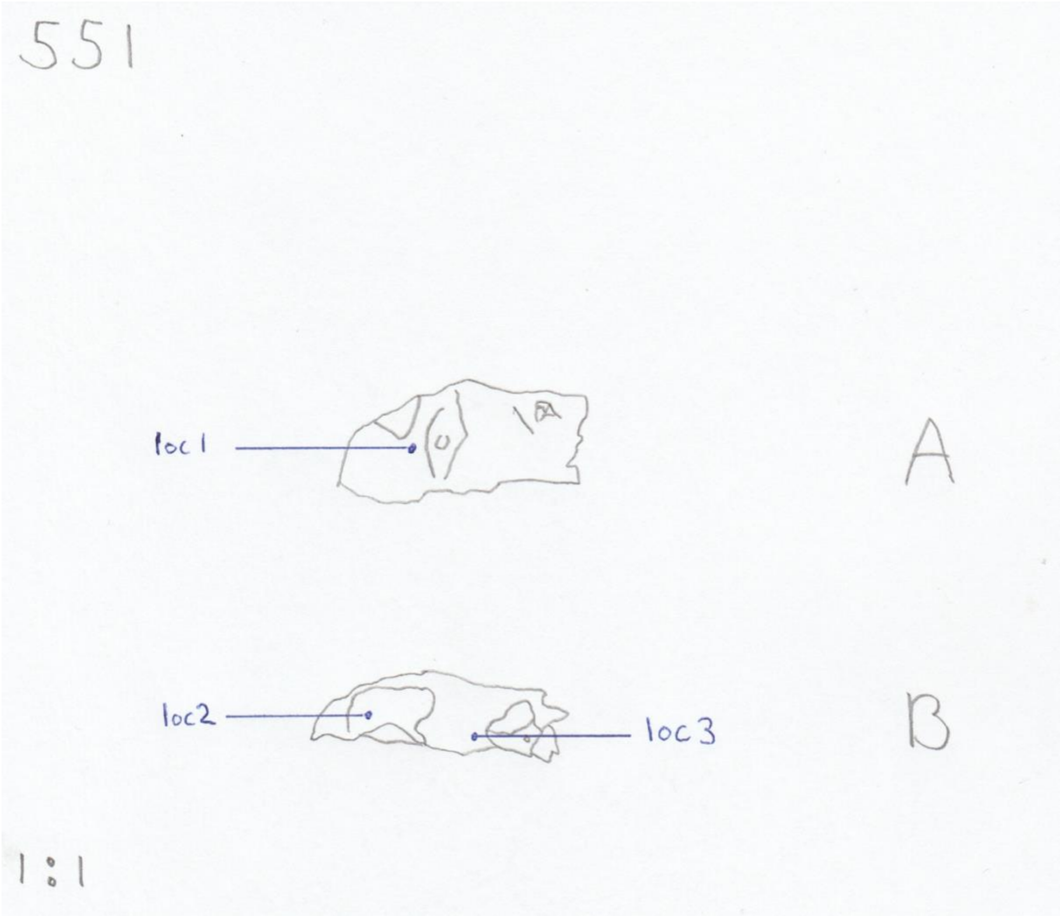

Figure 54 Drawing of ornament vnr 551, scale 1:1

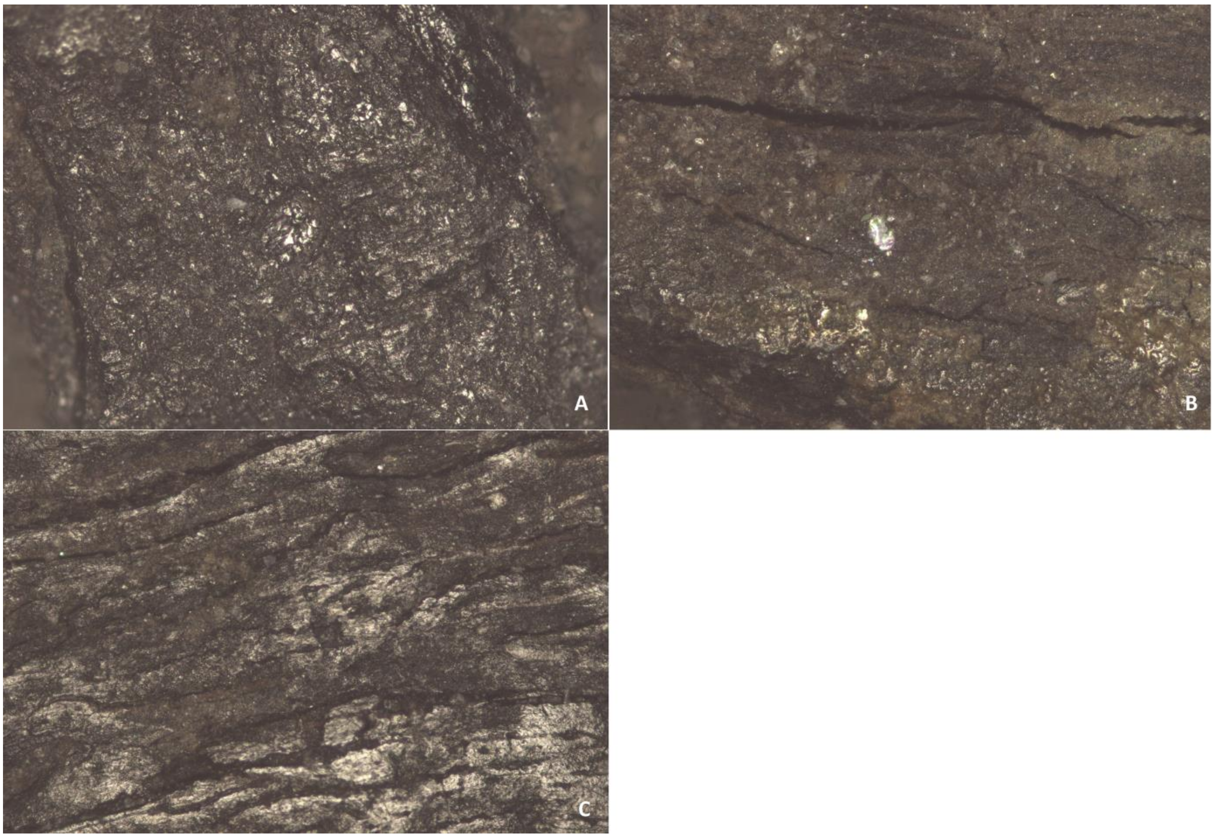

Figure 55 100x magnification of location 1 (A), 2 (B) and 3 (C), scale 1:1.5

The three locations on this half fabricate show the same cracked surface as on the other artifacts. The material shows distinct layers (C). This artifact contains several depressions from drilling attempts that were aborted, all parallel on the objects layering and it cracked in two on the final attempt, about half way through the object, presumably due to stress. The layering of the raw material suggests this is not jet, which is more amorphous and shows conchoidal fracture planes. This is further backed up by the XRF-data that classify it as different from true jet. The surfaces appear unworked on the top two pictures, but there are small scratches that are randomly distributed on picture C, which is the surface that was drilled prior to breakage. This suggests that some polishing took place prior to the perforation attempts.

Schipluiden ornament 1954, bead

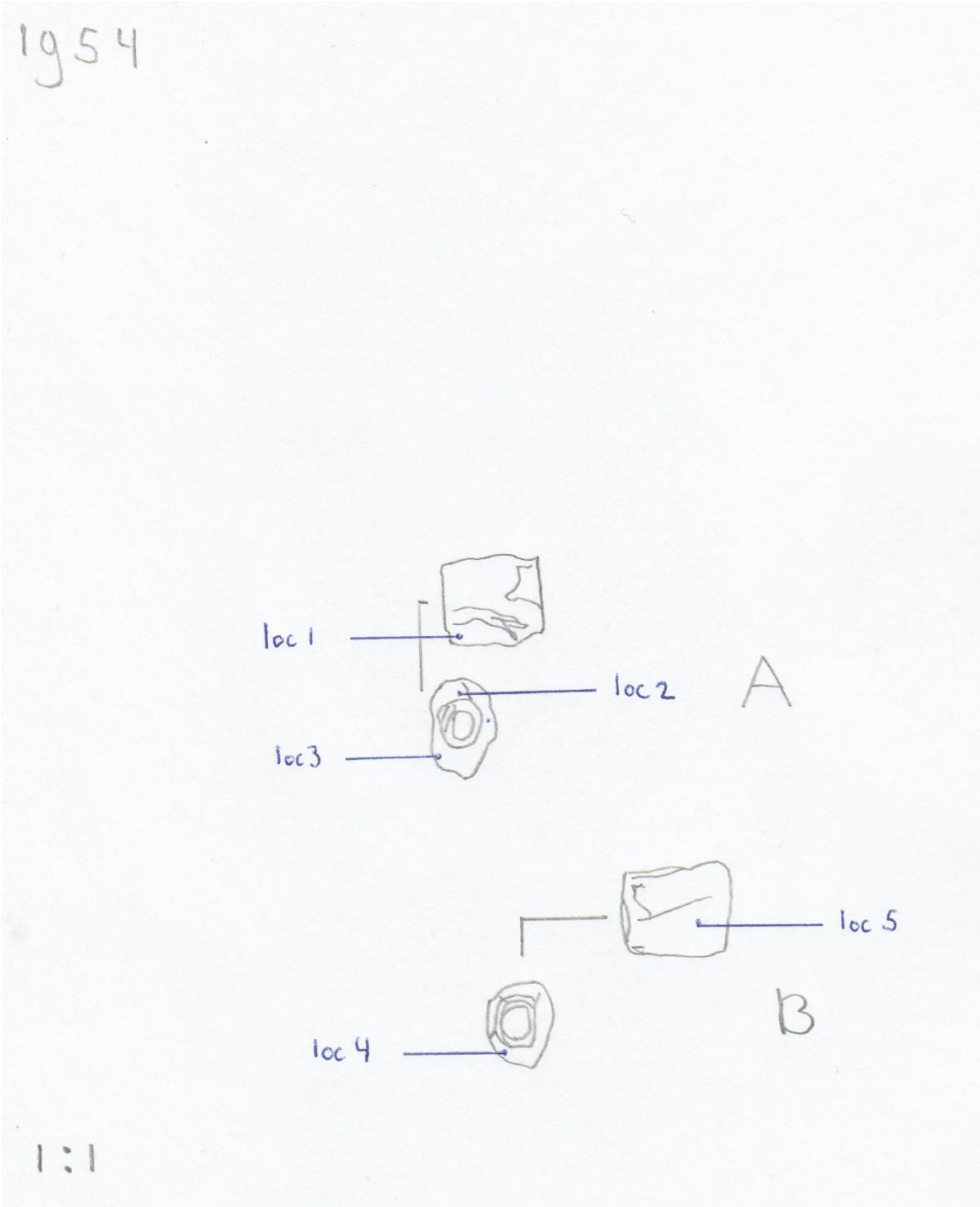

Figure 56 Drawing of ornament vnr 1954, scale 1:1

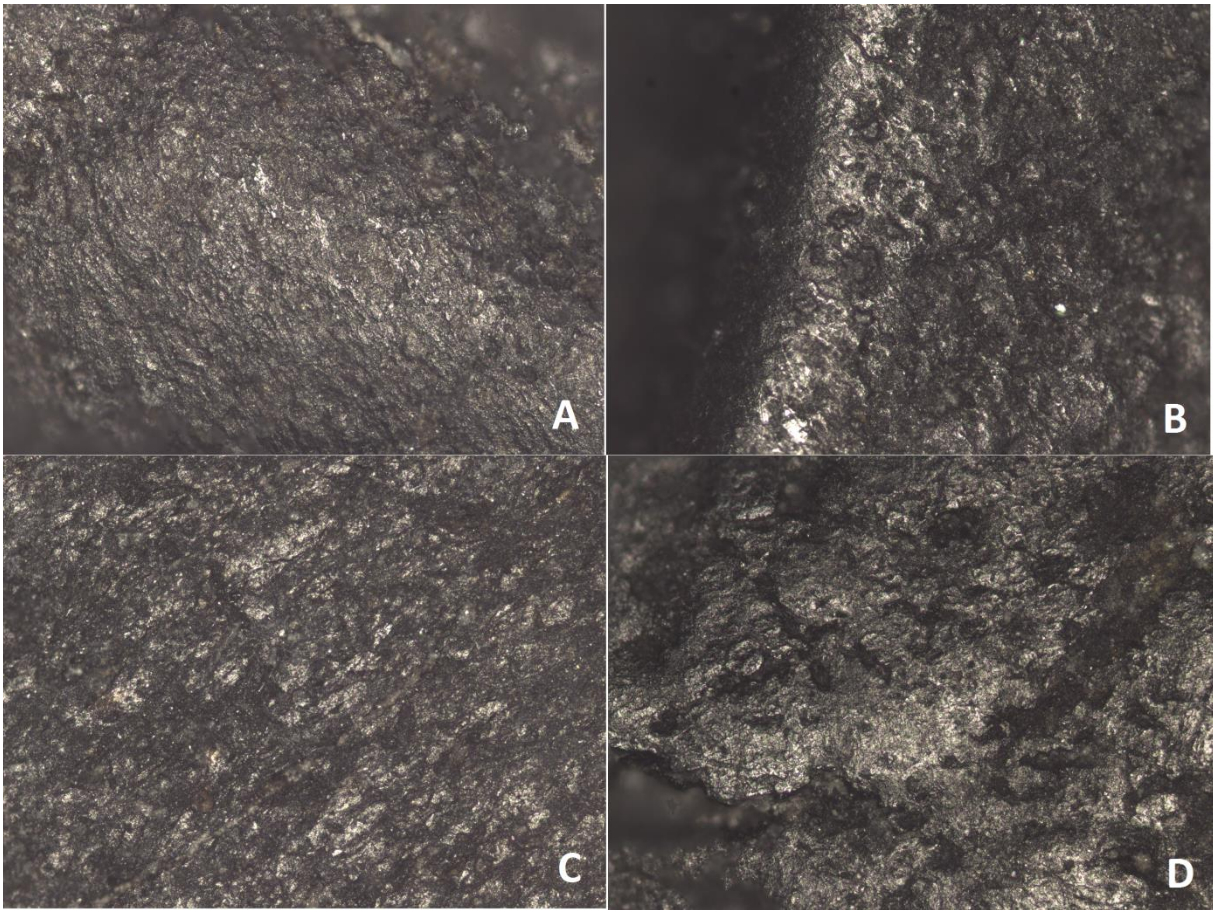

Figure 57 100x magnification of location 2 (A), 3 (B), 4 (C) and 5 (D), scale 1:1.5

This bead is tubular in shape. A bright gloss overlays the higher parts of the surface but overall the surface appears very rough when compared to the artifacts from Ypenburg. This may be related to the fact that the artifacts of Ypenburg are true jets and this is not. Pictures A, B and C represent surfaces of the bead that would have made contact with surfaces of other beads when worn on a necklace. There are striations around the drillhole that extend inwards (picture B), possibly related to wear from a necklace-string. Picture D represents the surface that would have made contact with either clothing or bare skin. This surface appears less rough than the surfaces near the drillholes. Traces of manufacture have almost completely faded although some grooves and scratches can be attested in picture D. If this wearing down of manufacture traces is caused by use, it would indicate that the object was intensively worn.

Schipluiden ornament 5076, bead

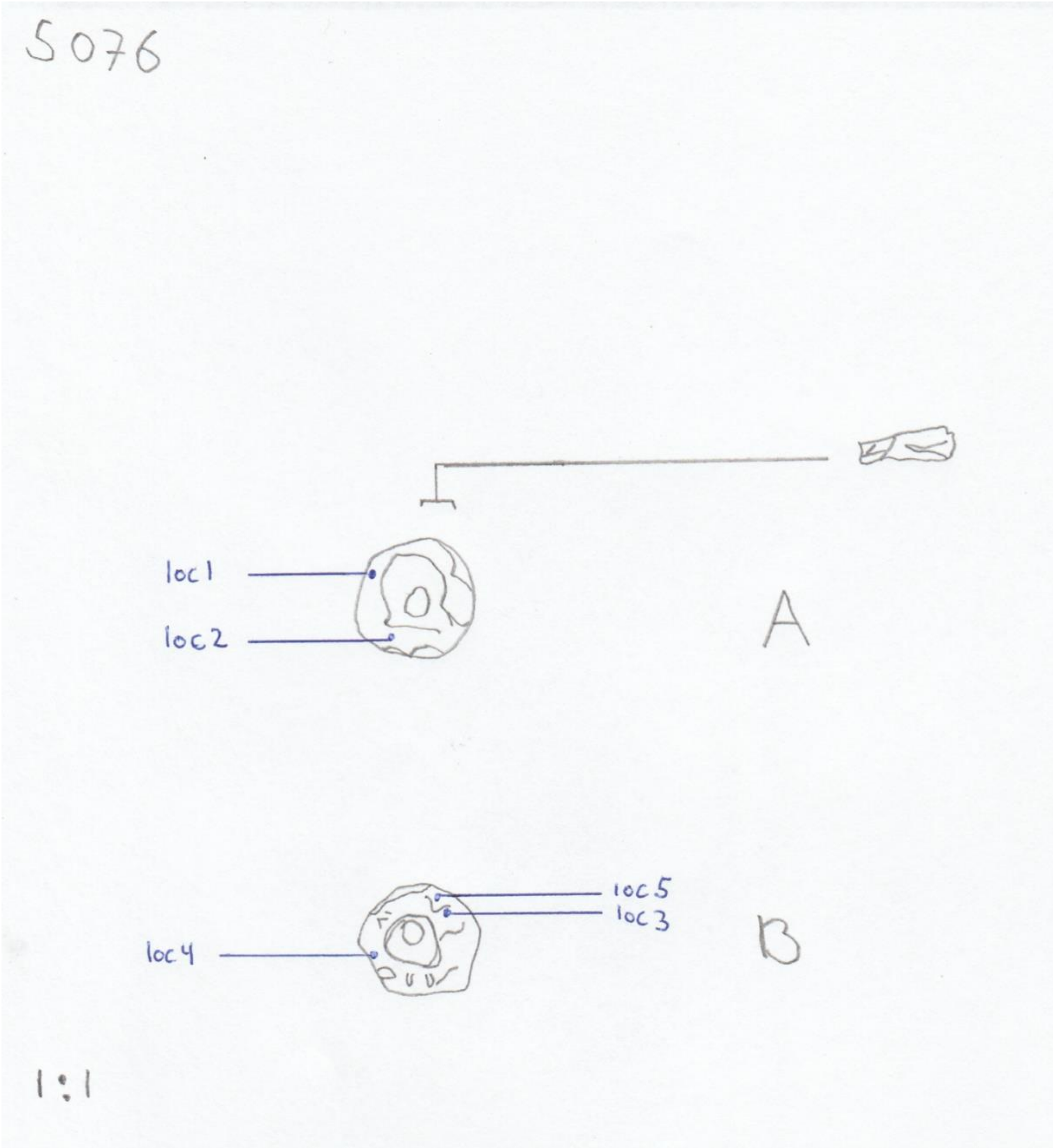

Figure 58 Drawing of ornament vnr 5076, scale 1:1

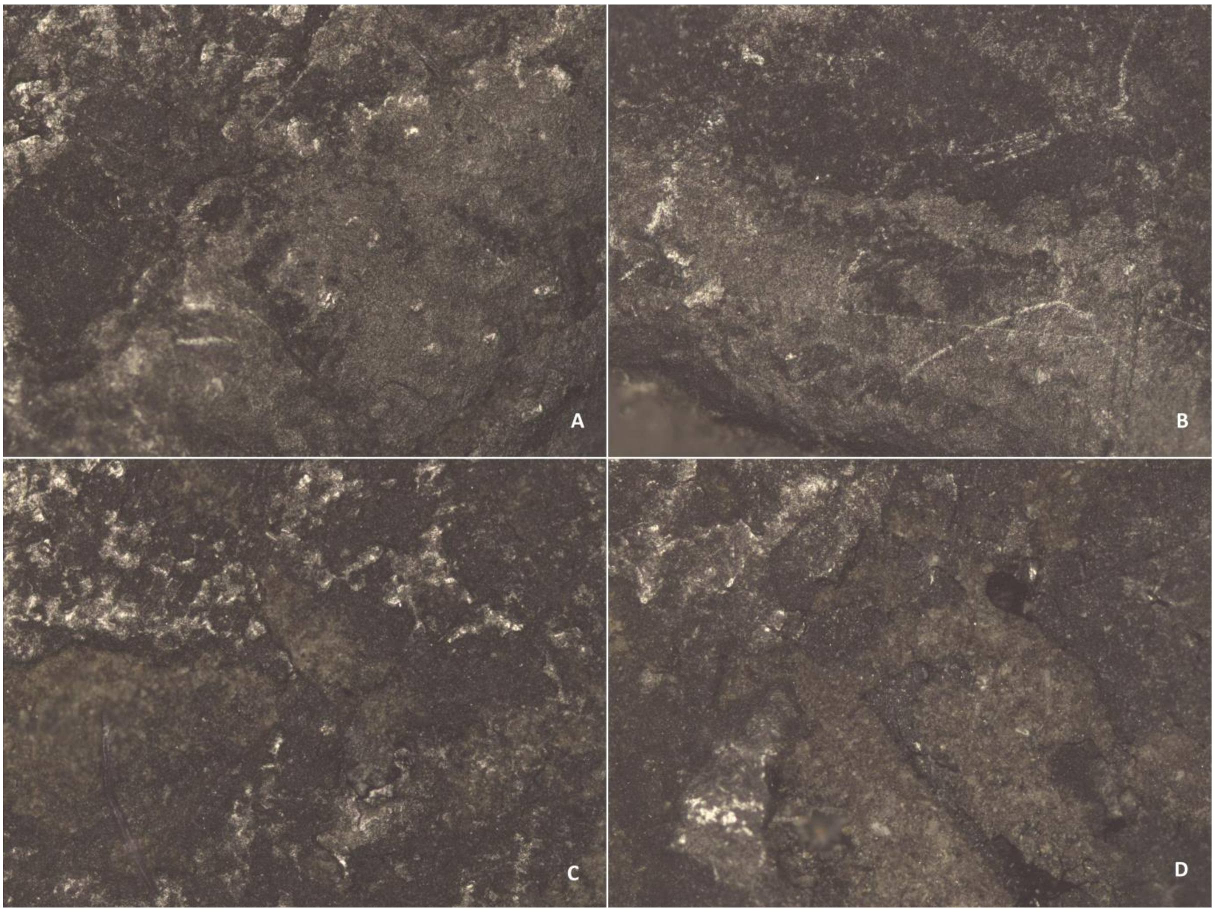

Figure 59 100x magnification of location 2 (A), 3 (B), 4 (C) and 5 (D), scale 1:1.5

This small bead is disc-shaped. Its strange surface appears very shiny from the outside, but seems rather dull under the microscope. Small islands of rougher, brighter surface material are scattered across a very smooth dull surface that does not show a lot of manufacturing traces. The scratches on the surface in picture B resemble scratches on stones. The surfaces that have been totally smoothed appear different than the smoothed surfaces of the Ypenburg ornaments. They are darker and lack the bright lustre of those artifacts.

