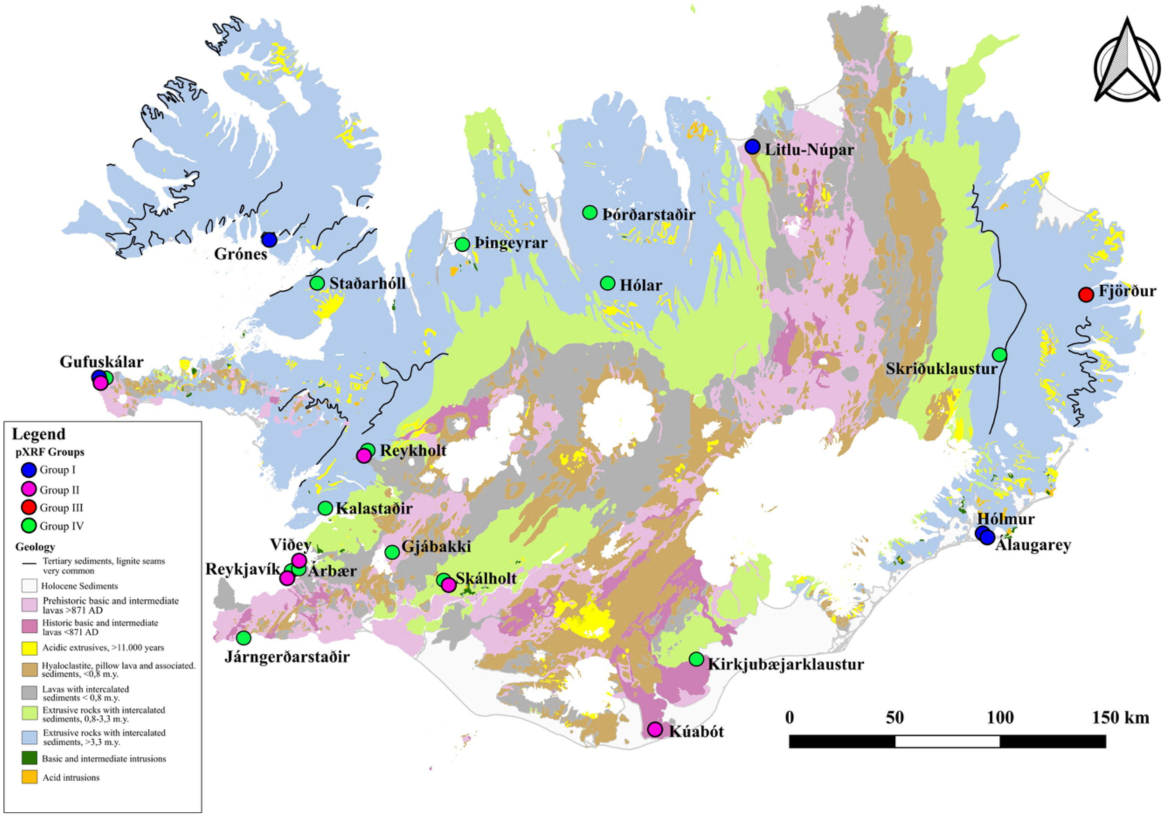
Beads and Bangles in Iceland

A pXRF analysis of black organic beads and armlets found in Iceland



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Fornleifastofnun Íslands ses
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The front-page map shows the known findspots of black beads and armlets in Iceland that are discussed in this report.

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Summary

This report presents the results of a portable X-ray fluorescence (pXRF) study of 71 black organic artefacts - 69 beads and two armlets - recovered from more than 25 sites in Iceland. The assemblage spans a broad chronological range, from the late 9th century through the 20th century, with particular emphasis on finds from late Viking Age and later medieval contexts. The primary aim of the study was to characterise the geochemical composition of these artefacts and to explore potential raw material types and sources, with a focus on distinguishing between different forms of carving coals, mainly jets, lignites and shales.