Schipluiden ornament 10764, bead

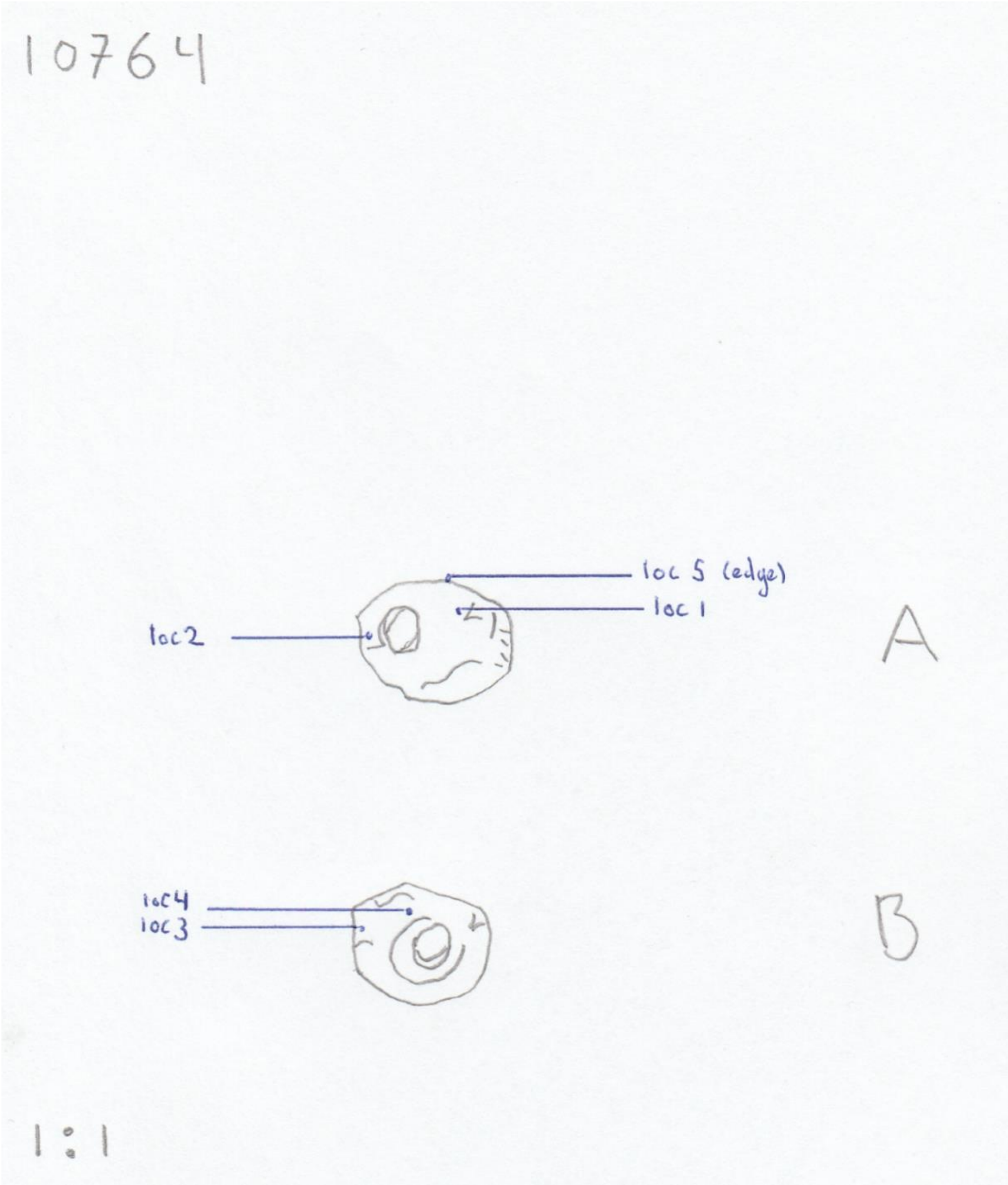

Figure 60 Drawing of ornament vnr 10764, scale 1.2:1

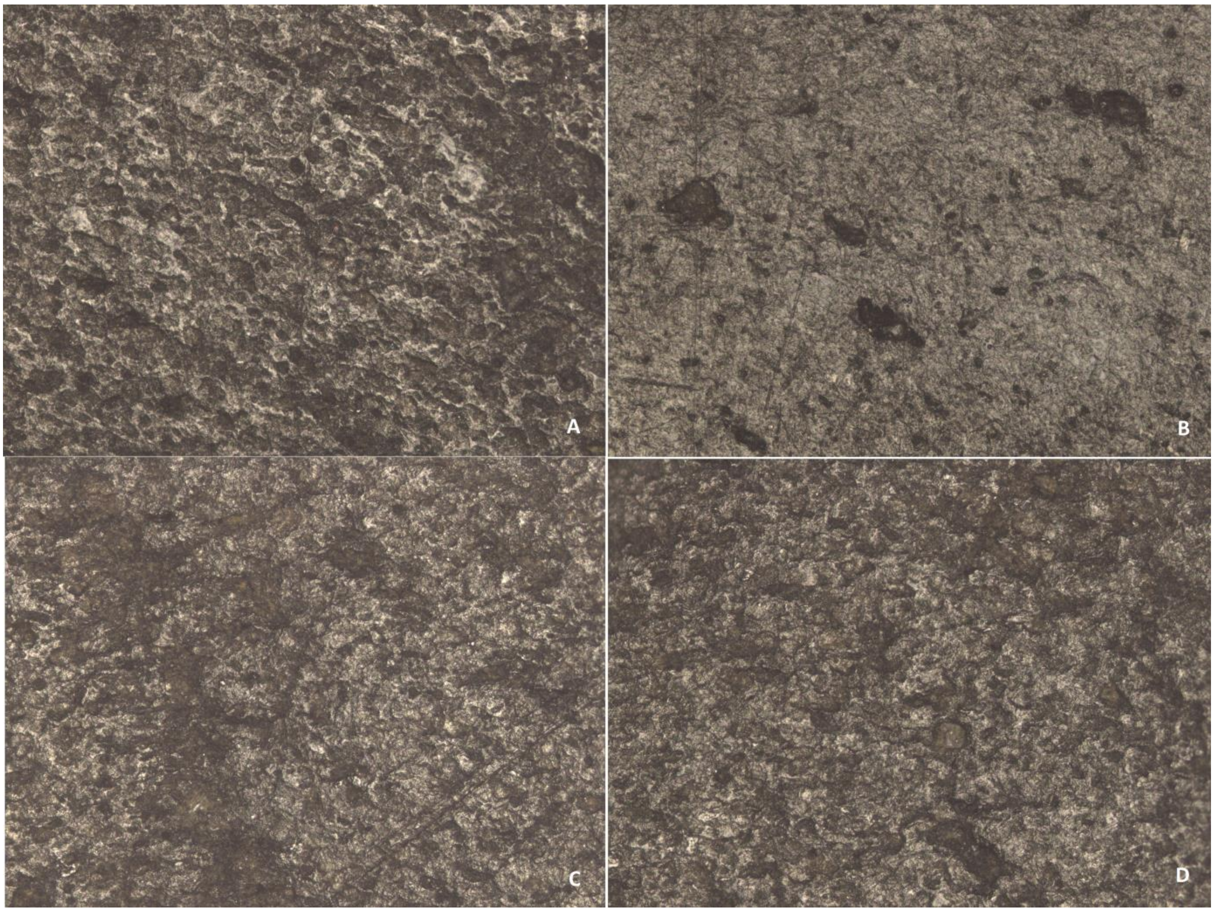

Figure 61 100x magnification of location 1 (A), 2 (B), 3 (C) and 4 (D), scale 1:1.5

Bead 10764 is a very small disc-shaped bead with a decentralized drillhole, indicating that it was worn as a single ornament rather than as part of a string of beads. The surface scattered with microcraters and generally appears very rough. The smoothest part of the surface is shown on picture B which is above the drillhole near the edge, where most wear from the string would have taken place. Manufacturing traces appeared to be absent, but on closer inspection a lot of linear scratches can be distinguished. The higher parts of the surface are generally more glossy than the background. Most of the surface resembles the leather polish from the experiment, characterized by randomly distributed sharp, short, angular scratches and a higher gloss on elevated parts. Some parts of the surface (picture B) appear heavely worn down.

Schipluiden ornament 7131 A, half-product

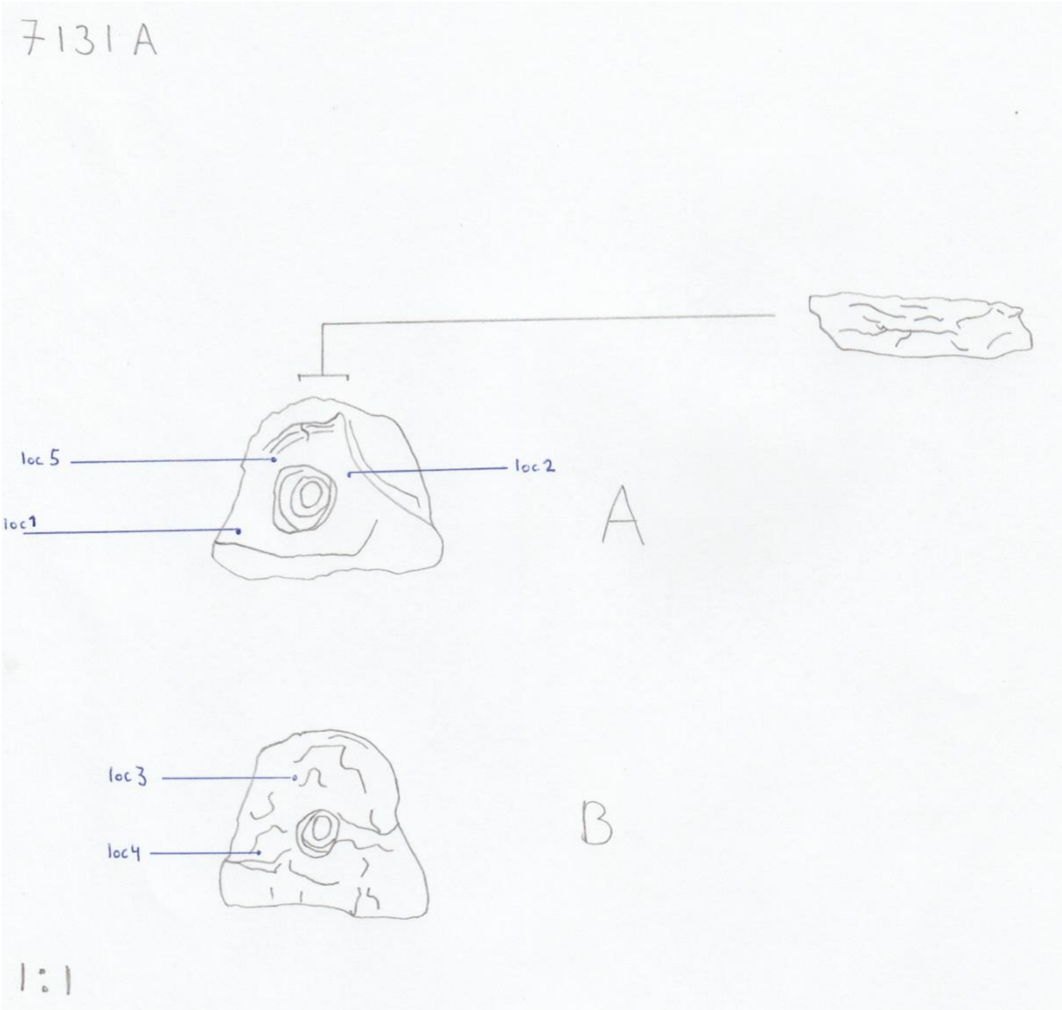

Figure 62 Drawing of ornament vnr 7131A, scale 1:1.5

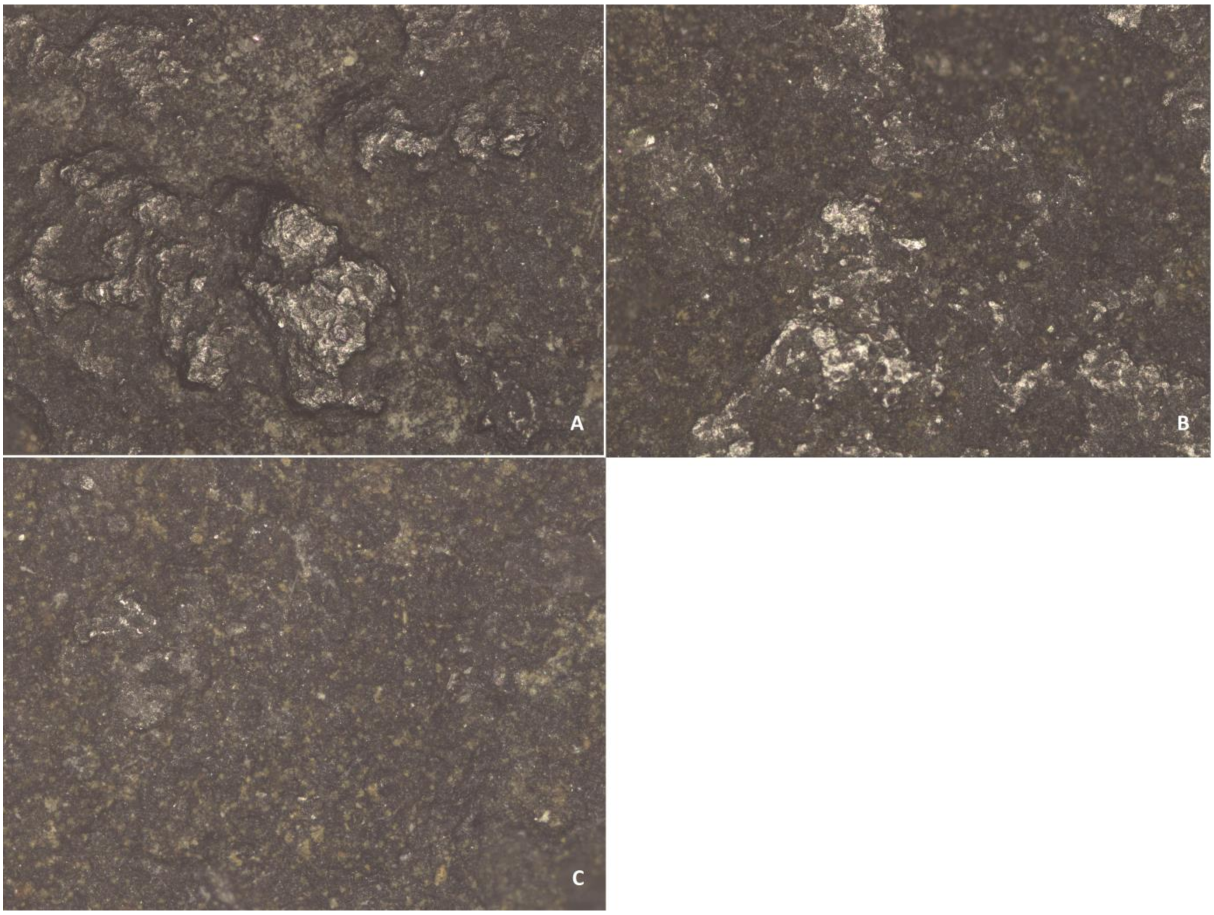

Figure 63 100x magnification of location 1 (A), 2 (B) and 3 (C), scale 1:1.5

This pendant was almost finished before it was discarded. On some places surfaces have been worked (A, B) whilst other places remain natural (C). A greenish organic layer, or perhaps an oxidation layer, covers the entire object. This oxidation does not seem to have affected highly polished areas. According to the XRF-distinction this object was not a jet, and the greenish surface layer might relate to a different raw material.

Schipluiden ornament 7131 B, half-product

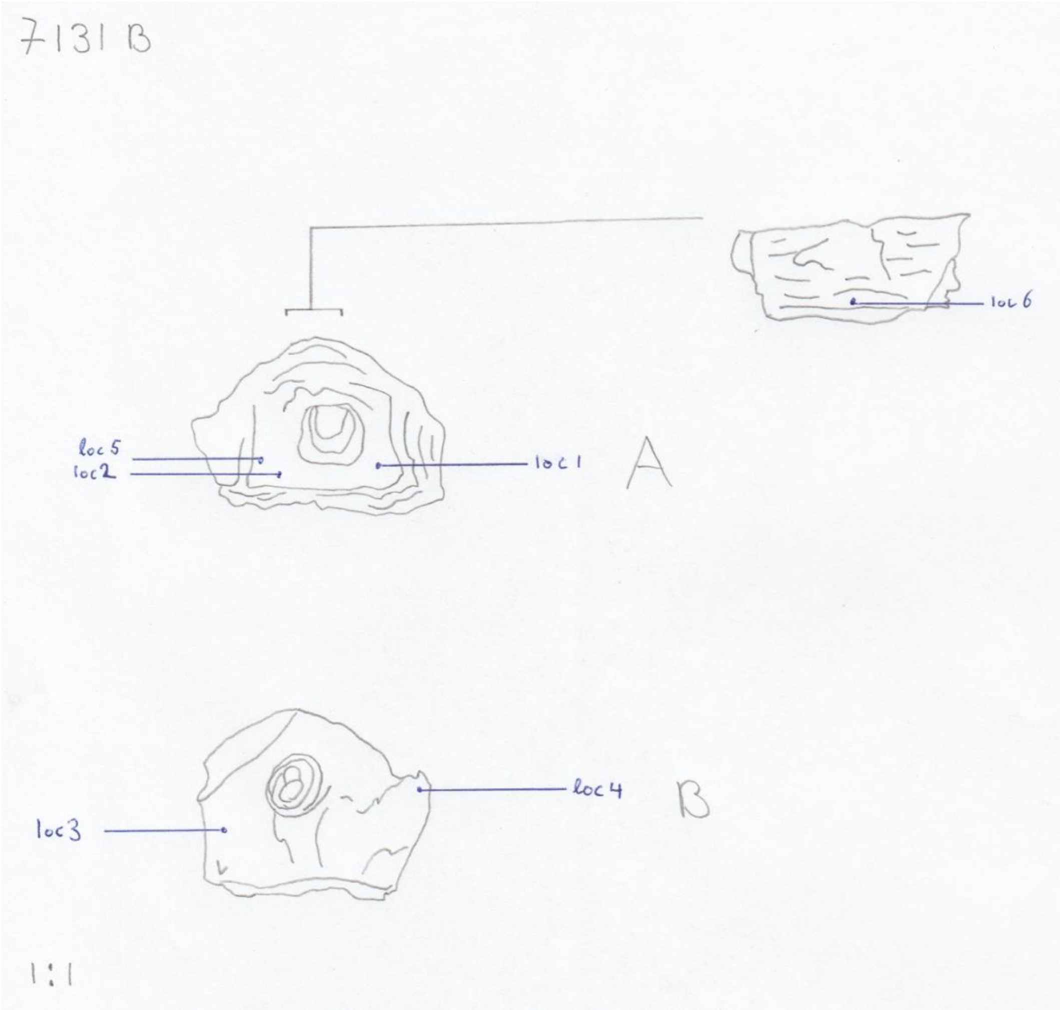

Figure 64 Drawing of ornament vnr 7131B, scale 1:1.7

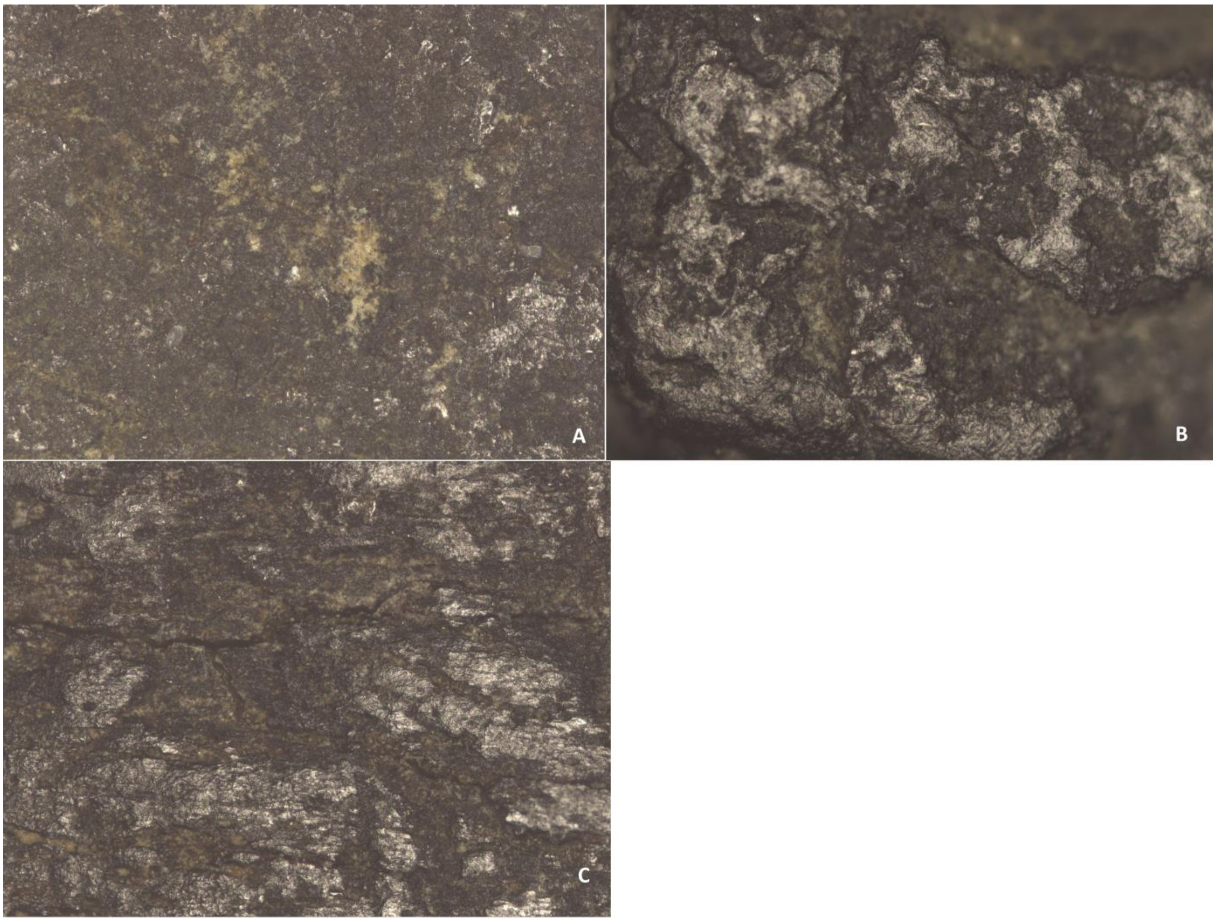

Figure 65 100x magnification of location 1 (A), 2 (B) and 3 (C), scale 1:1.5

This nearly-finished pendant heavily resembles half-product 7131 A. It has the same greenish layer surrounding the elevated polished places on the surface. Under the green layer the objects surface resembles the smooth dull surface of bead 5076. The surface also shows severe cracking on some spots (C). On one picture (C), it almost seems as if the greenish layer was present before polishing took place and has resided to depressions in the surface. Picture A clearly shows, however, that the layer is lying on top of some polished parts of the surface. A possible hypothesis is that the dull dark background in between the bright scattered zones is related to a lower quality material, such as lignite, that does not take a very high polish and is therefore susceptible to environmental attacks on the surface.

6.6) Discussion on the surfaces of the archaeological artifacts

There appears to be a general difference between polished and unpolished surfaces. Polished surfaces are smoother and may be less susceptible to environmental processes than the rougher unpolished surfaces such as half-products 551, 7131A and 7131B. On these objects a greenish organic layer is present. Most polished surfaces, however, have developed cracks and show a degree of exfoliation, in which angular chips start breaking off the outer skin of the object, following the lines of the cracks. This peeling of the outer polished skin is probably the post-depositional effect of time and burial environment.