All artefacts were analysed non-destructively using a Thermo Fisher Scientific Niton XL5 Plus handheld pXRF analyser. Each object was measured two to three times, and where possible both inner and outer surfaces were analysed. Elemental concentrations were considered and manually compared as major and trace elemental pattern combinations, not through singular elements. Comparative data were drawn from published geochemical studies of jet, coal and shale, mainly from Great Britain and Spain, as well as from selected comparative raw material samples measured during the project.

Based on statistically significant differences in major element compositions, the assemblage was divided into four principal geochemical groups. Group I artefacts were characterised by elevated silica and aluminium contents and include two armlets and three atypical beads. These objects were likely made from shale or mineral-rich coal, with several showing geochemical similarities to materials from the Whitby area in Great Britain, although one bead from Gufuskálar may represent a locally sourced Icelandic lignite. Group II artefacts exhibited high sulphur concentrations and are interpreted as being made from coal or jet-like materials, with several showing affinities to Spanish raw materials, particularly from Bocamina, in the Asturias region in Northeastern Spain. Group III consists of two beads from Fjörður in East Iceland with unusually high calcium concentrations, interpreted as coal but without a clear source attribution, possibly Seyðisfjörður lignite. Group IV comprises the majority of the assemblage and includes beads of very high organic purity. While internal variation exists, many of these beads show overall geochemical patterns consistent with jet or relatively pure coal, with potential sources e.g. being Saltwick Bay in Whitby and Llantones in the Asturias region in Northestern Spain, but more data is needed to fully determine their origin.

Introduction

At present, around 70 beads from black organic material have been found during excavation and as stray finds in Iceland, from a total of 25 sites. The focus of this study was to conduct a portable XRF analysis of the whole collection (Tables 1 and A1, Figures 1 and 2). The project, *Rýnt í rafið svarta: Efnagreinin á íslenskum perlum úr lífrænu svörtu efni*, was funded in 2023 by the Archaeological Research Fund (grant no. 202301-0118) of The Cultural Heritage Agency of Iceland. The analysed artefacts consist of 69 black beads and two armlets dated from the late Viking Age (late 9th to 11th century) and up to the 20th century. The bead assemblage has already been analysed with regard to typology by Elín Ósk Hreiðarsdóttir[1] (Figure 1 and Table 1). The artefacts were analysed with a Niton XL5 Plus pXRF device owned by the Archaeology Department at the University of Iceland. Five beads (from Árbær, Gufuskálar no. 1207 and 253 and Skálholt (no. 663, 2392 and 2971) were first analysed in 2021[2], while the remaining artefacts were analysed in 2023 with that same device at the National Museum of Iceland. The beads derive from contexts dating from the Settlement of Iceland in the late 9th century up to the 20th century.

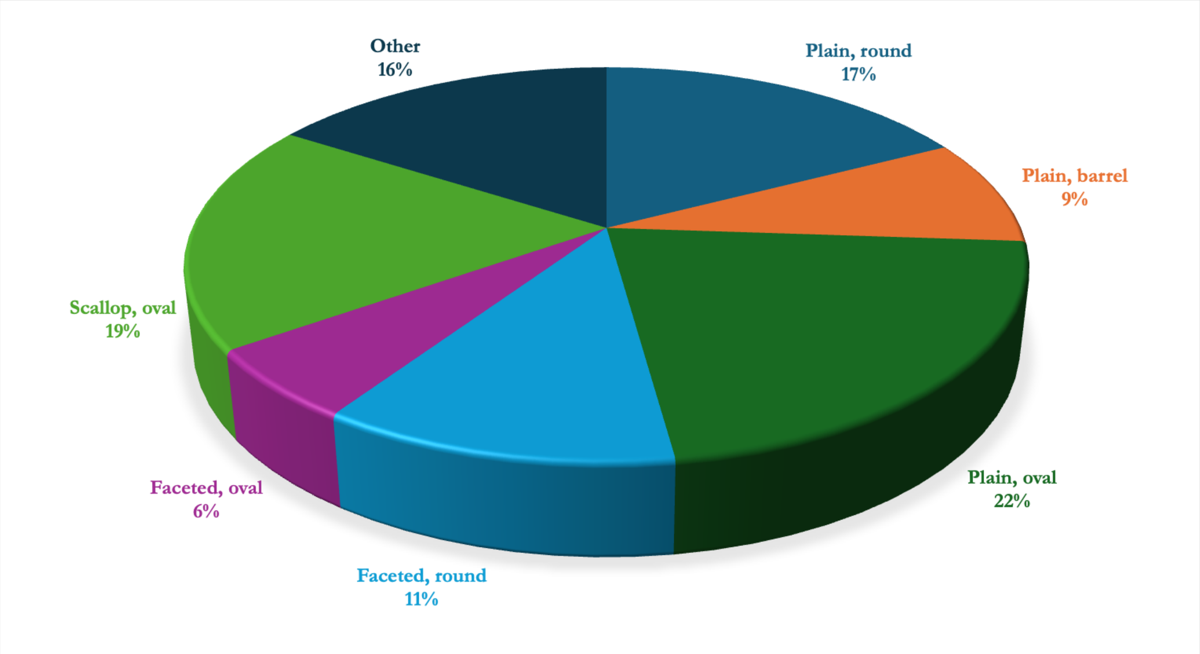

Figure 1. *A coarse overview of the main shapes of beads in the analysed assemblage. Elín Ósk Hreiðarsdóttir (2005-2025) analysed the beads´ typology.*

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[1] Elín Ósk Hreiðarsdóttir 2005, MA. Thesis, University of Iceland; 2025, Unpuplished analyses of artefacts from excavations between 2005-2025.

[2] Elín Ósk Hreiðarsdóttir 2024, pp. 244-245.