6.6.1) Ypenburg

The artifacts of Ypenburg, which have been distinguished as true jets on the basis of XRF, have surfaces that generally appear very smooth in a 100x magnification. The manufacturing traces are still clearly attestable and have not completely faded. The gloss that resembles the tumble effects, which may be indicative of prolonged wear, is often present. The XRF-analysis cannot ascertain the nature of the materials, although the initial distinction is likely to be correct (chapter 5). Since these objects are likely to be true jets, they may be more durable than other materials and therefore less prone to the effects of wear. Many of the surfaces show scratches that resemble the traces left by *Equisetum* on the experimental beads, although one of them resembles the experimental bead that was polished with leather (497). It is off course possible that a combination of materials may have been used to achieve a desired polish effect.

6.6.2) Schipluiden

The surfaces of finished artifacts appear very rough compared to the artifacts derived from Ypenburg. Manufacture and intentional polish traces are more difficult to detect microscopically on these objects and in some cases are largely absent. Many of the objects closely resemble the wear effects that have been assessed in the tumble experiment, albeit to a much higher degree. The distinction between an intentional polish and a use-wear related shine is not always clear, but if the distinction that was made based on the experiment is correct, then an interesting connection can be made between the XRF-distinction and the degree of wear on the artifacts: the Schipluiden artifacts, labeled as non-jet, lesser quality materials may have been more prone to the effects of wear than the Ypenburg artifacts, labeled as true jets. If these materials could only reach a certain amount of gloss then it would not have been logical in the past to work their surfaces as intensively as true jets that can attain a much higher degree of shine.

7) Conclusion

It has been pointed out that the term jet means different things for different people throughout history (Allason-Jones and Jones 2001, 233). For the Neolithic inhabitants of Schipluiden and Ypenburg it would have meant a raw material that is particularly suited for the purpose of ornamental display, due to its inherent properties that give it such a deep black color and high shine. If jet was not available, other black materials that resemble true jet would have fitted the same purposes, but to a lesser degree. Jet has been historically ascribed supernatural and magical attributes due to its electrostatic properties and in this respect may have had an even more special value.

The initial XRF distinction has shown that the finished ornaments of Ypenburg are possibly all true Upper Lias jets. A large amount of the objects under investigation are probably not, however, including all finished ornaments from Schipluiden. The XRF-analysis of the lighter elements further confirmed this initial distinction and showed very low aluminum contents in all objects. It did not reveal other patterns and provenancing has not proven possible with HH-XRF in this investigation.

It has proven possible to distinguish between an intentional polish and a use-wear related shine. Intentional polishes are readily attestable. Interestingly there is a strong resemblance between the intentional polish on the experiments and the intentional polish on some artifacts from Ypenburg: Among the used materials in the experiment was *Equisitum hyemale*, and this plant was also attested in the botanical assemblage of both sites. The artifacts from Ypenburg showed much resemblance to the polish traces in the experiment and the artifacts from Schipluiden showed much more effects of wear. The reason why the polish marks were still present in the Ypenburg artifacts may be related to the true jet nature of these objects: As has been pointed out in earlier chapters, polished jet is a highly durable material that retains its polish for thousands of years.

Use wear related polish is much more difficult to attest than an intentional polish, as use-wear is characterized by the blurring out of earlier manufacture traces and it does not leave characteristic traces of its own, at least after 50 hours of tumbling. The high durability of polished jet surfaces may account for the minimal effects of wear. Especially pigskin was effective in dulling a jet surface, and responsible for cracks to appear in the surface. The leather pouches were less effective and effects from the linen were hardly attestable. We can expect that human skin would have had a considerable effect on jet ornaments that were worn for a long time, making surfaces greasy. Leather clothing would have had an effect as well. Problems that arise with characterizing the wear of these objects include the fact that post depositional surface alteration is not well understood. Some microscopic effects that are possibly resulting from burial are documented here and include the cracking of the outer polished surface (skin) which results in angular chips breaking off. Conclusively it should be remarked that 50 hours of wear in a tumbler showed some differences on the surfaces, but it is very difficult to estimate the effect on an artifact that was actually worn for years, which is off course much longer than 50 hours.

This experiment, although insightful, is incomplete as it lacks the evidence to conclusively distinguish an intentional polish from a use-wear related shine. Similar experiments could be set up for future research with longer tumbling durations and allow the use of different polish materials. Qualitative handheld XRF analysis has been highly effective in distinguishing jet from non-jet materials; it would be interesting to analyze other Dutch jet assemblages in this way. In the study of provenance a vast body of research is required to chemically characterize European sources of jet. Although handheld XRF is inferior to organic techniques in this type of analysis on jet, it is non-destructive, much cheaper and much more accessible; therefore further analysis of trace elements in jet materials from different European sources is desirable.

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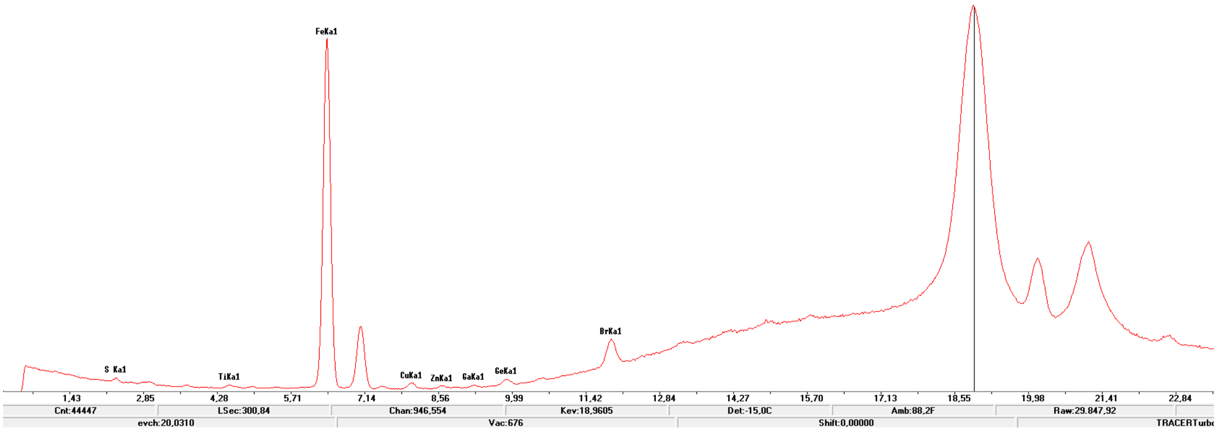
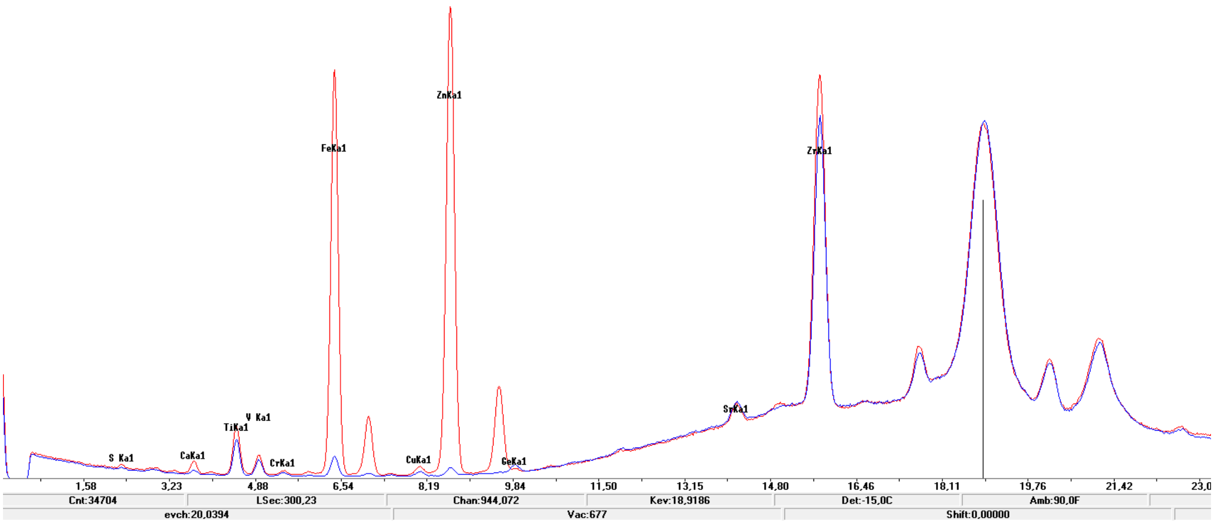
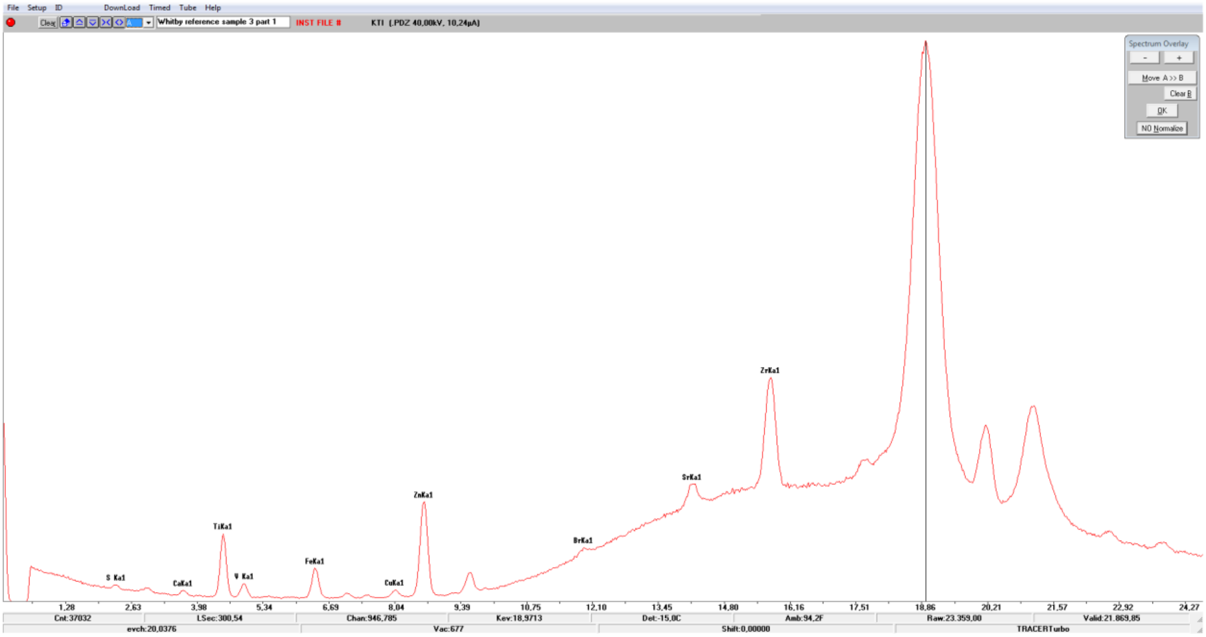
Appendix 1: XRF-spectra of iron and the heavier elements



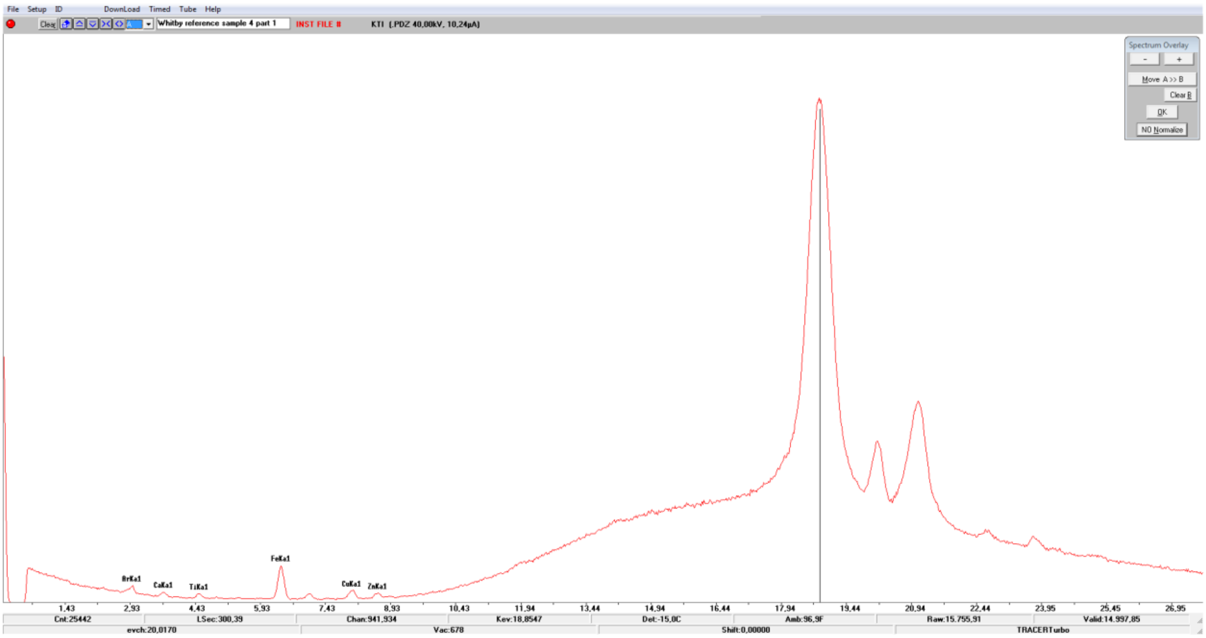
Whitby reference pebble 1. yellow filter, single measurement, Compton normalized. High iron content although still below the Compton peak, absence of Zr and Sr. Initial distinction: intermediate.



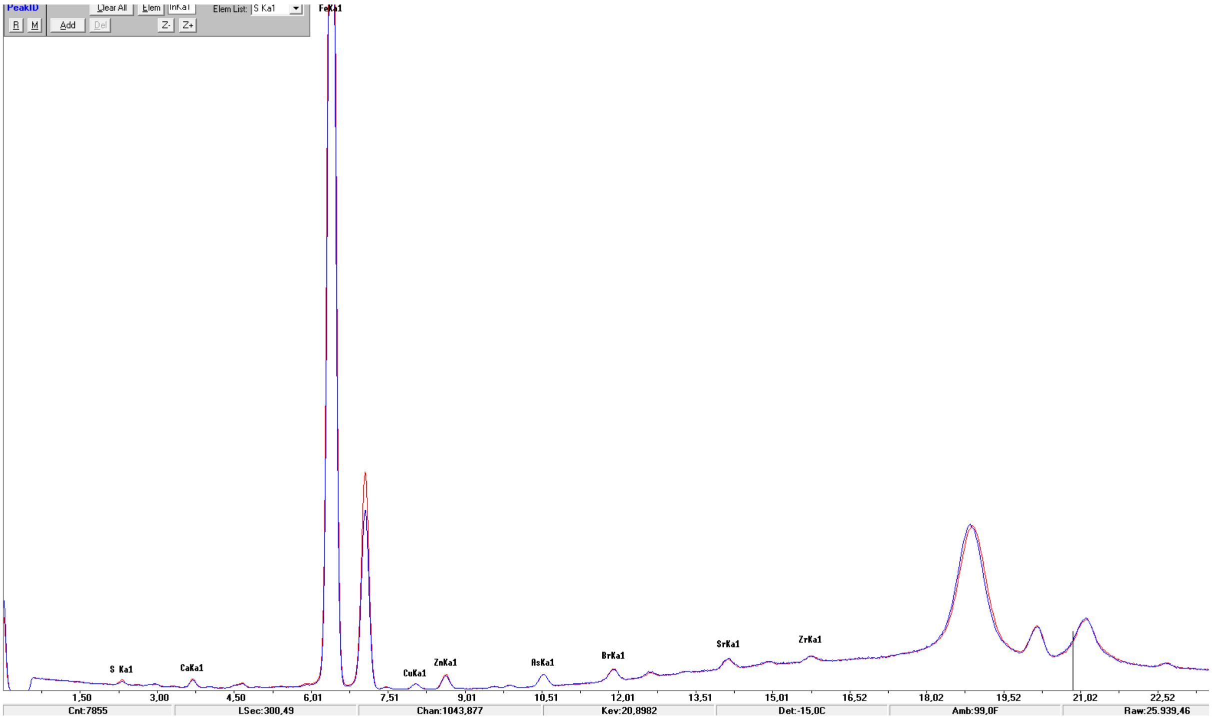
Whitby reference pebble 2, yellow filter, double measurement, Compton normalized. Problematic piece as it shows very high internal variation in Ca, Fe and Zn. Possibly contamination? Initial distinction: unknown.



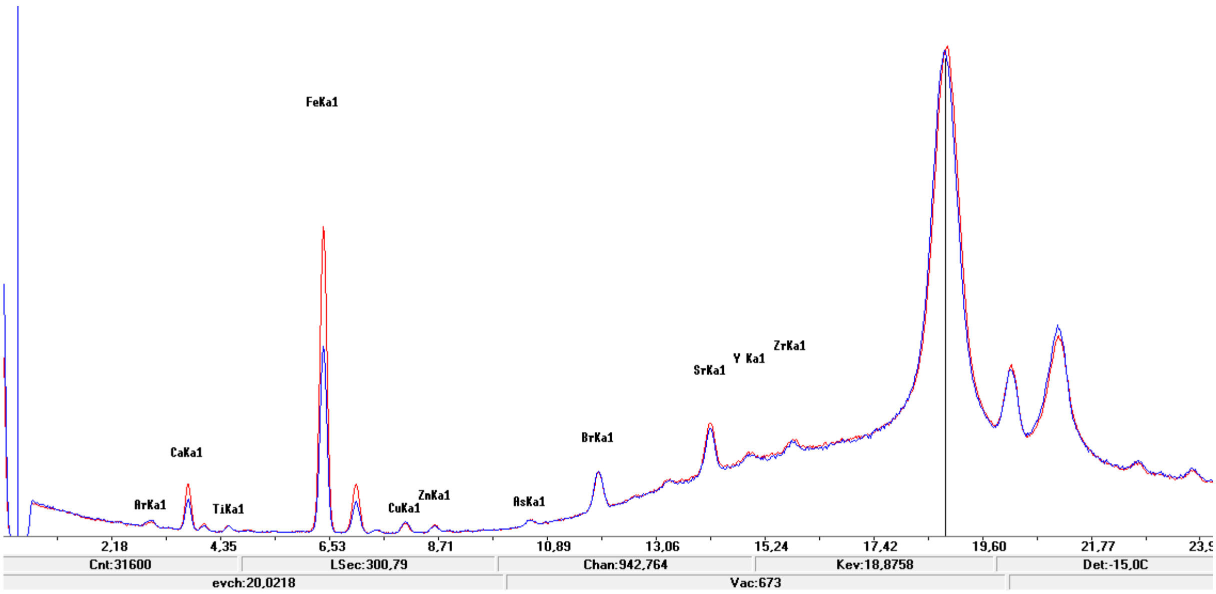
Whitby reference pebble 3, yellow filter, single measurement, Compton normalized. Shows a very low relative iron content. Initial distinction: jet.



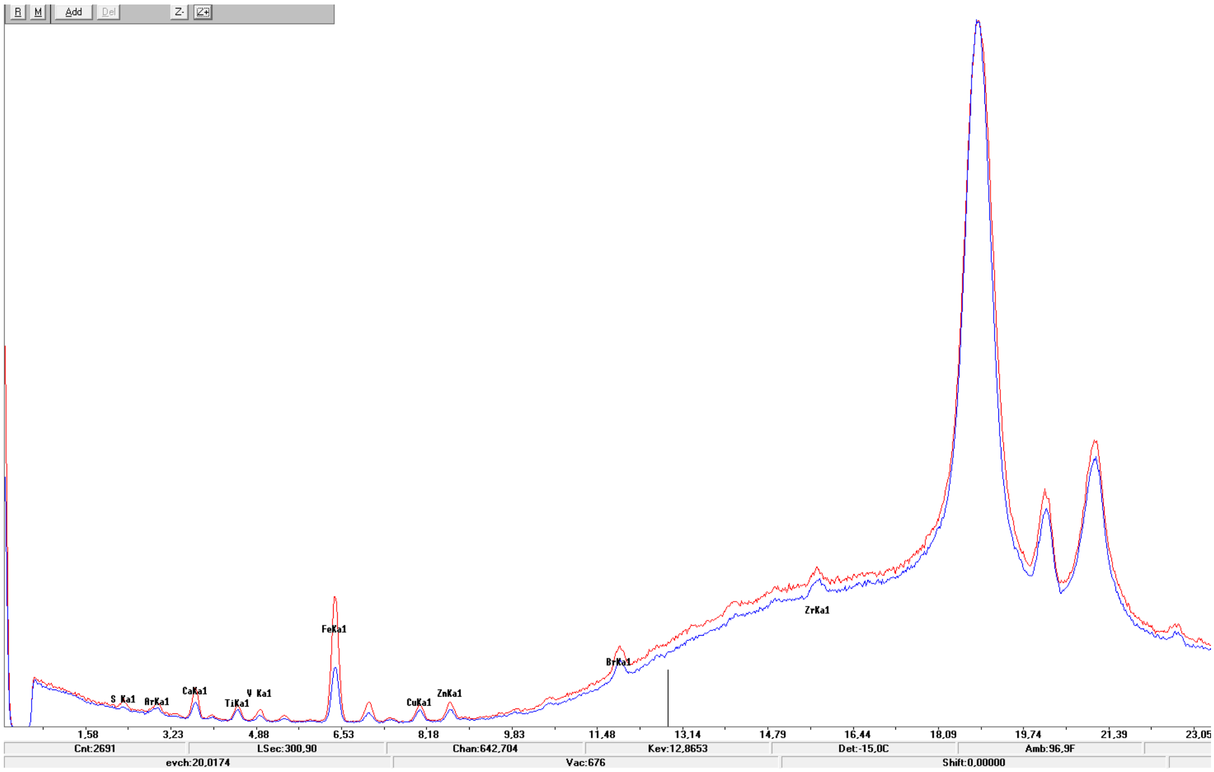
Whitby reference pebble 4, yellow filter, single measurement, Compton normalized. Shows a very low relative iron content. Initial distinction: jet.



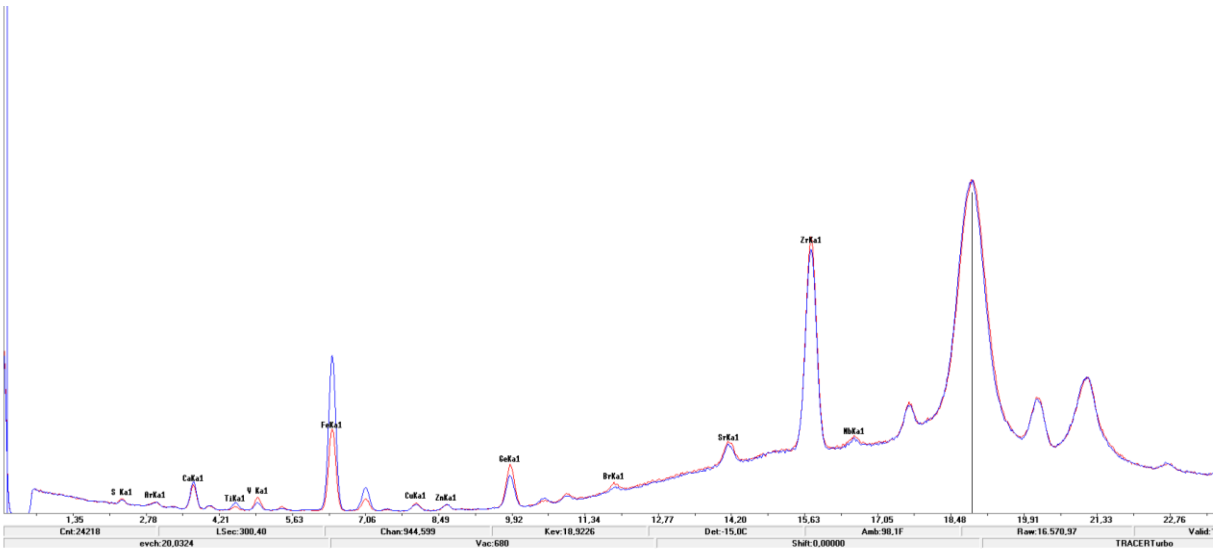
Whitby reference pebble 5, yellow filter, double measurement, Compton normalized. Shows a very high relative iron content compatible with lignite or even shale. Initial distinction: non-jet.



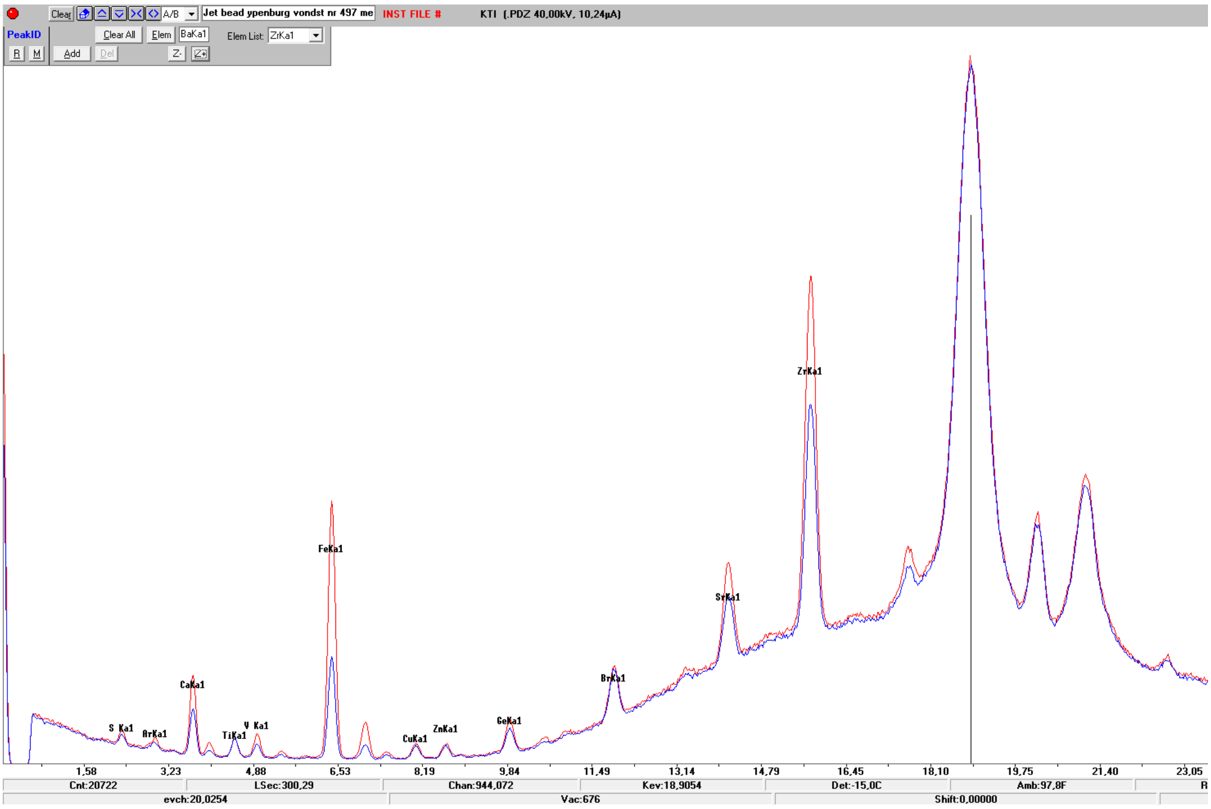
Ypenburg 385 (artifact), yellow filter, double measurement, Compton normalized. Initial distinction: jet.



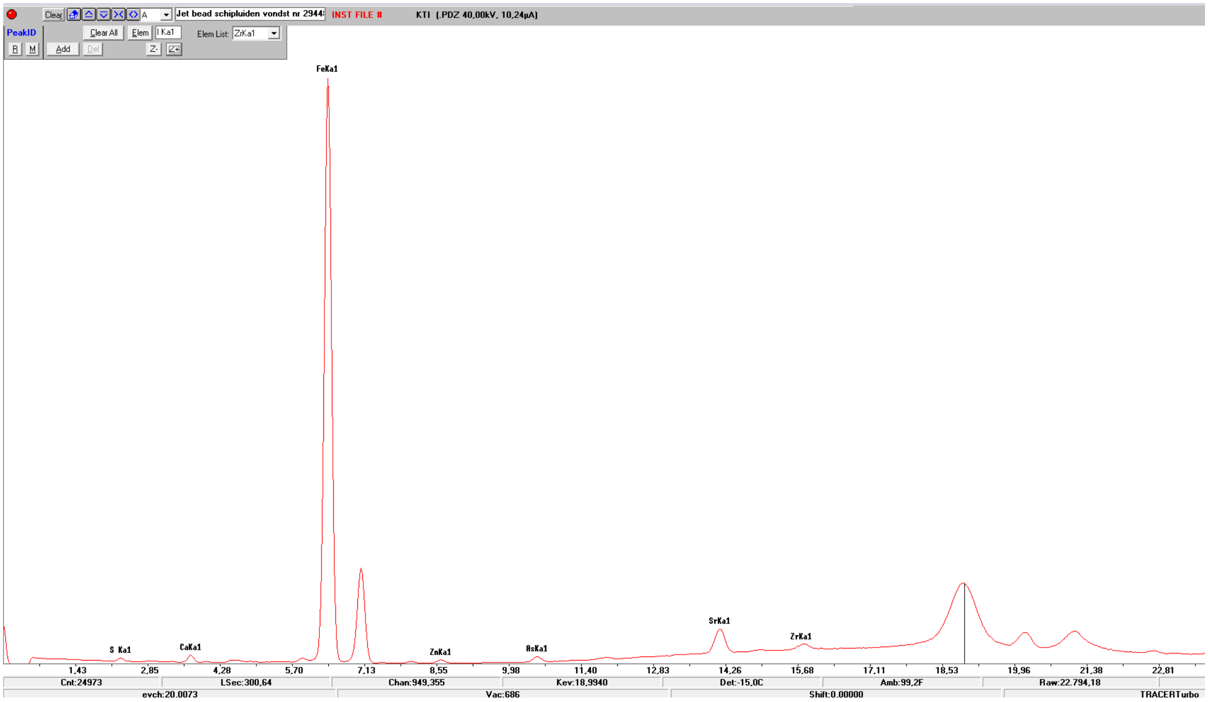
Ypenburg 467 (artifact), yellow filter, double measurement, Compton normalized. Initial distinction: jet.



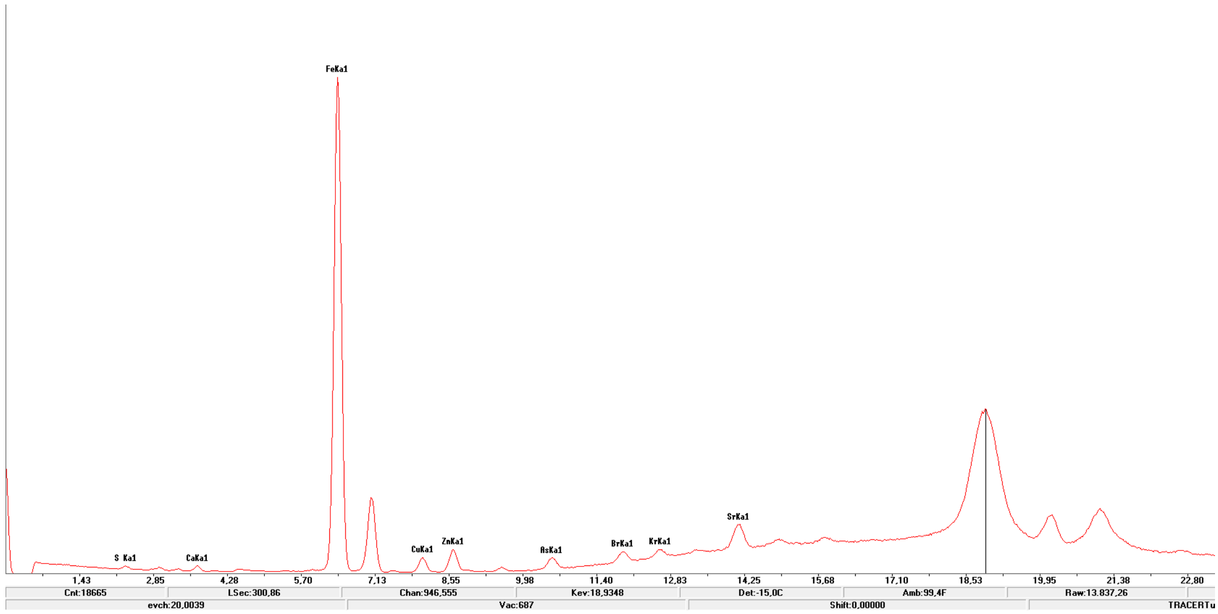
Ypenburg 468 (artifact), yellow filter, double measurement, Compton normalized. Initial distinction: jet.



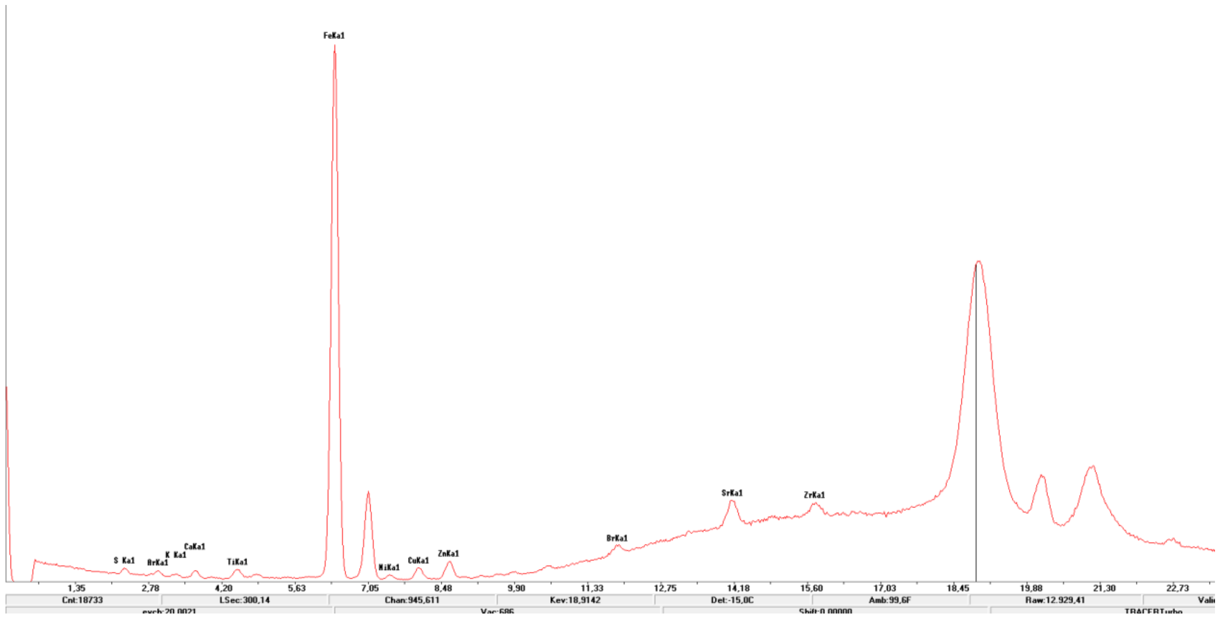
Ypenburg 497 (artifact), yellow filter, double measurement, Compton normalized. Initial distinction: jet.



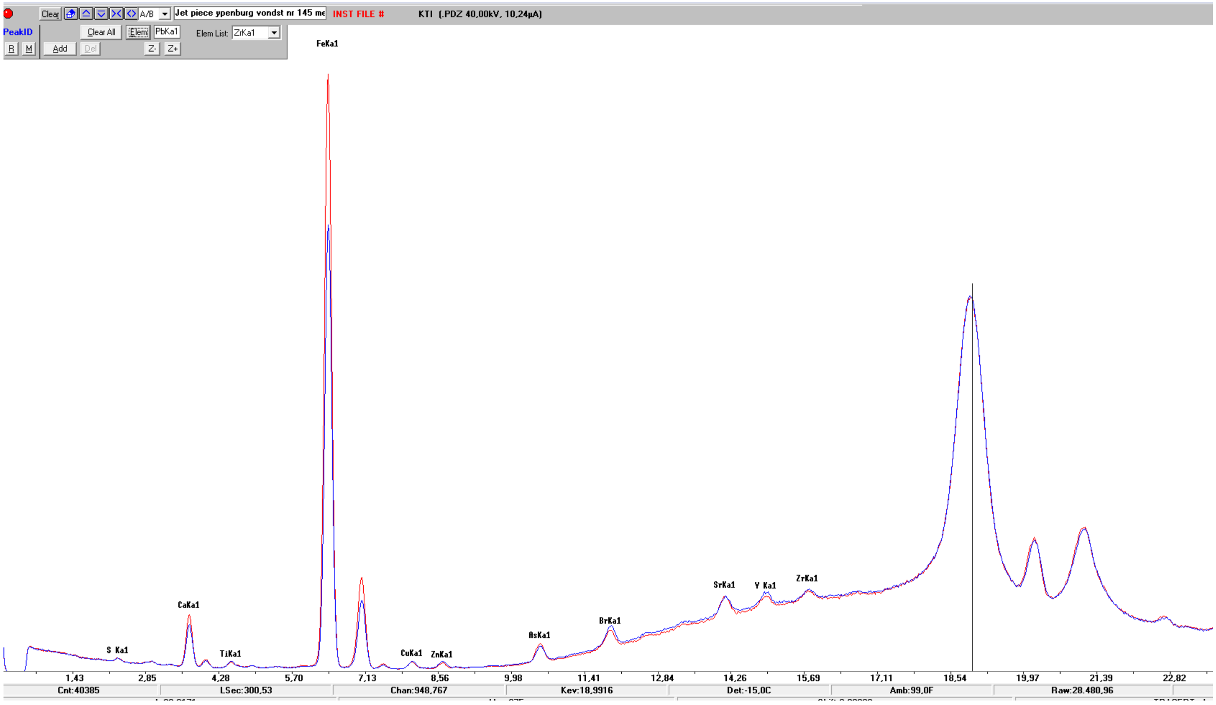
Schipluiden 1954 (artifact), yellow filter, single measurement, Compton normalized. Shows a very high iron content relative to the Compton peak, compatible with lignite or even shale. Initial distinction: non-jet.



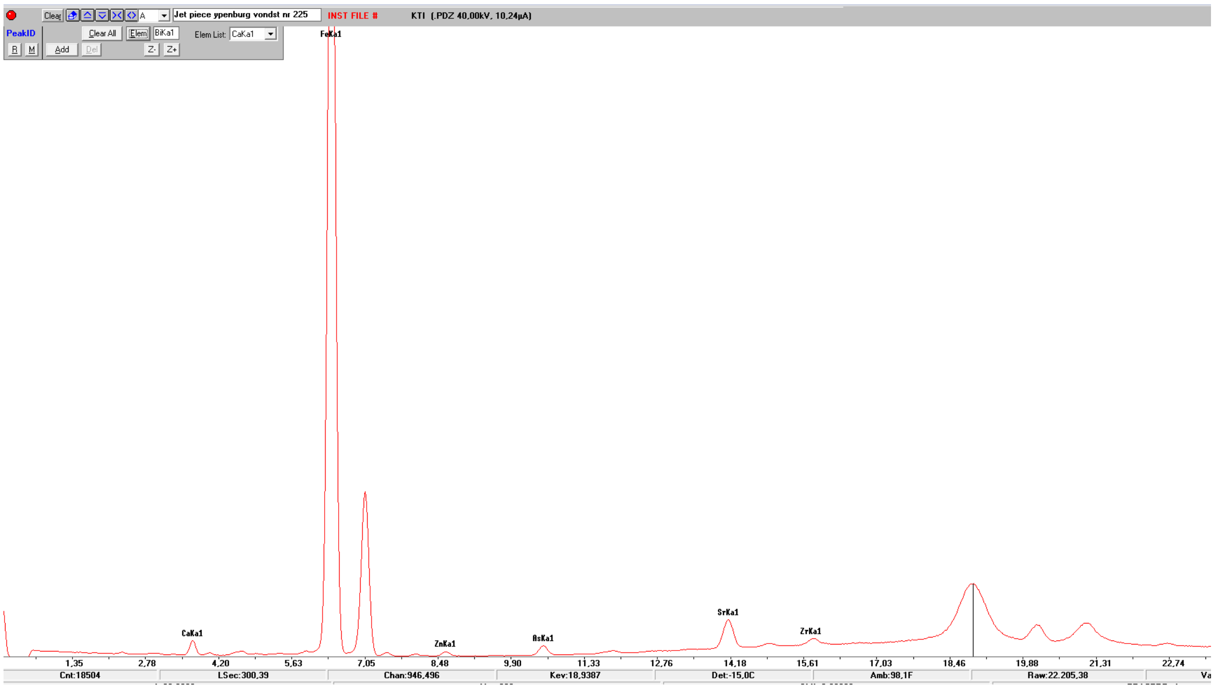
Schipluiden 5067 (artifact), yellow filter, single measurement, Compton normalized. Shows a very high iron content relative to the Compton peak. Initial distinction: non-jet.



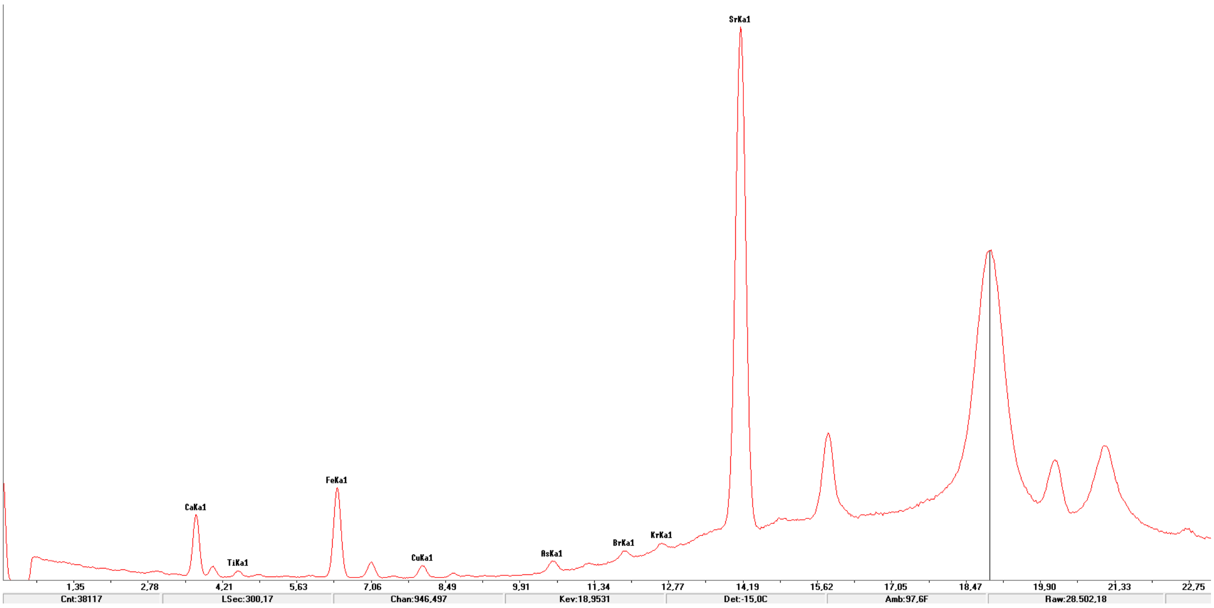
Schipluiden 10764 (artifact), yellow filter, single measurement, Compton normalized. Shows a very high iron content relative to the Compton peak. Initial distinction: non-jet.



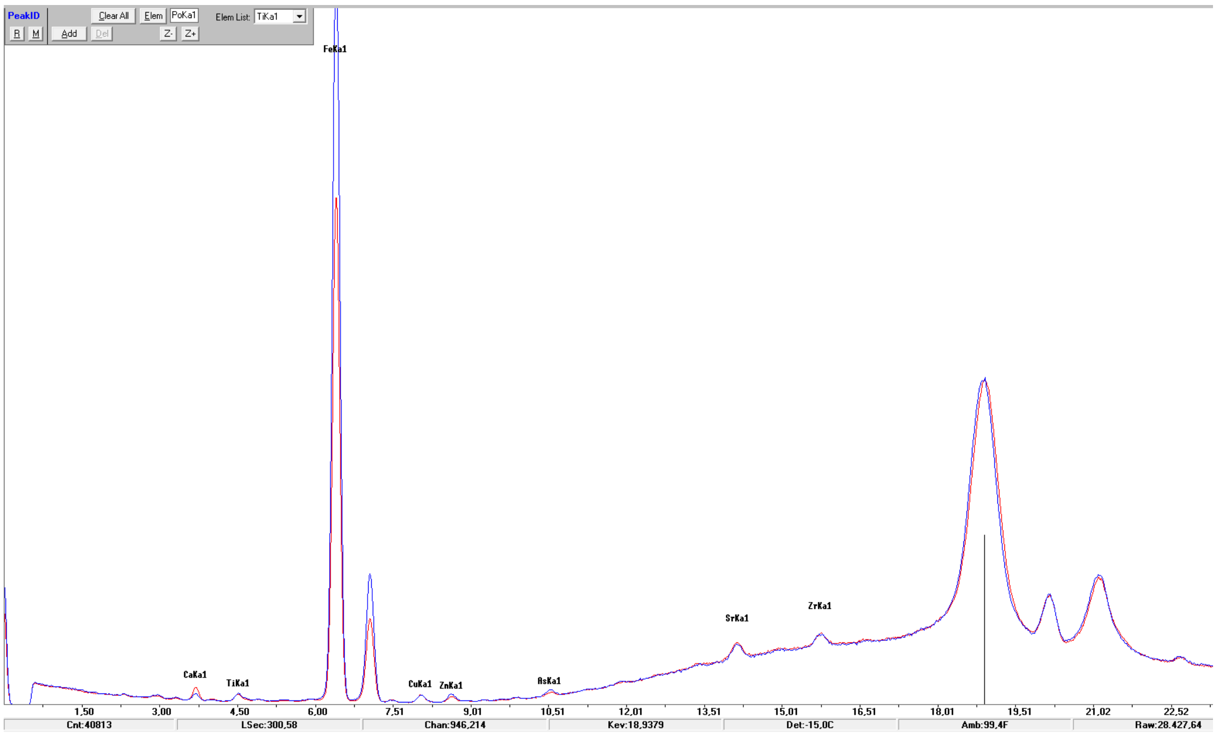
Ypenburg 145 (blank). yellow filter, double measurement, Compton normalized. Shows high iron content relative to the Compton peak. Initial distinction: non-jet.