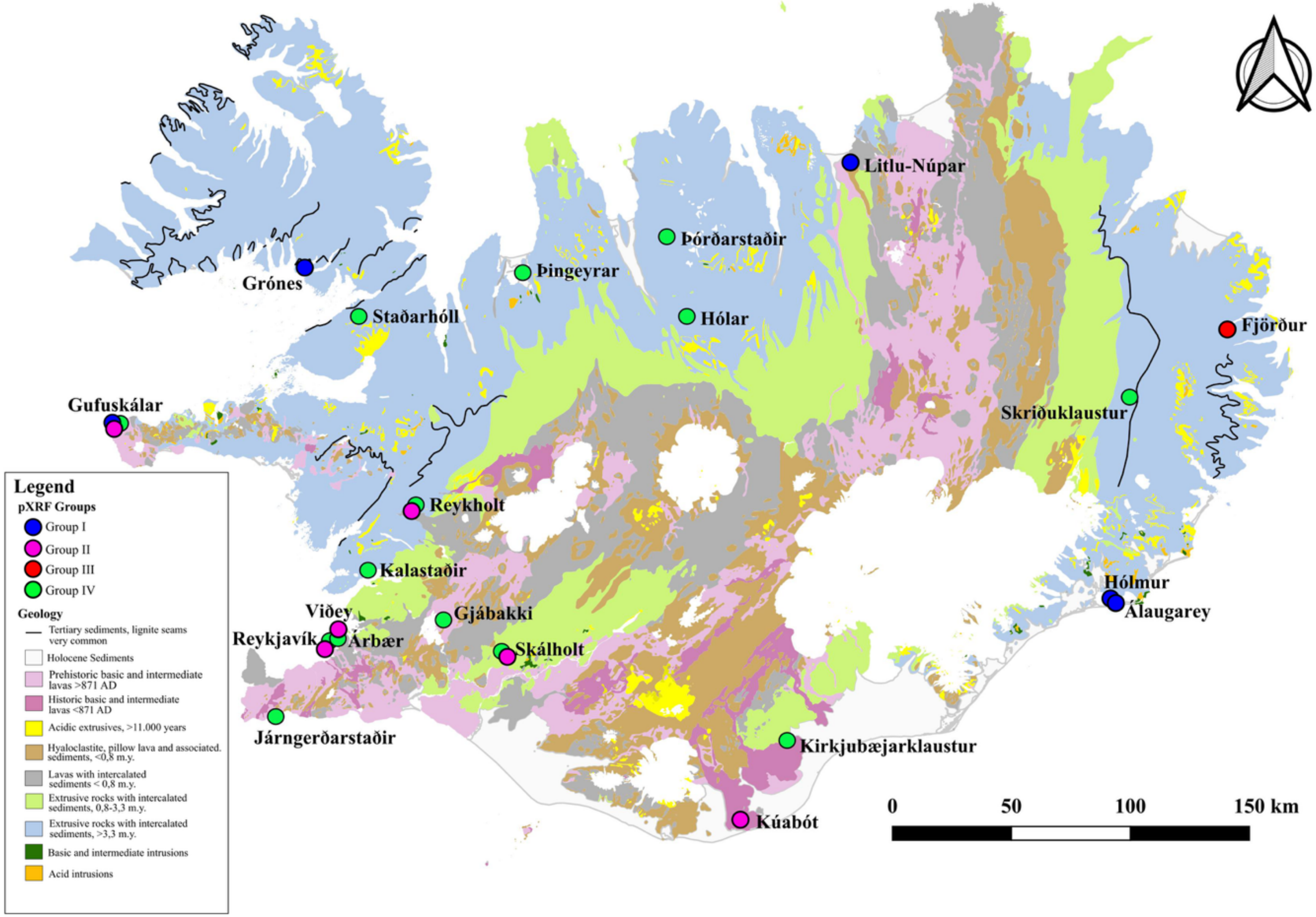

Figure 2. *The find spots of the majority of black organic beads and armlets measured with pXRF during the research. Original location of four finds is unknown and only marked as being found in Iceland (see tables 1 and A1; Geological map base is available online through Náttúrufræðistofnun, 2025).*

Table 1. *Artefacts analysed with the Niton XL5 Plus pXRF in this project and their elemental pattern groups.*

Location	Finds no.	Find Type	Time Period	Site Type	Shape	Surface	Group
Grónes	2021-46-046	Armlet	870-1000 AD	Norse settlement site, late Viking Age	Circle, broken	Plain	Ia
Álaugarey	Þjms. 11565b	Armlet	870-1000 AD	Norse Burial, late Viking Age	Circle, whole	Plain	Ib
Litlu-Núpar	2007-141	Bead, large	870-1000 AD	Norse Burial, late Viking Age	Cylinder	Plain	Ib
Hólmur	2001-34-60	Bead	870-1200 AD	Norse settlement site, late Viking Age	Cylinder	Plain	Ic
Gufuskálar	2013-36-1276	Bead	1450-1500 AD	Fishing station	Irregular Rounded	Triangular	Id
Reykjavík, Alþingishúsreitur	2009-32-1393	Bead	870-1900 AD	Urban activity site	Round	Plain	IIa
Reykjavík, Alþingishúsreitur	1999-424	Bead	1500-1900 AD	Urban activity site	Oval	Scallop	IIa
Skálholt	2002-64-663	Bead	1800-1830 AD	Ecclesiastical site, farm and school	Flat	Faceted ends	IIa
Reykholt	2000-6-49	Bead	1700-1800 AD	Ecclesiastical site, farm	Flat	Faceted ends	IIa
Gufuskálar	2013-36-1207	Bead	1400-1800 AD	Fishing station	Oval	Spiral	IIb
Kúabót	1975-615-46/884	Bead	1300-1500 AD	Medieval farm, church	Round	Plain	IIb
Viðey	V90-41	Bead	1200-1800 AD	Ecclesiastical site	Oval	Boat/Leaf	IIb
Viðey	1989-153-57108	Bead	1200-1800 AD	Ecclesiastical site	Barrel	Ridged	IIb
Fjörður	2021-28-335	Bead	900-1000 AD	Norse Boat Burial, late Viking Age	Oval	Plain	III
Fjörður	2021-28-347	Bead	900-1000 AD	Norse Burial, late Viking Age	Oval	Plain	III
Kirkjubæjarklaustur	2002-70	Bead	1600-1700 AD	Ecclesiastical site	Oval	Plain	IVa
Árbær, Reykjavík	2021-20-71	Bead	1800-1900 AD	Farm mound, midden	Oval	Faceted	IVa
Reykholt	2003-25-91	Bead	1778-1835 AD	Ecclesiastical site, church	Oval	Scallop	IVa
Reykholt	2004-25-308	Bead/Button	1500-1800 AD	Ecclesiastical site, church	Hemishpere, split bead	Faceted	IVa
Hólar	2009-37-11790	Bead	1000-1800 AD	Ecclesiastical site	Round	Plain	IVa
Hólar	2009-37-11224	Bead	1000-1800 AD	Ecclesiastical site	Oval	Plain	IVa
Hólar	2002-37-1368	Bead	1000-1800 AD	Ecclesiastical site	Oval	Faceted	IVa
Staðarhóll	2021-52-1a	Bead	1500-1900 AD	Farm mound, unstratified	Round	Flower	IVa
Skálholt 1954	S229	Bead	1000-1900 AD	Ecclesiastical site, church, unstratified	Oval	Plain	IVa