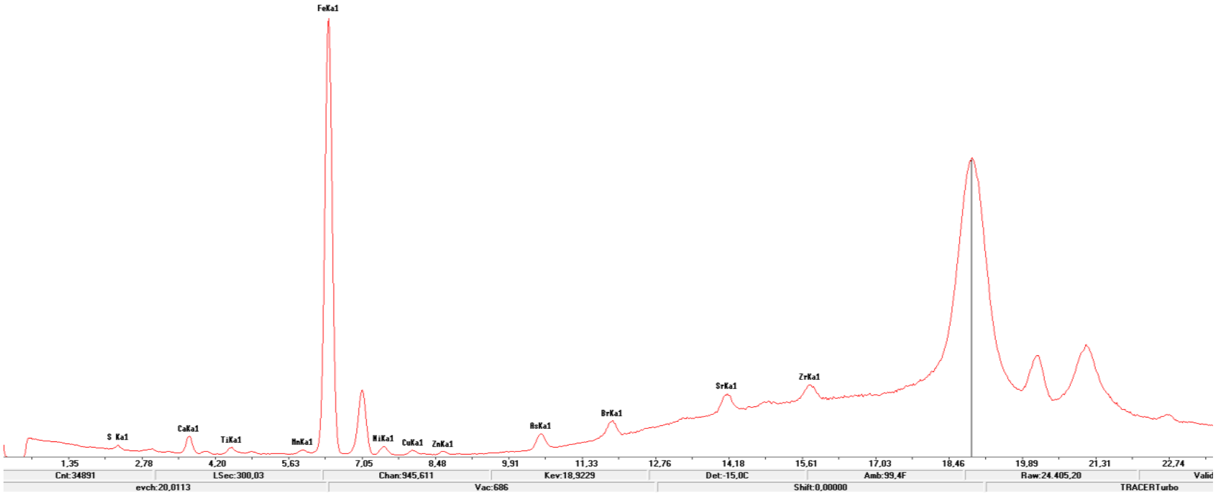
Ypenburg 225 (half-product), yellow filter, single measurement, Compton normalized. Shows a very high iron content relative to the Compton peak. Initial distinction: non-jet.



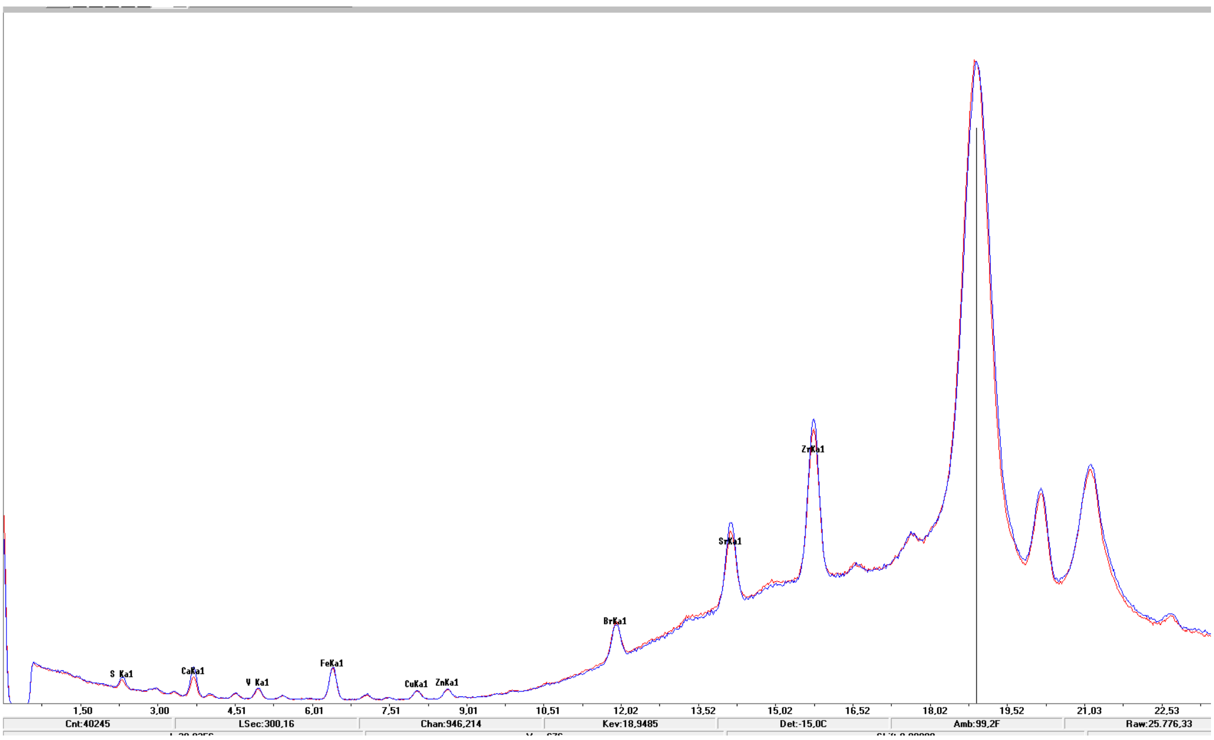
Ypenburg 267 (half-product), yellow filter, single measurement, Compton normalized. Shows a very low iron content relative to the Compton peak. Initial distinction: jet.



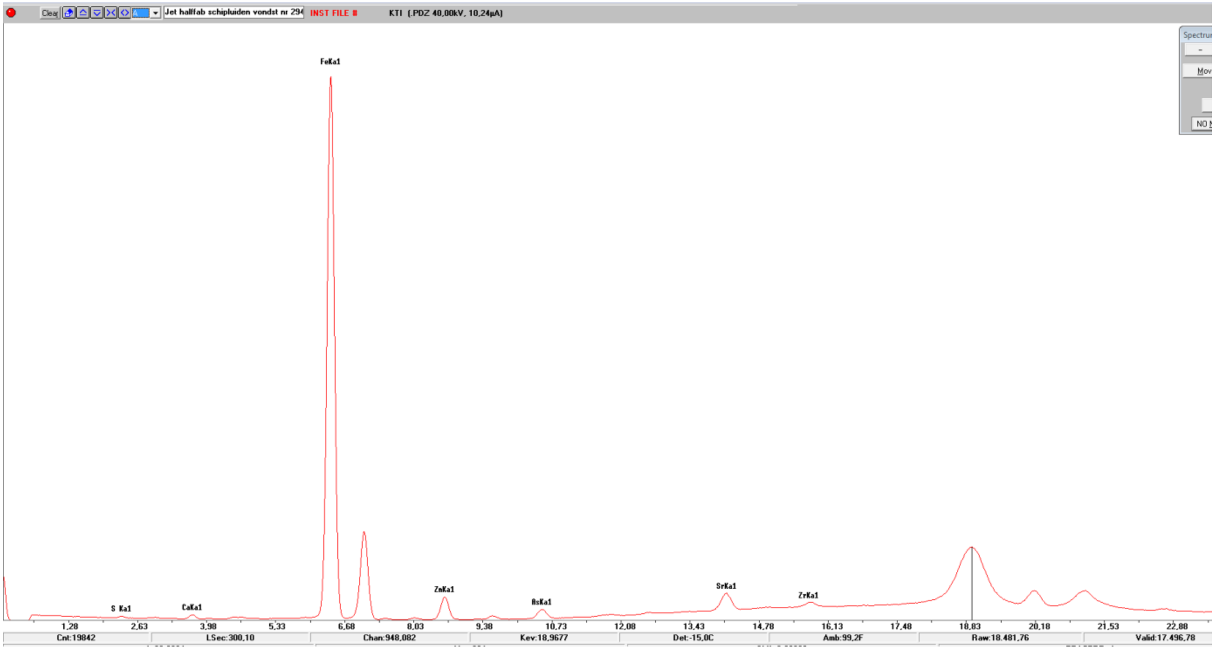
Ypenburg 427 (blank). yellow filter, double measurement, Compton normalized. Shows high iron content relative to the Compton peak. Initial distinction: non-jet.



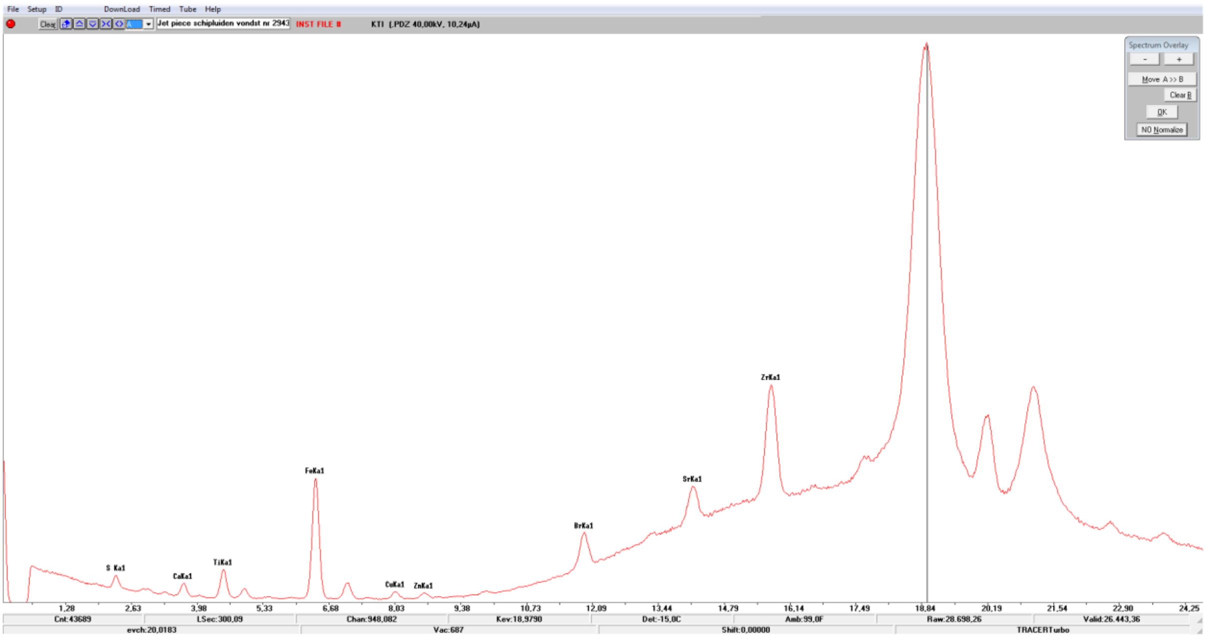
Ypenburg 551 (half-product). yellow filter, single measurement, Compton normalized. Shows high iron content relative to the Compton peak. Initial distinction: non-jet.



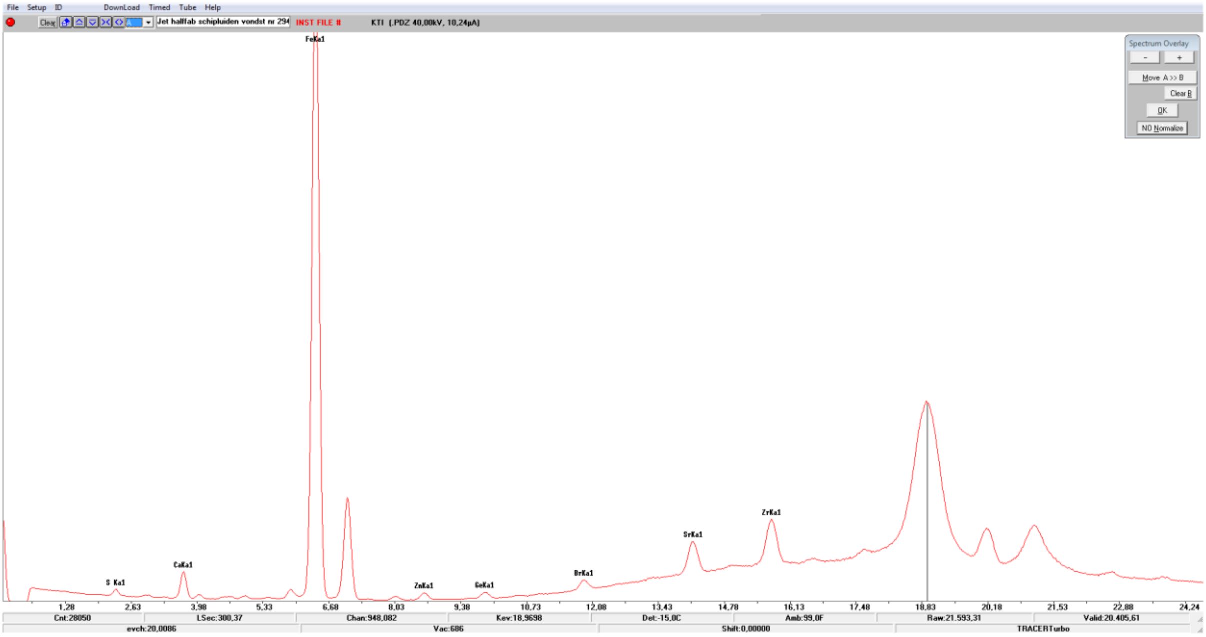
Ypenburg 613 (half-product). yellow filter, double measurement, Compton normalized. Shows very low iron content relative to the Compton peak. Initial distinction: jet.



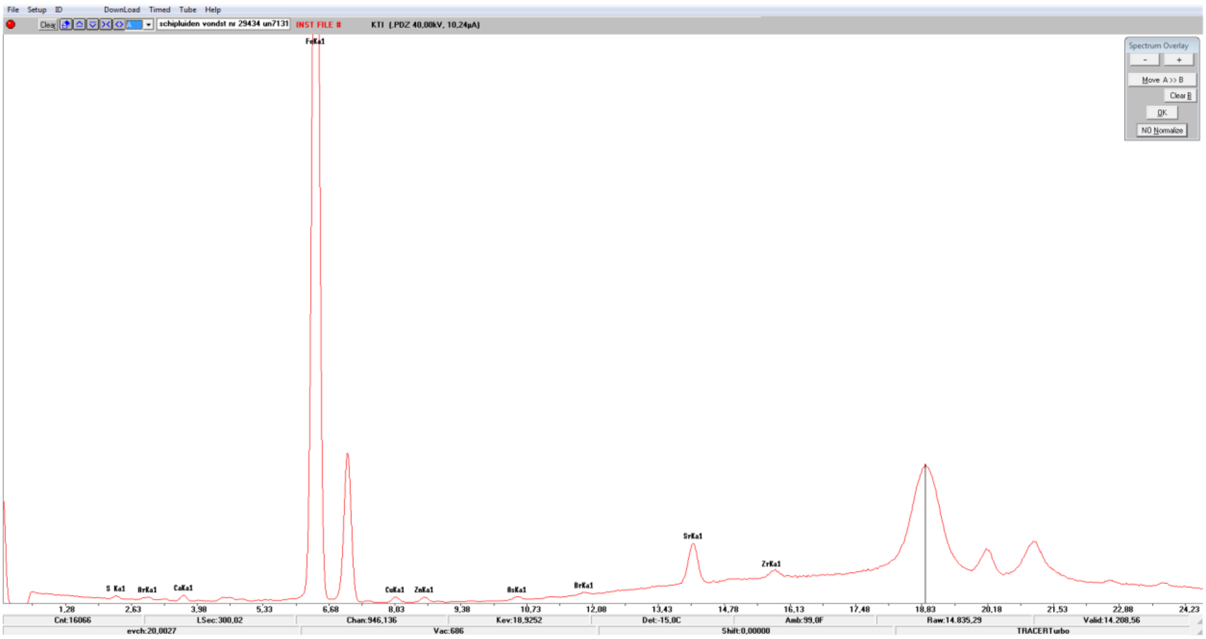
Schipluiden 2488 (half product). yellow filter, single measurement, Compton normalized. Shows a very high iron content relative to the Compton peak. Initial distinction: non-jet.



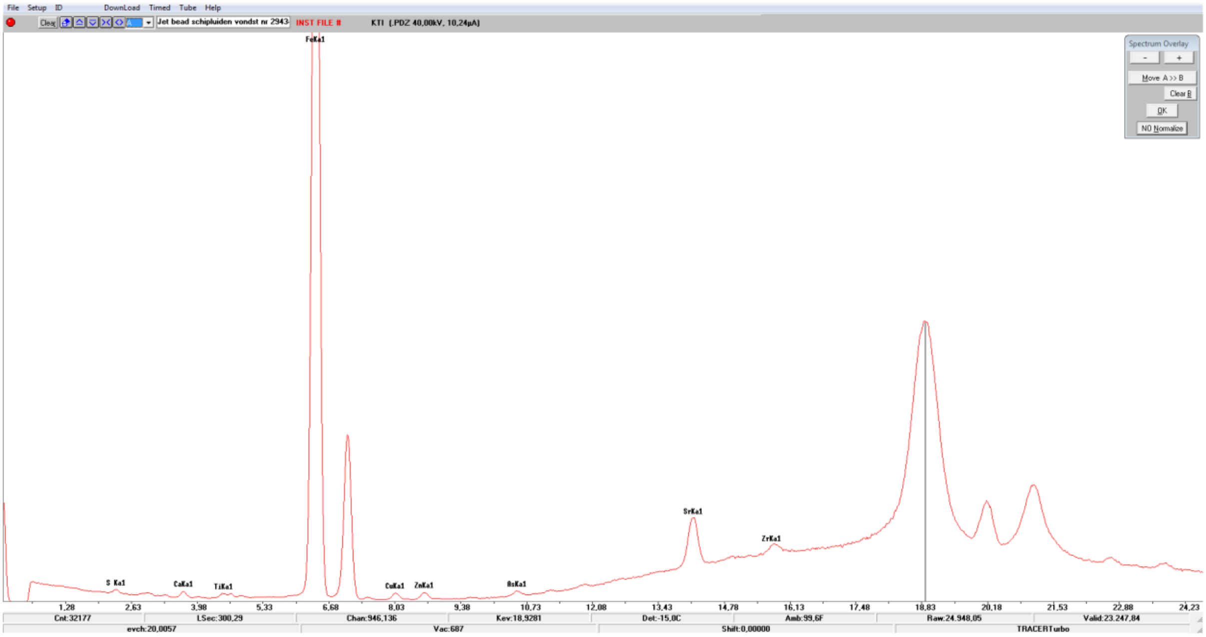
Schipluiden 3622 (half product). yellow filter, single measurement, Compton normalized. Shows a very low iron content relative to the Compton peak. Initial distinction: jet.



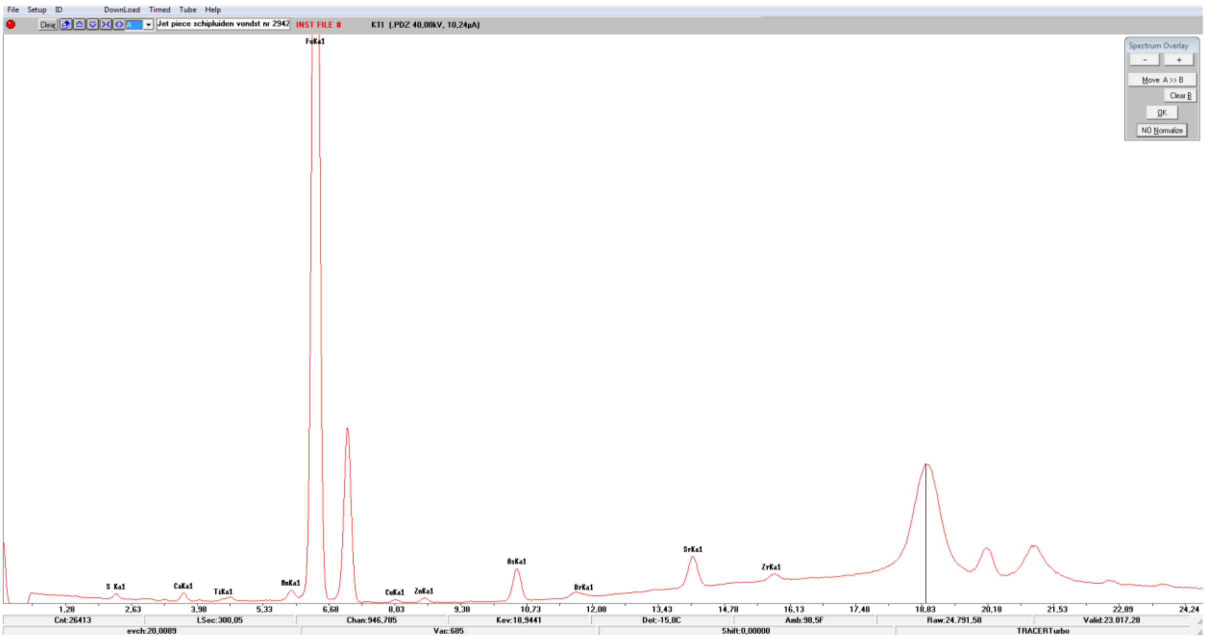
Schipluiden 3565 (half product). yellow filter, single measurement, Compton normalized. Shows a very high iron content relative to the Compton peak. Initial distinction: non-jet.



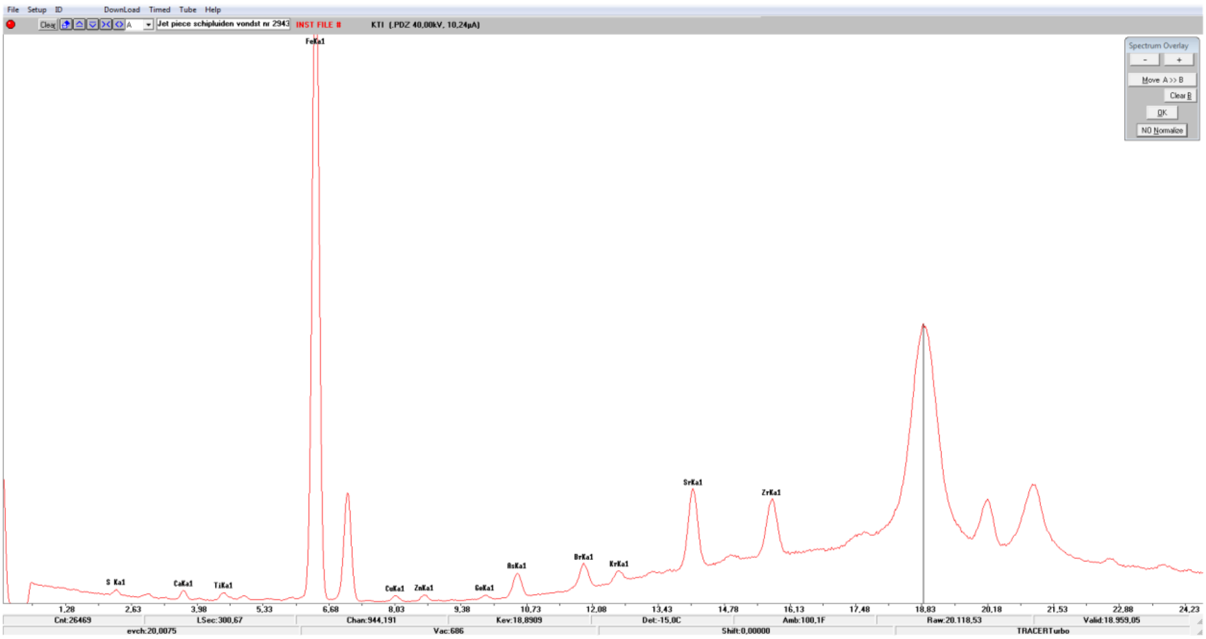
Schipluiden 7131A (half product). yellow filter, single measurement, Compton normalized. Shows a very high iron content relative to the Compton peak. Initial distinction: non-jet.



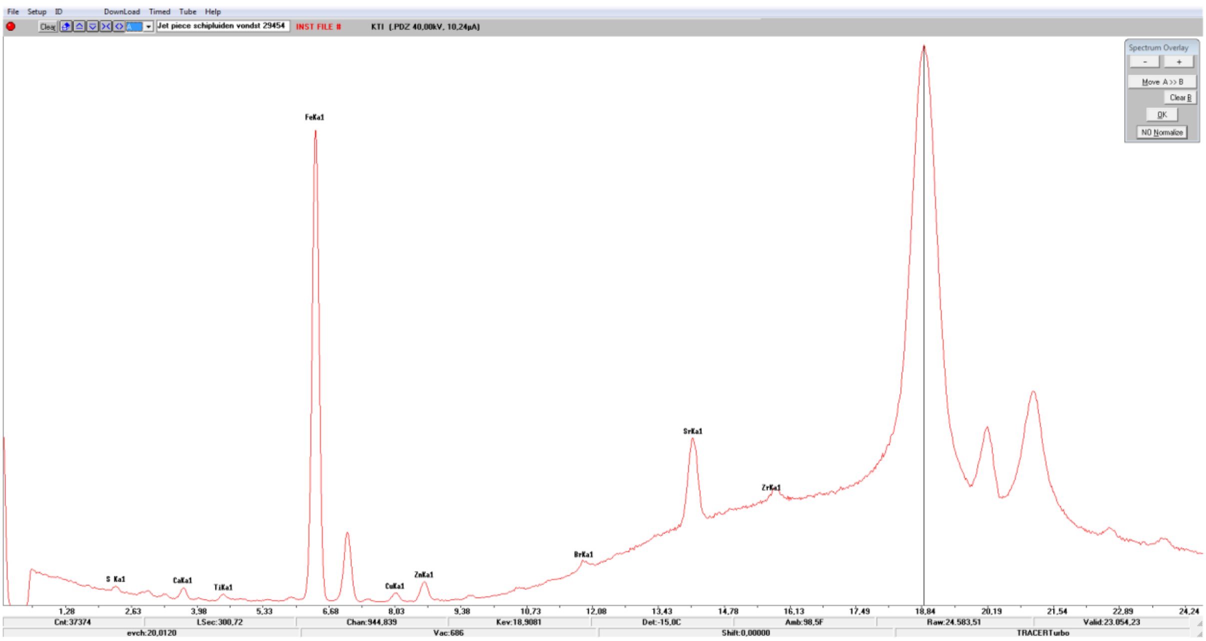
Schipluiden 7131B (half product). yellow filter, single measurement, Compton normalized. Shows a very high iron content relative to the Compton peak. Initial distinction: non-jet.



Schipluiden 29428 (half product). yellow filter, single measurement, Compton normalized. Shows a very high iron content relative to the Compton peak. Initial distinction: non-jet.

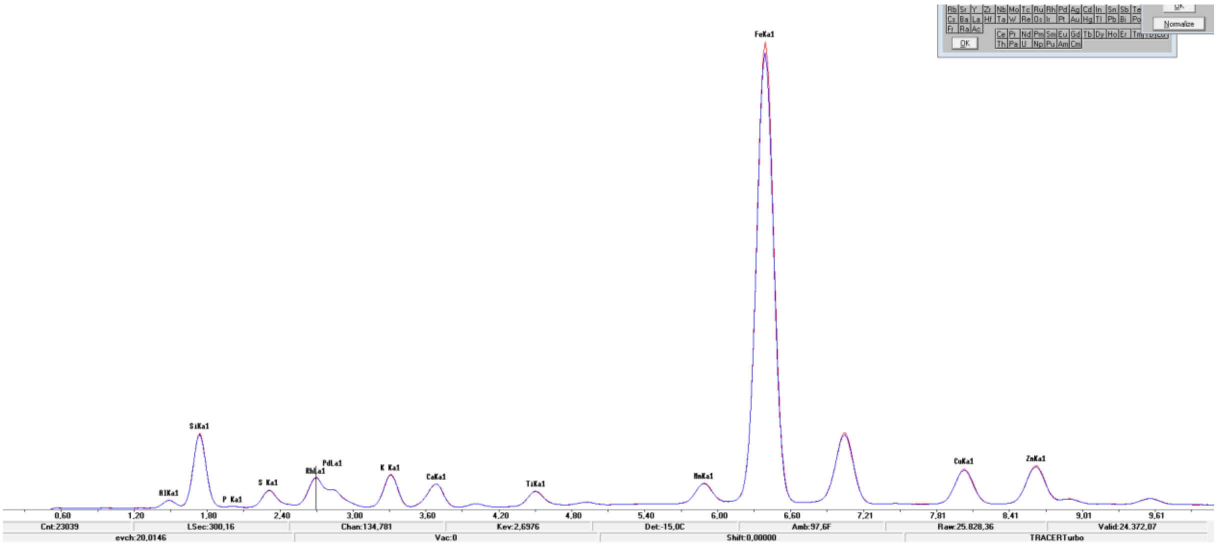


Schipluiden 29431 (half product). yellow filter, single measurement, Compton normalized. Shows a very high iron content relative to the Compton peak. Initial distinction: non-jet.

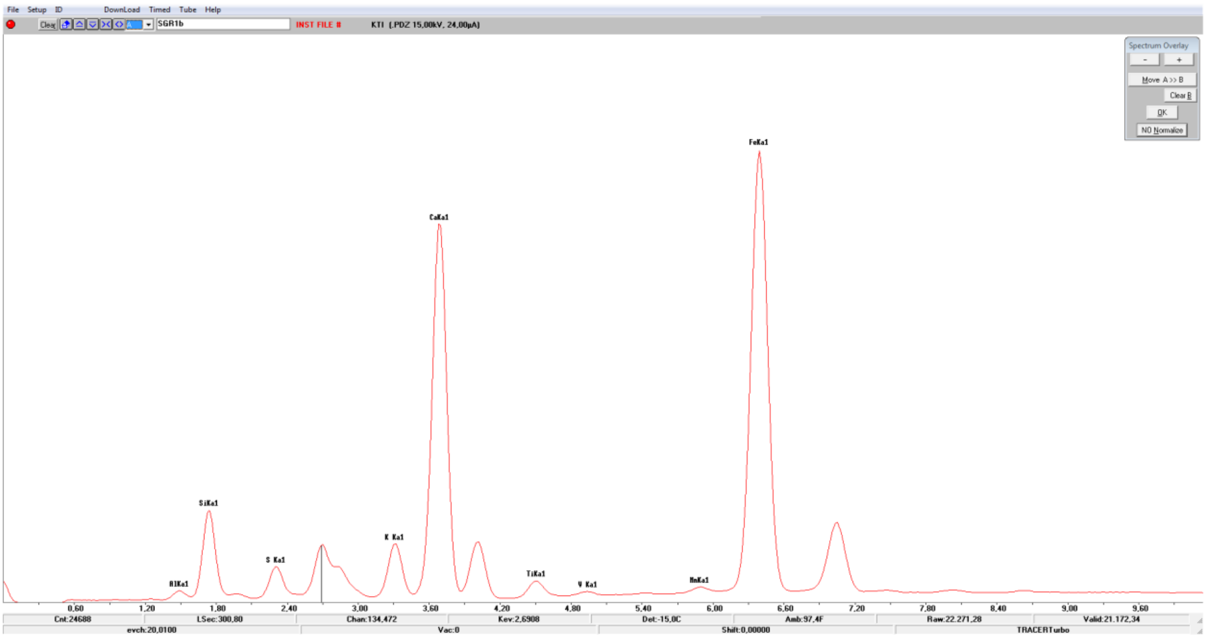


Schipluiden 29454 (blank). yellow filter, single measurement, Compton normalized. Shows a lower iron content relative to the Compton peak. Initial distinction: intermediate.

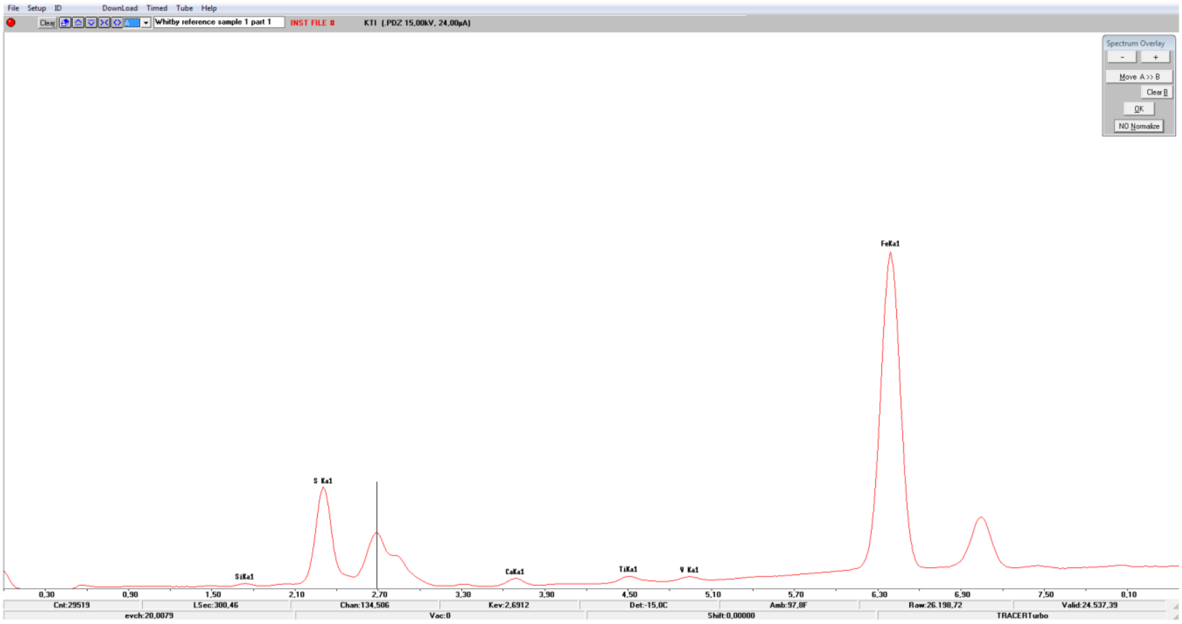
Appendix 2: XRF-spectra of the lighter elements



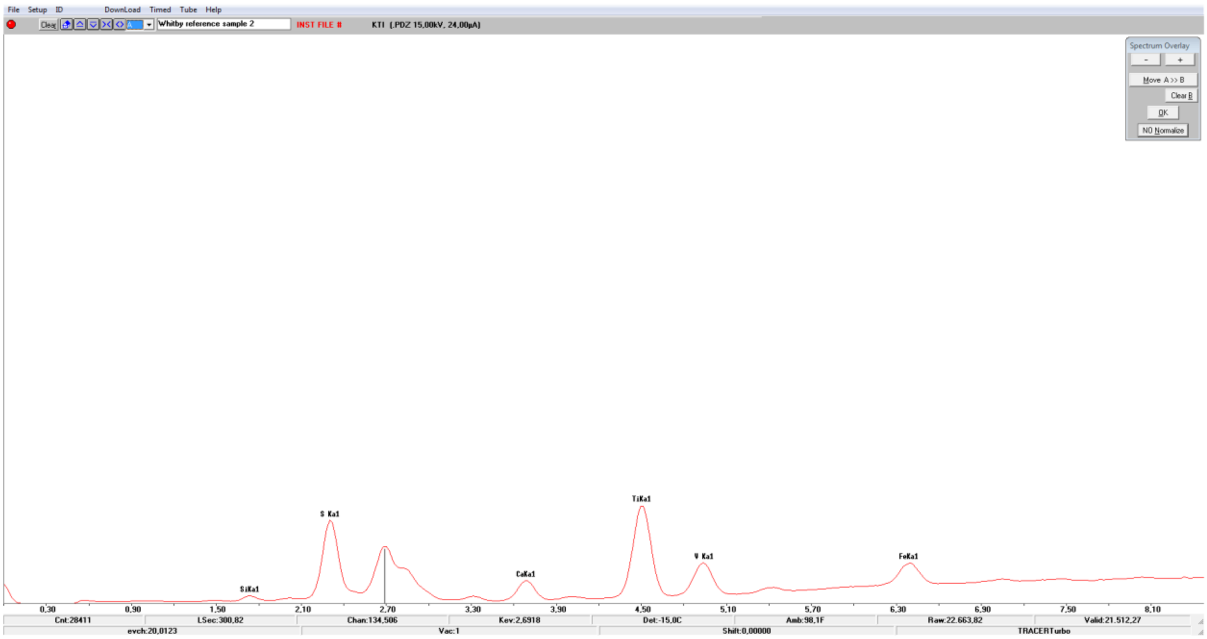
Two vacuum measurement overlapping spectra (red/blue) of montana soil sample 2710 a, RhLα-normalized, taken at the beginning and the end of the measurement. Note that the elemental variation is (nearly) absent here.



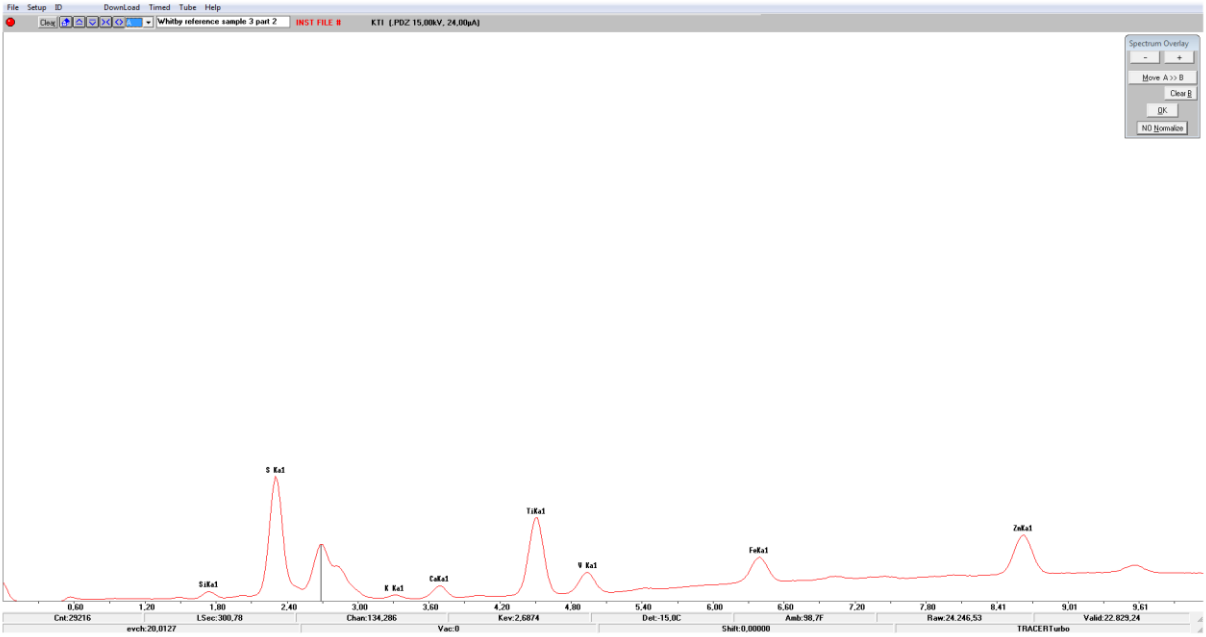
Reference standard SGR-1b (Oil shale). Vacuum, no filter, RhLα-normalized.



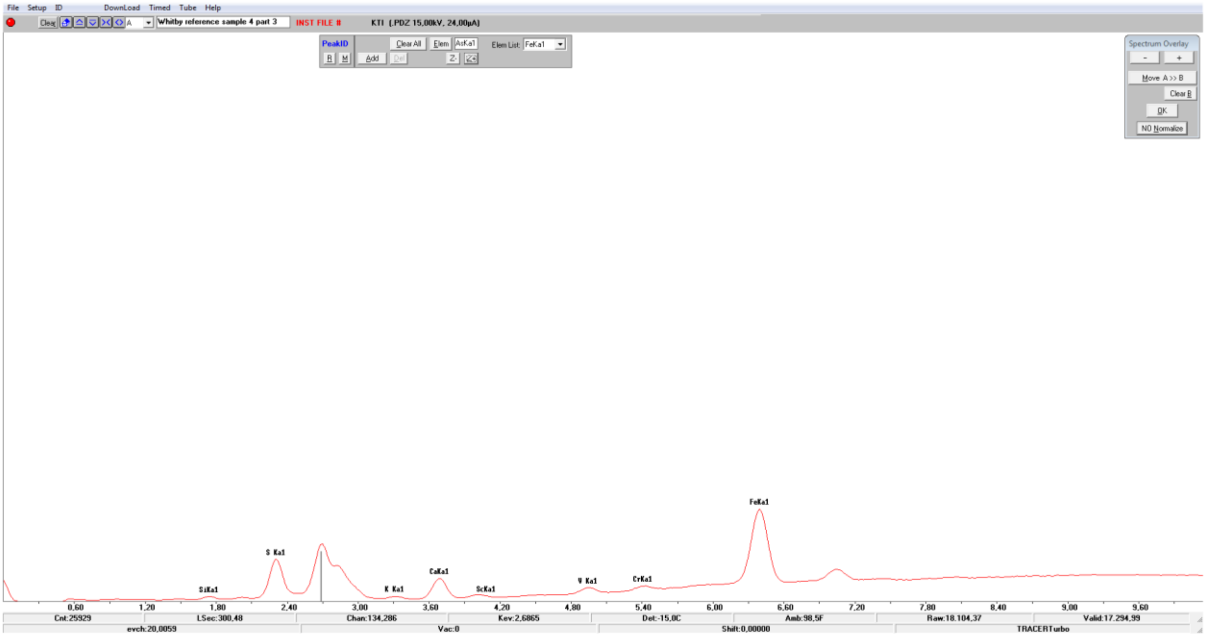
Whiby pebble 1, vacuum no filter, RhLα-normalized.



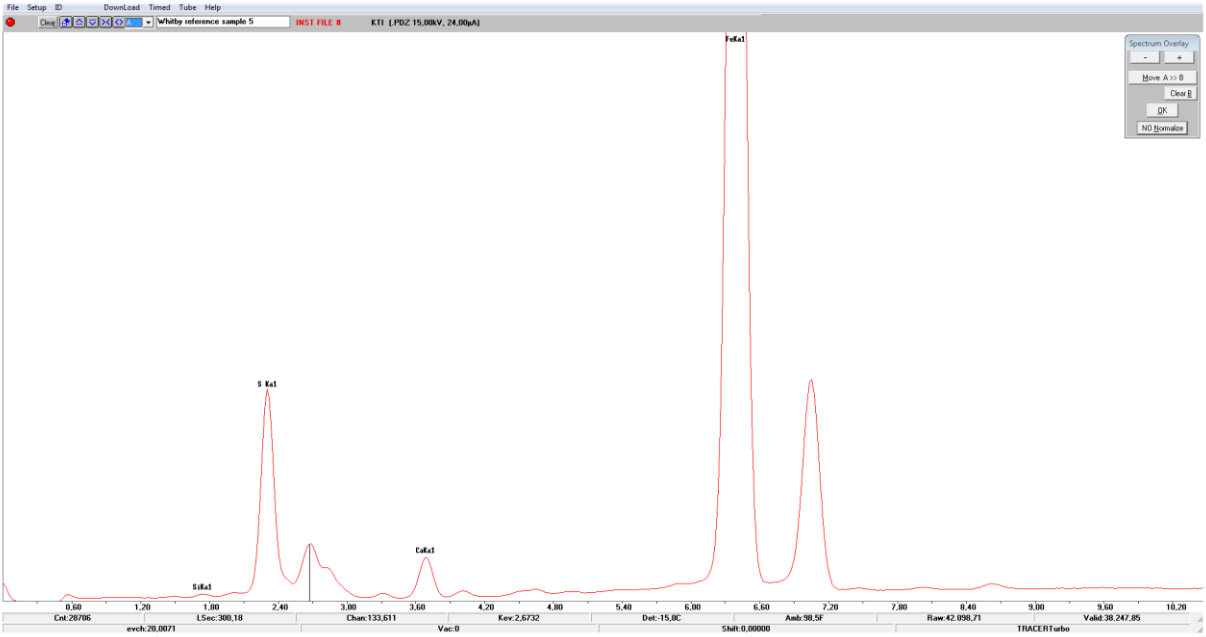
Whiby pebble 2, vacuum no filter, RhLα-normalized.



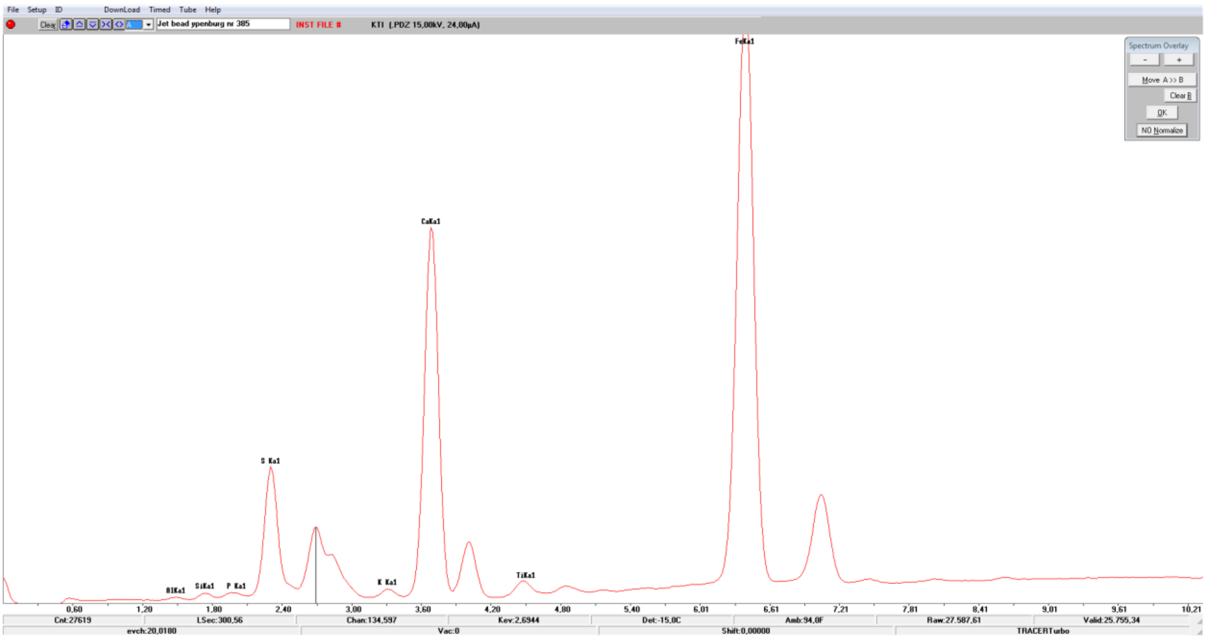
Whiby pebble 3, vacuum no filter, RhLα-normalized.