Iceland, Ásbúðarsafn	Ásb-1	Bead, group	1500-1900 AD	Not from an archaeological context	Round	Faceted	IVa
Iceland, Ásbúðarsafn	Ásb-4	Bead, group	1500-1900 AD	Not from an archaeological context	Round	Faceted	IVa
Kalastaðir	884-3	Bead, group	1500-1900 AD	Stray find	Oval	Plain	IVb
Kalastaðir	884-4	Bead, group	1500-1900 AD	Stray find	Oval	Plain	IVb
Kalastaðir	884-5	Bead, group	1500-1900 AD	Stray find	Oval	Plain	IVb
Kalastaðir	884-6	Bead, group	1500-1900 AD	Stray find	Oval	Plain	IVb
Kalastaðir	884-8	Bead, group	1500-1900 AD	Stray find	Oval	Faceted	IVb
Kalastaðir	884-9	Bead, group	1500-1900 AD	Stray find	Oval	Plain	IVb
Kalastaðir	884-10	Bead, group	1500-1900 AD	Stray find	Oval	Plain	IVb
Kalastaðir	884-11	Bead, group	1500-1900 AD	Stray find	Oval	Plain	IVb
Skálholt 1954	S220	Bead	1600-1700 AD	Christian grave	Round	Plain	IVb
Skálholt 1954	S230	Bead	1000-1900 AD	Church, unstratified	Barrel	Plain	IVb
Skriðuklaustur	2004-36-1680	Bead	1493-1554 AD	Ecclesiastical site	Barrel	Plain	IVb
Skriðuklaustur	2004-36-1718	Bead	1493-1554 AD	Ecclesiastical site	Barrel	Plain	IVb
Iceland, Skaftafellssýsla	Þjms. 3911	Bead	1000-1900 AD	Stray find	Barrel	Plain	IVb
Þingeyrar	2018-28-567	Bead	1100-1800 AD	Ecclesiastical site, unstratified	Round	Plain	IVb
Hólar	1179-1	Bead	1000-1800 AD	Ecclesiastical site, unstratified	Barrel	Plain	IVb
Hólar	1179-2	Bead	1000-1800 AD	Ecclesiastical site, unstratified	Barrel	Plain	IVb
Hólar	2009-37-11792	Bead	1000-1800 AD	Ecclesiastical site, unpublished	Oval	Plain	IVb
Hólar	2009-37-11218	Bead	1000-1800 AD	Ecclesiastical site, unpublished	Round	Plain	IVb
Hólar	2009-37-11214	Bead	1000-1800 AD	Ecclesiastical site, unpublished	Round	Plain	IVb
Iceland, Ásbúðarsafn	Ásb-3	Bead, group	1500-1900 AD	Not from archaeological context	Round	Faceted	IVb
Skálholt	2003-64-2971	Bead	1900-1930 AD	Ecclesiastical site, farm and school, disturbed context	Round	Faceted	IVb
Staðarhóll	2021-52-1b	Bead	1500-1900 AD	Farm mound, unstratified	Round	Plain	IVb
Iceland	Þjms. 5918	Bead	1000-1900 AD	Stray find	Oval	Scallop	IVb
Þórðarstaðir	Þjms. 5253	Bead, large	1000-1900 AD	Stray find	Rectangle	Bevelled	IVb