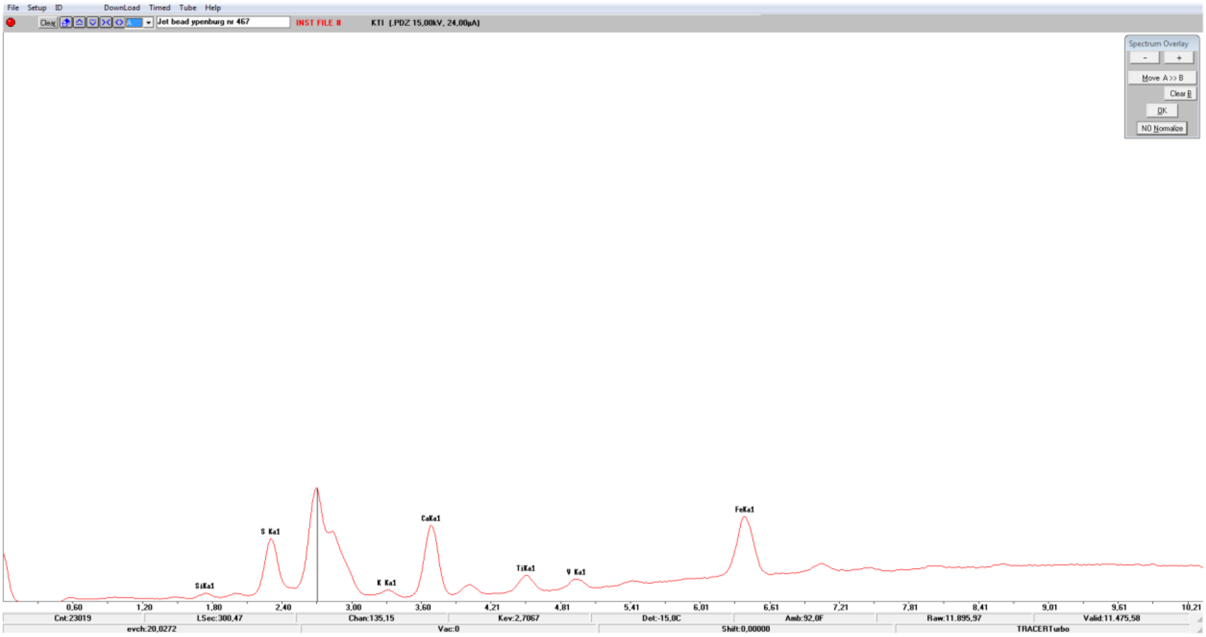
Whiby pebble 4, vacuum no filter, RhLα-normalized.



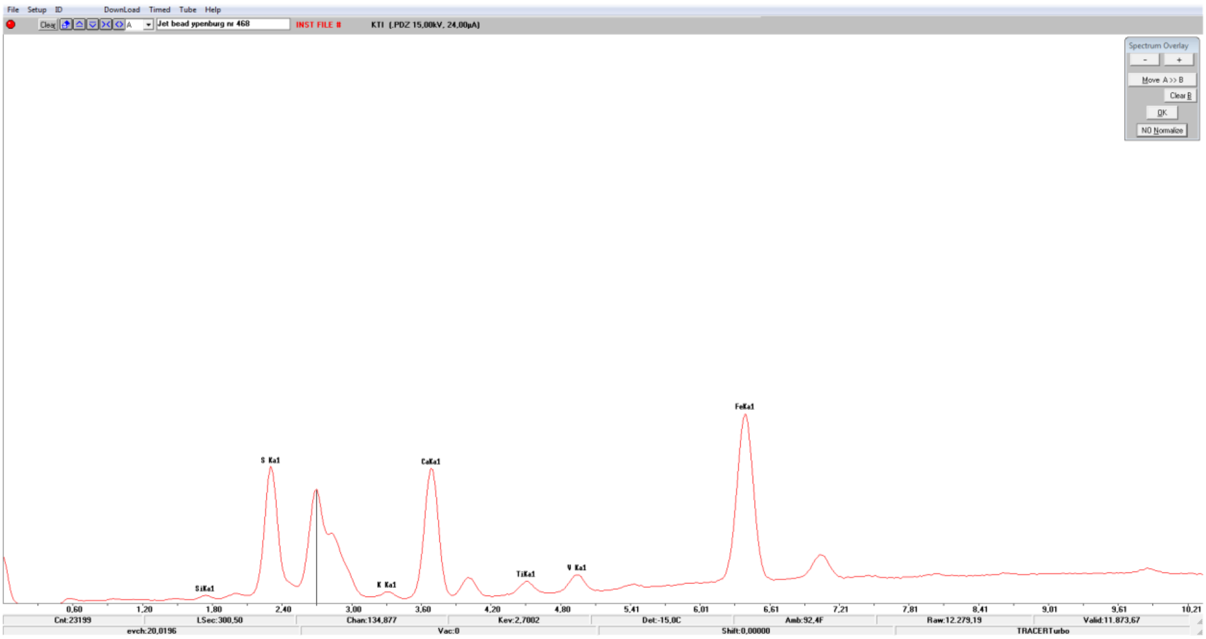
Whiby pebble 5, vacuum no filter, RhLα-normalized.



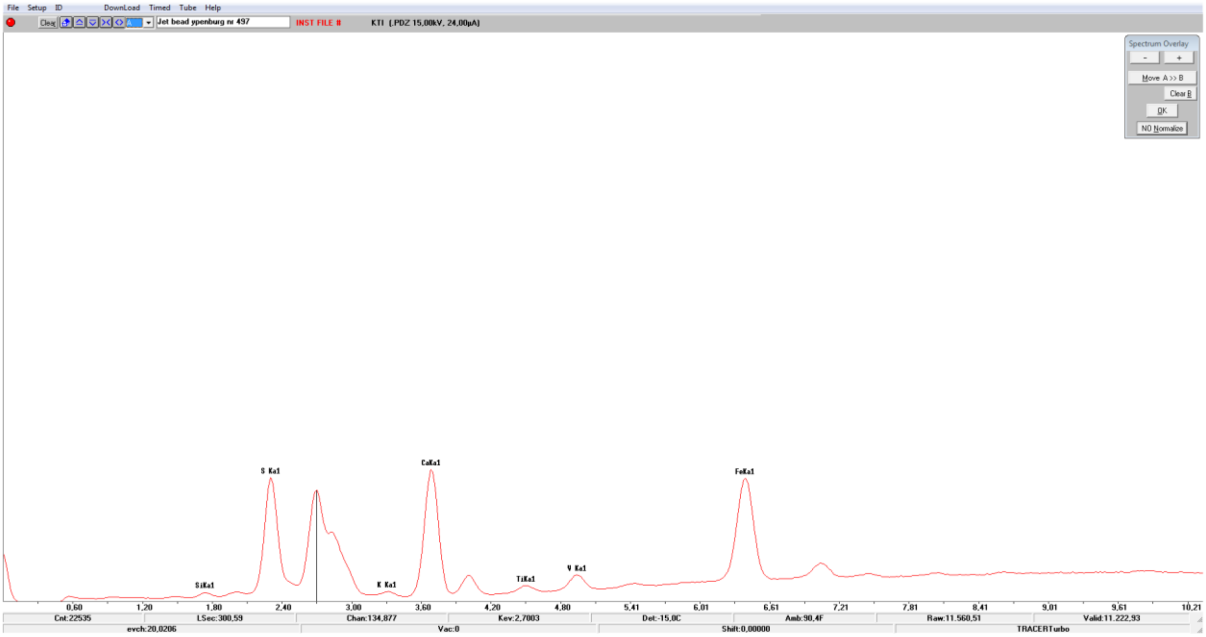
Ypenburg 385 (artifact), vacuum no filter, RhLα-normalized.



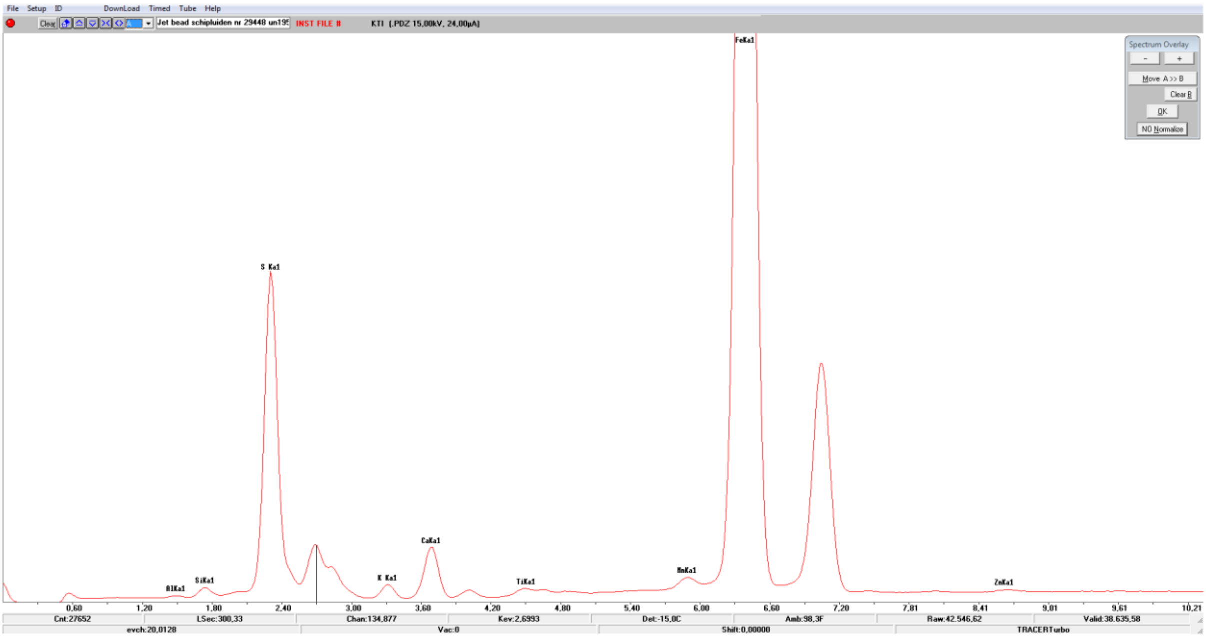
Ypenburg 467 (artifact), vacuum no filter, RhLα-normalized.



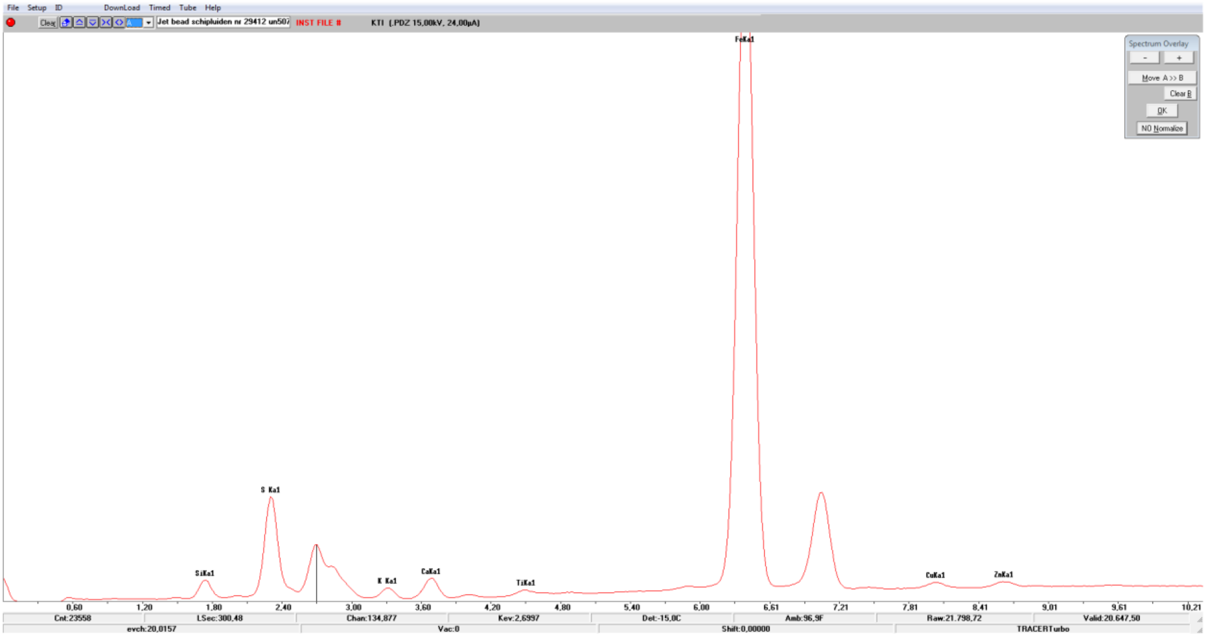
Ypenburg 468 (artifact), vacuum no filter, RhLα-normalized.



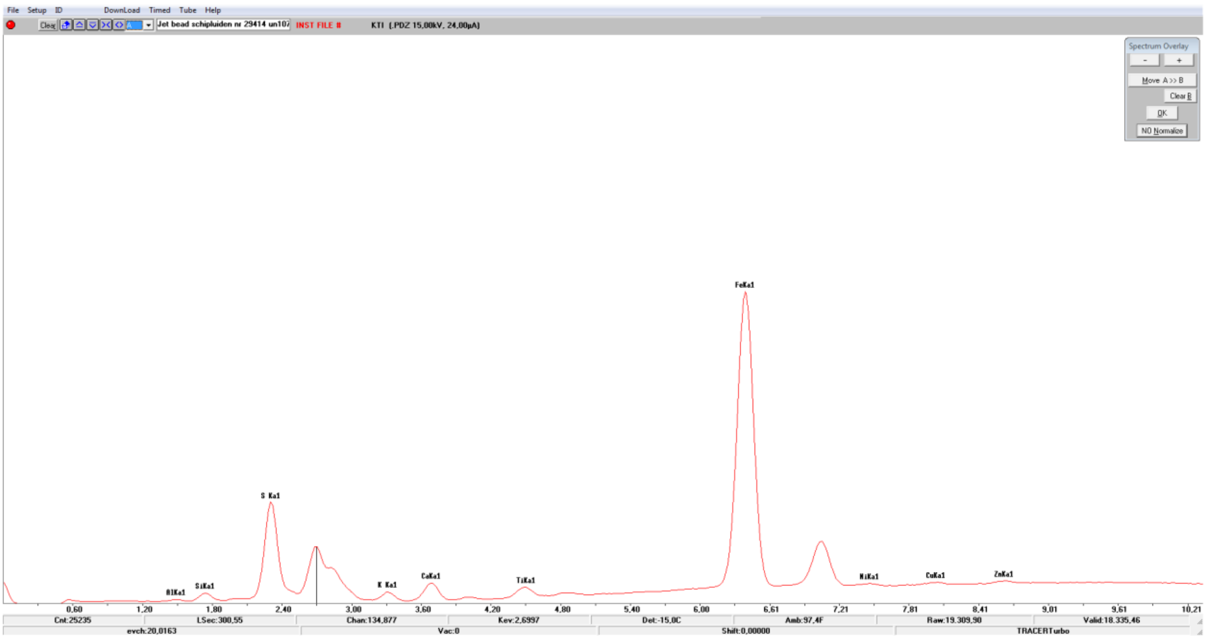
Ypenburg 497 (artifact), vacuum no filter, RhLα-normalized.



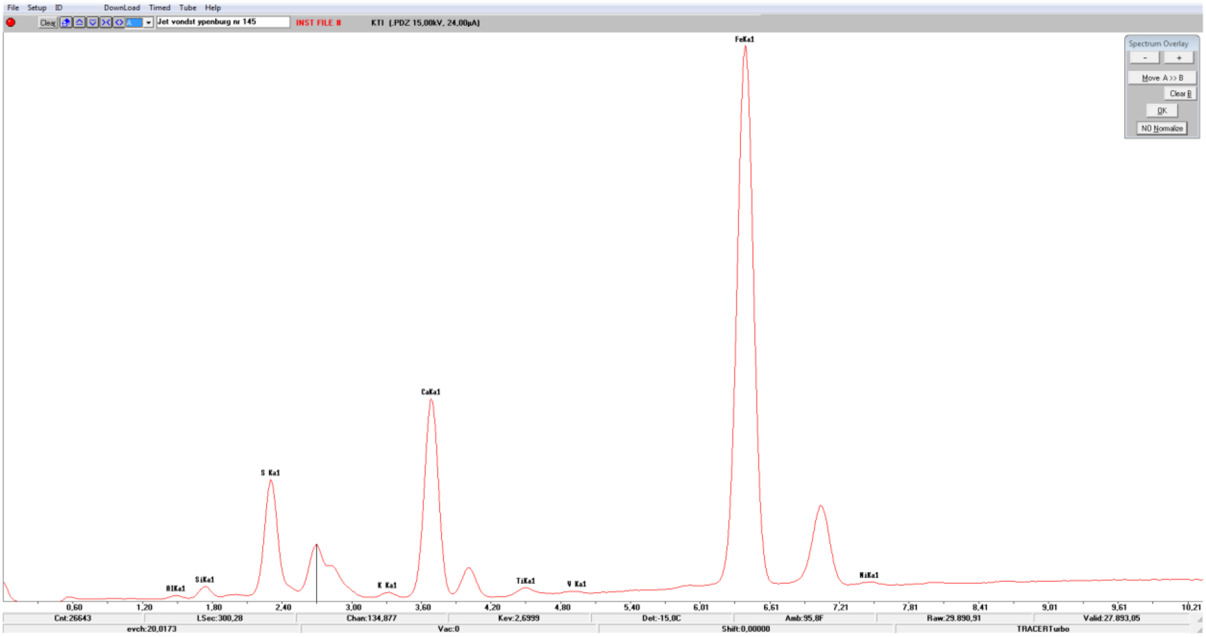
Schipluiden 1954 (artifact), vacuum no filter, RhLα-normalized.



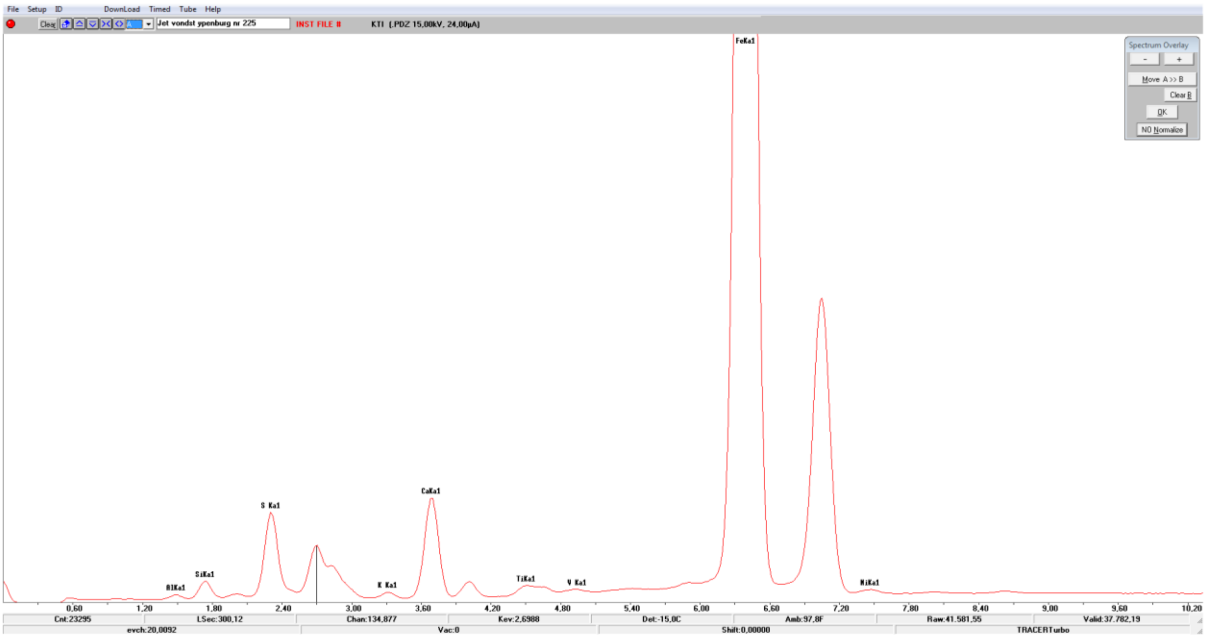
Schipluiden 5067 (artifact), vacuum no filter, RhLα-normalized.



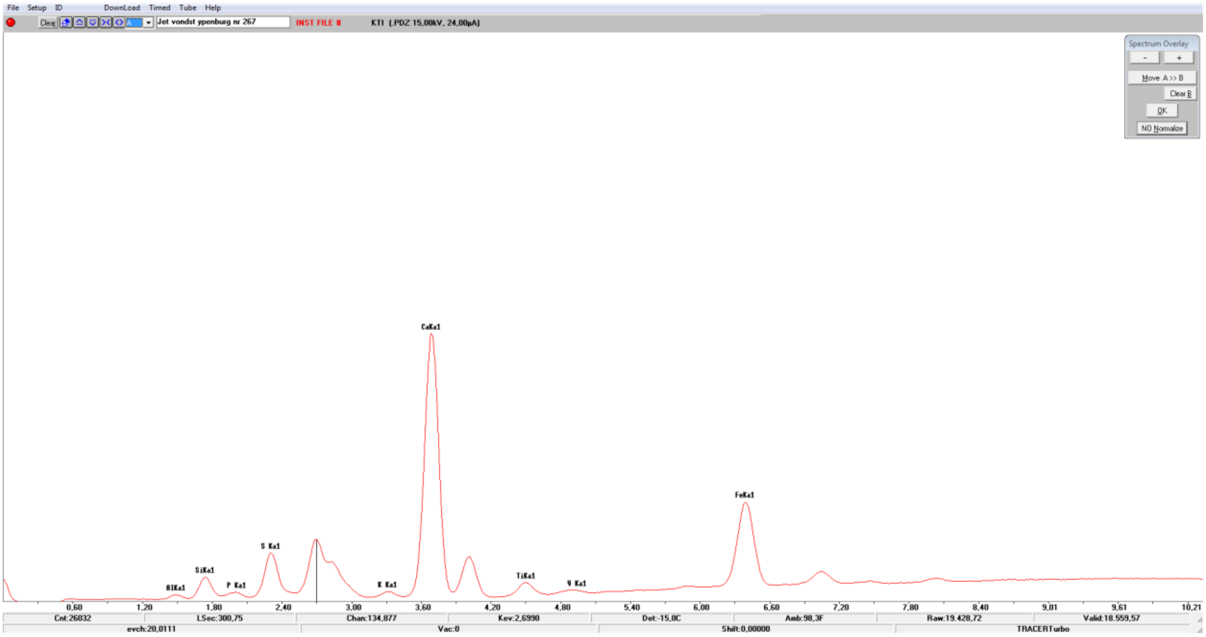
Schipluiden 10764 (artifact), vacuum no filter, RhLα-normalized.



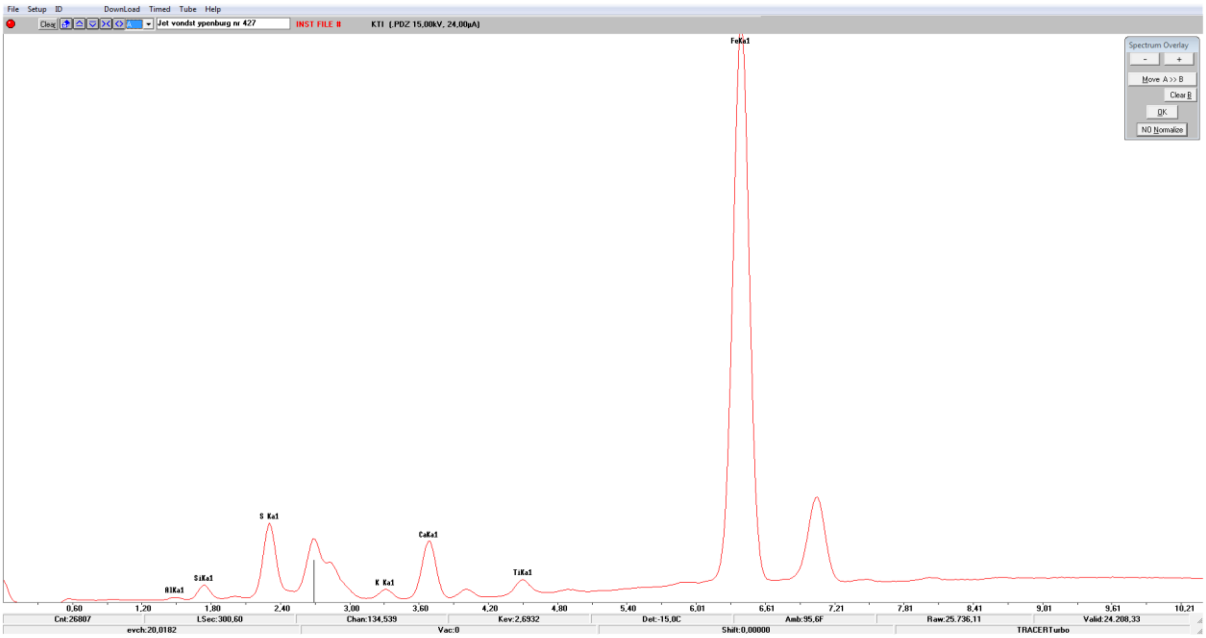
Ypenburg 145 (blanc), vacuum no filter, RhLα-normalized.



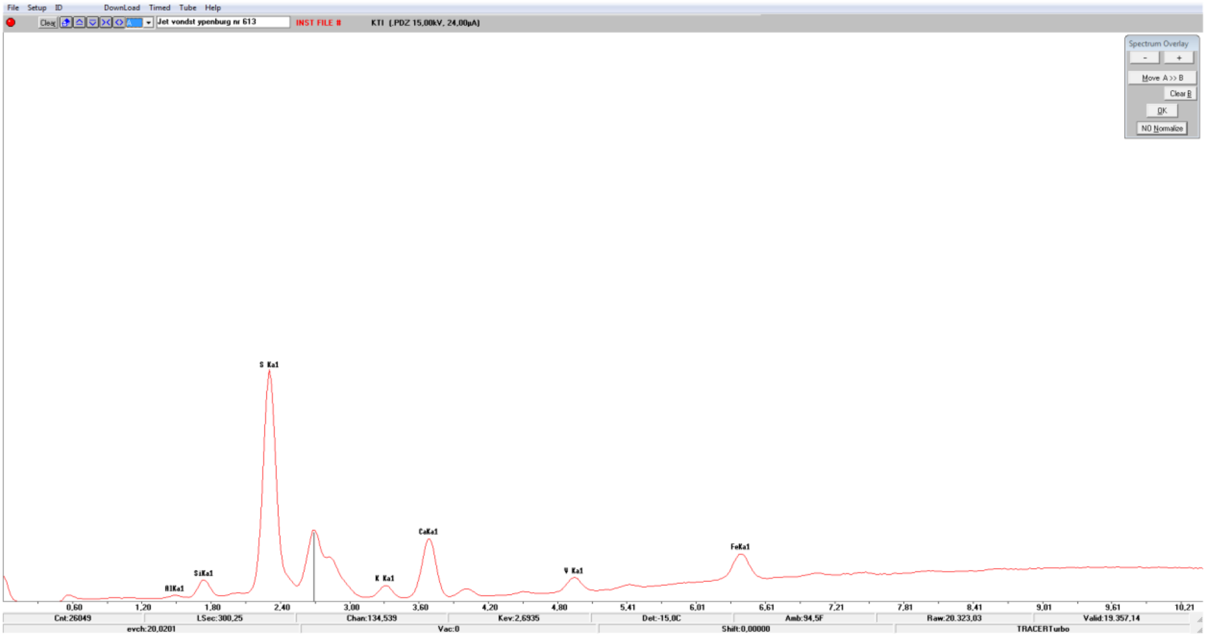
Ypenburg 225 (half product), vacuum no filter, RhLα-normalized.



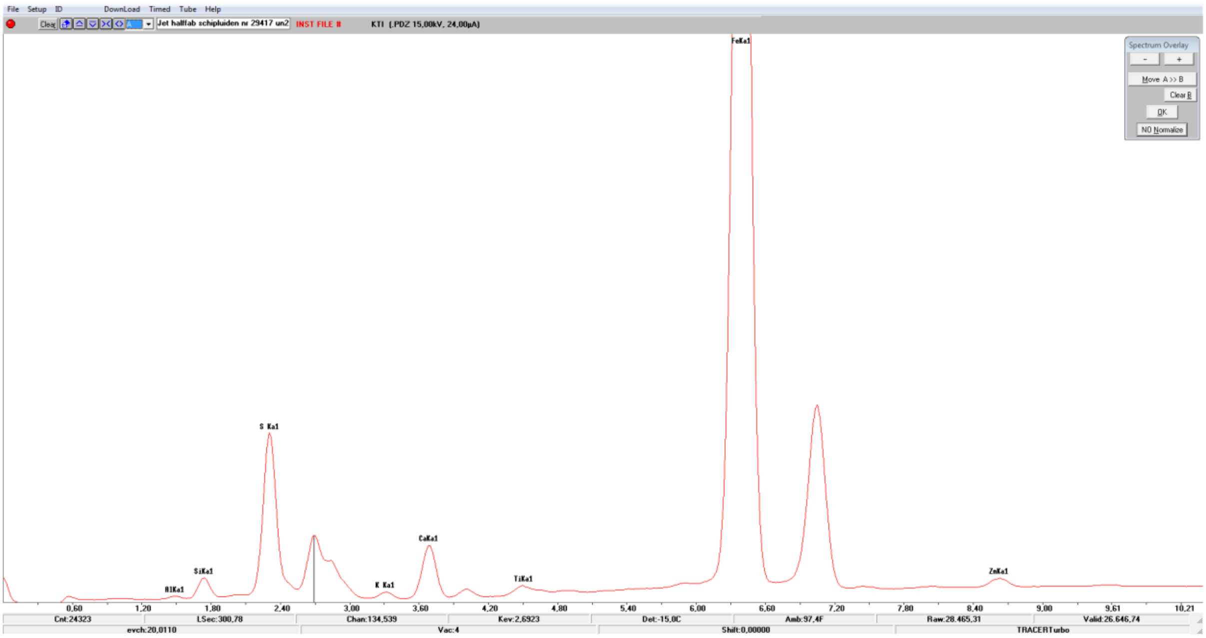
Ypenburg 267 (half product), vacuum no filter, RhLα-normalized.



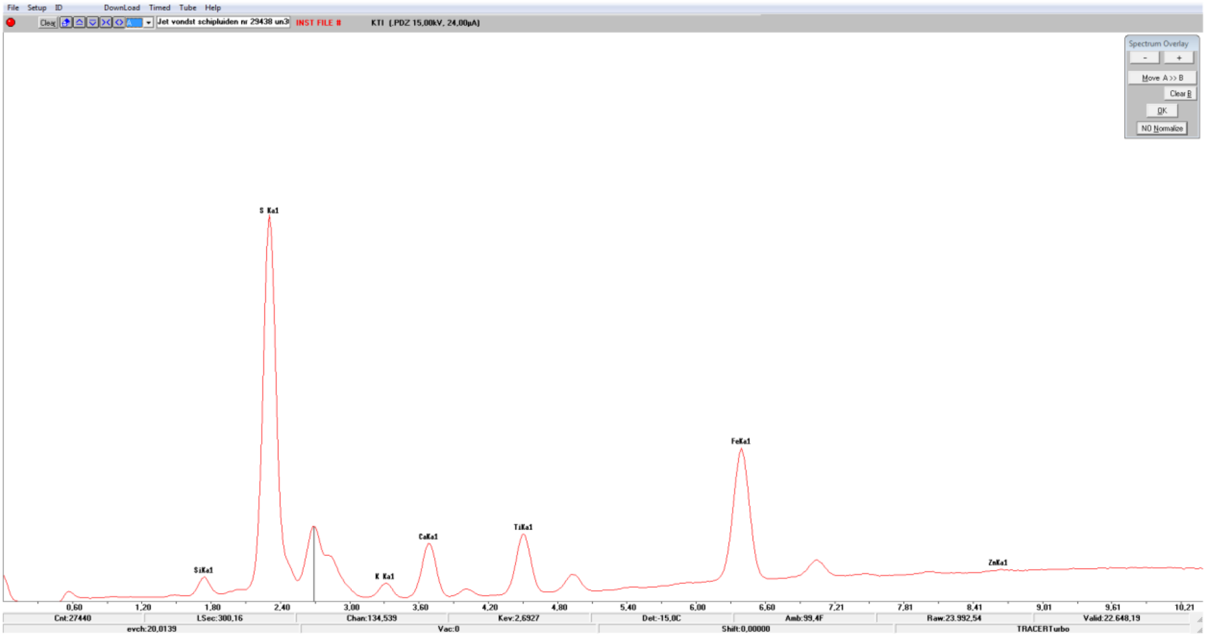
Ypenburg 427 (blank), vacuum no filter, RhLα-normalized.



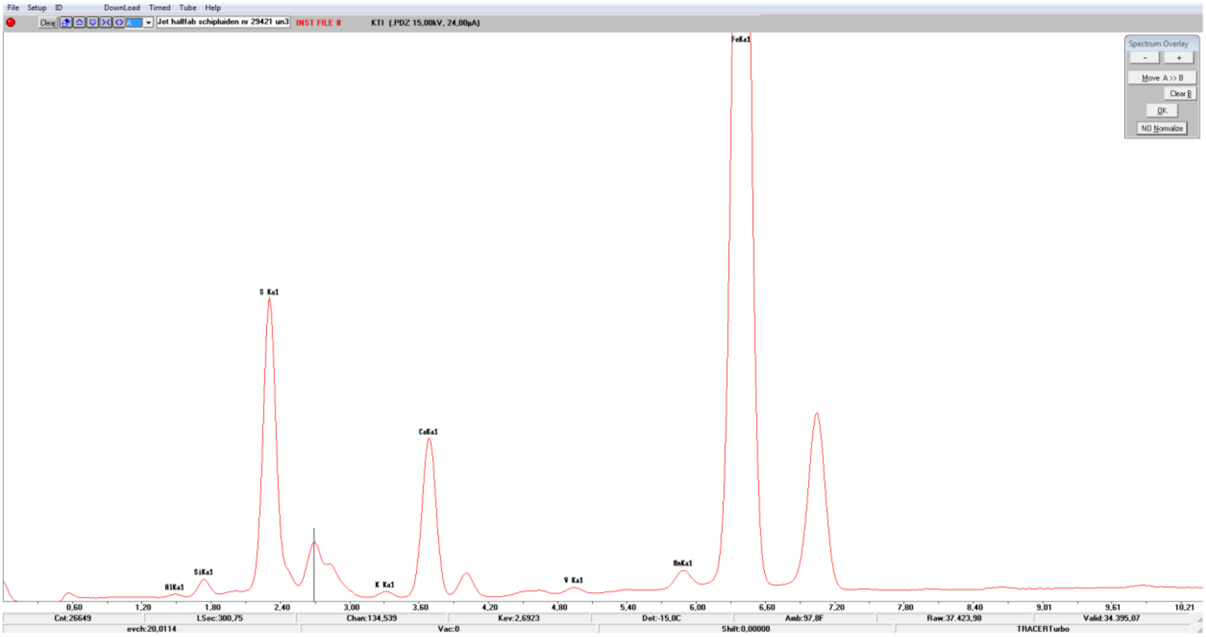
Ypenburg 613 (half product), vacuum no filter, RhLα-normalized.



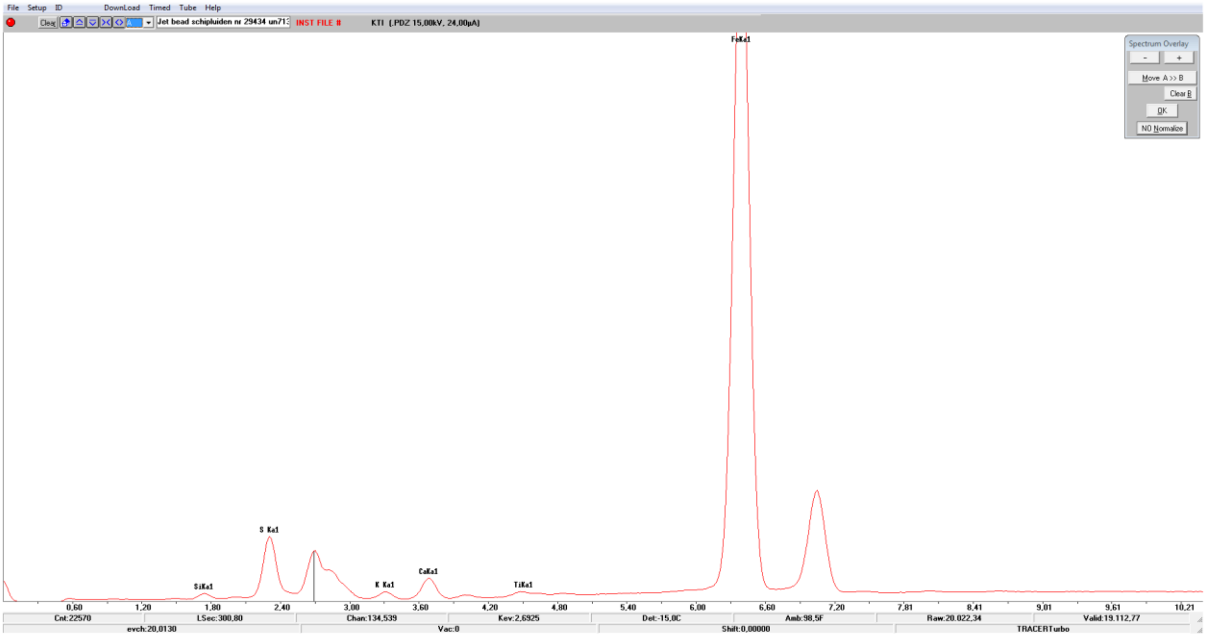
Schipluiden 2488 (half product), vacuum no filter, RhLα-normalized.



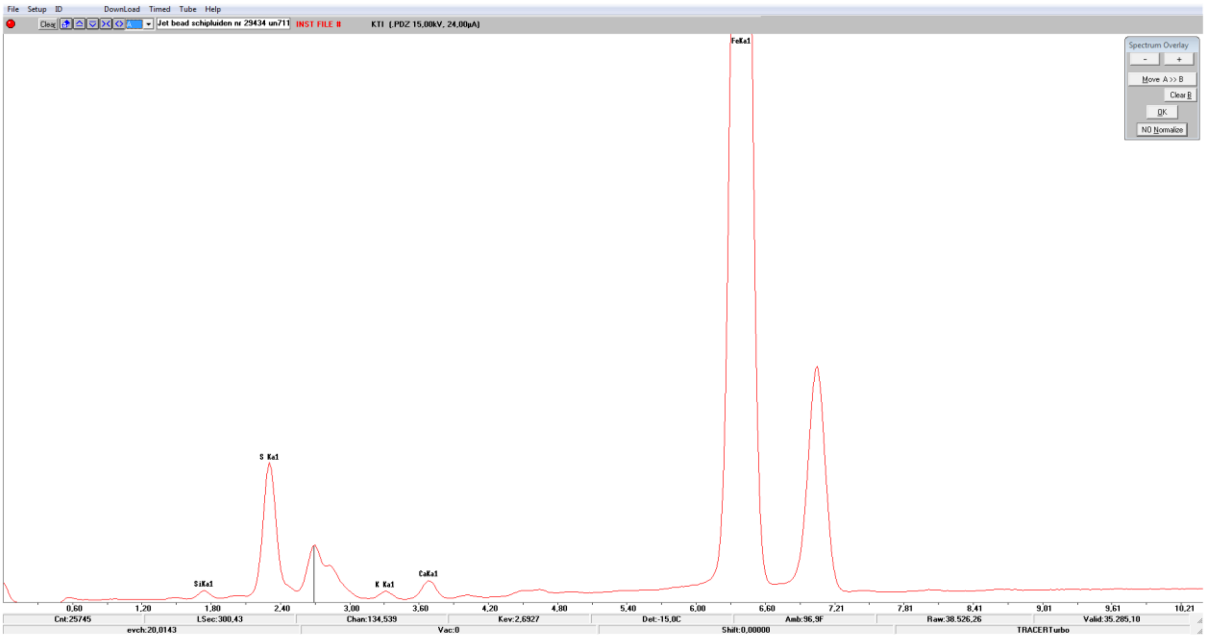
Schipluiden 3622 (half product), vacuum no filter, RhLα-normalized.



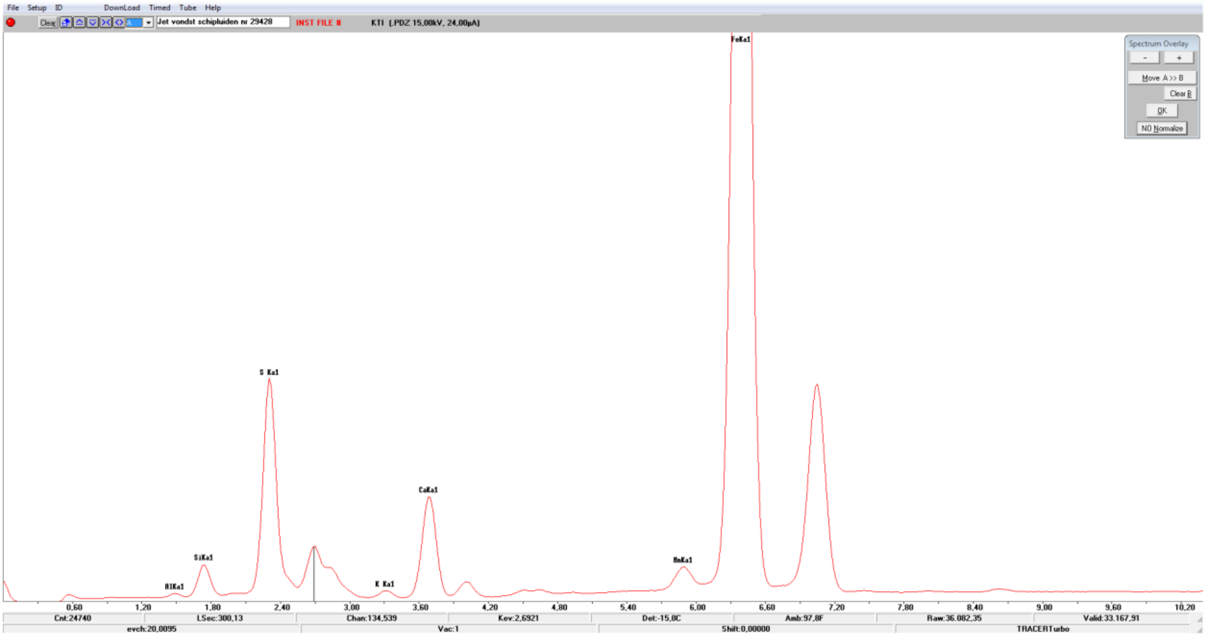
Schipluiden 3565 (half product), vacuum no filter, RhLα-normalized.



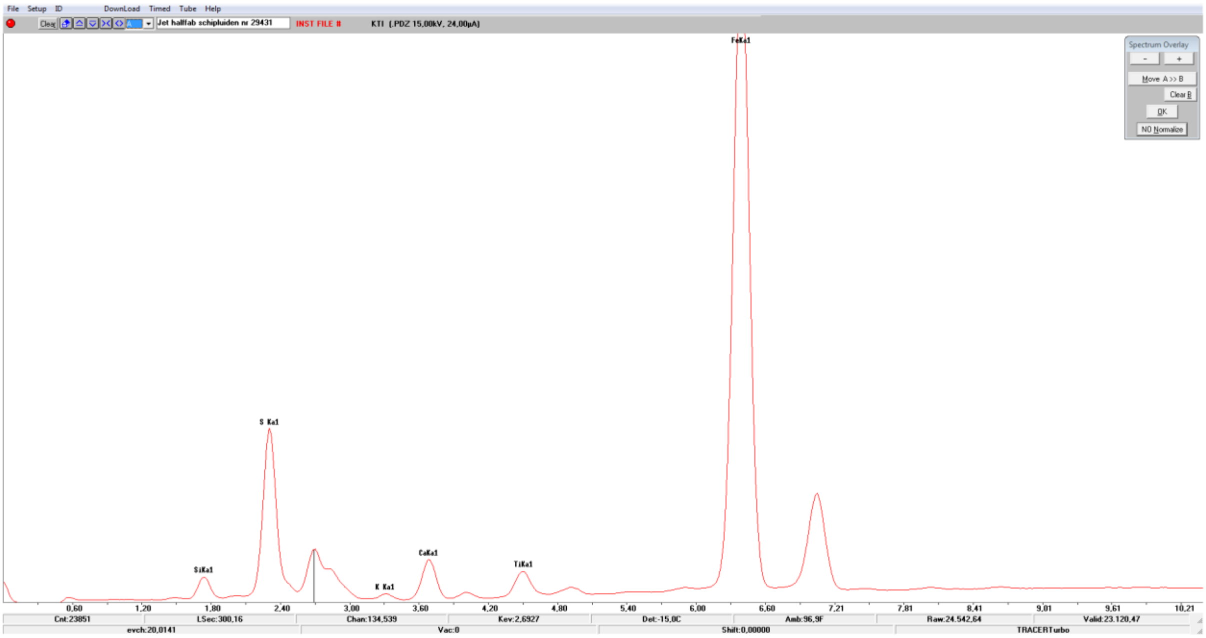
Schipluiden 7131a (half product), vacuum no filter, RhLα-normalized.



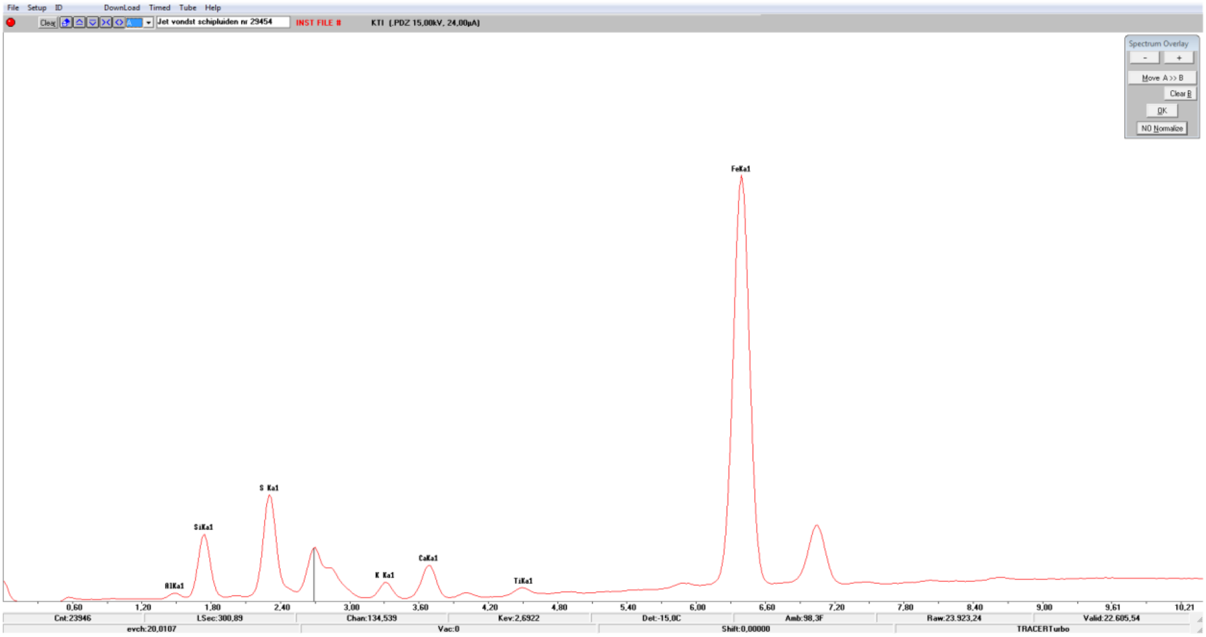
Schipluiden 7131b (half product), vacuum no filter, RhLα-normalized.



Schipluiden 29428 (half product), vacuum no filter, RhLα-normalized.



Schipluiden 29431 (half product), vacuum no filter, RhLα-normalized.



Schipluiden 29454 (blanc), vacuum no filter, RhLα-normalized.