Járngerðarstaðir	Þjms. 345	Bead	1000-1900 AD	Stray find	Oval	Scallop	IVb
Gjábakki	Þjms. 344	Bead	1000-1900 AD	Stray find	Oval	Scallop	IVb
Gufuskálar	2015-40-2030	Bead	1400-1800 AD	Fishing station	Round	Plain	IVb
Reykholt	2006-25-304	Bead	1200-1500 AD	Ecclesiastical site, church	Oval	Scallop	IVb
Reykholt	2005-25-336	Bead	1400-1600 AD	Ecclesiastical site, church	Oval	Ridged	IVb
Reykholt	2005-25-126	Bead	1400-1600 AD	Ecclesiastical site, church	Oval	Scallop	IVb
Reykholt	2004-25-047	Bead	1500-1800 AD	Ecclesiastical site, church	Oval	Faceted	IVb
Reykholt	2004-25-111	Bead	1500-1800 AD	Ecclesiastical site, church	Oval	Scallop	IVb
Reykholt	2004-25-128	Bead	1500-1800 AD	Ecclesiastical site, church	Oval	Scallop	IVb
Reykholt	2003-25-147	Bead	1778-1835 AD	Ecclesiastical site, church	Oval	Scallop	IVb
Reykholt	2002-25-142	Bead	1778-1835 AD	Ecclesiastical site, church	Oval	Scallop	IVb
Reykjavík, Alþingishúsreitur	2009-2856	Bead	870-1900 AD	Urban activity site	Round	Plain	IVb
Árbær, Reykjavík	2021-20-043	Bead	1800-1900 AD	Farm mound, midden	Round	Faceted	IVc
Árbær, Reykjavík	2019-36-026	Bead	1800-1900 AD	Farm mound, midden	Round	Faceted	IVc
Kalastaðir	884-1	Bead, group	1500-1900 AD	Stray find	Oval	Plain	IVc
Skálholt	2003-64-2392	Bead	1760-1780 AD	Ecclesiastical site, farm and school	Round	Plain	IVc
Gufuskálar	2011-253	Bead	1400-1800 AD	Fishing station	Round	Plain	IVc
Skriðuklaustur	2003-36-400	Bead	1500-1600 AD	Ecclesiastical site	Oval	Scallop	IVc
Reykholt	2006-25-181	Bead	1778-1835 AD	Cemetery, grave A007	Oval	Scallop	IVc
Skálholt 1954	S217	Bead	1200-1600 AD	Ecclesiastical site, church choir	Oval	Plain	IVc
Skálholt 1954	S218	Bead	1200-1600 AD	Ecclesiastical site, church choir	Round	Faceted	IVc

Methods

The Niton XL5 Plus and the Measurements

For the geochemical analysis of the artefacts a Thermo Fisher Scientific$^{\text{TM}}$, Niton$^{\text{TM}}$ XL5 Plus handheld XRF analyser was used. The device has a 6-50kV/500uA 5W X-ray tube with standard 8 mm beam collimation, with an Ag-anode and a GOLDD detector. The tube is protected with a <4μm thick prolene window. The standard mining calibration mode (FP calibr.) was used which is designed for scanning unknown samples, and can be used e.g. in oil and gas exploration, mineral discovery, mining operations, museum conservation and archaeology. In mining mode, the XL5 Plus uses 4 filters on a position filter wheel to scan for 41 elements from Mg to U. Their limits of detection (LOD) are calculated as 3STD (99.7% confidence interval) for each element. Limits of detection for each element are recorded in Table A1.

The artefacts were all analysed without surface cleaning. For analysis they were positioned on a makeshift plastic stage and situated before the aperture with the aid of acid free paper. Every artefact was measured 2-3 times at different surface points on average for about 125 seconds each time. Surfaces chosen for analysis were always pristine areas without any visible flaws or blemishes but potential for micro flaws and/or damage due to burial could not be eliminated. A comparative sample of Whitby jet (SSI.10) was kindly provided by Sarah Caldwell Steele, director of The Ebor Jetworks Ltd in Whitby, United Kingdom.

The initial semi-quantitative measurements were expressed in ppm. For data representation, comparison and interpretation the main elements were recalculated manually to oxides (wt%) in Excel, while trace element concentrations are expressed in parts per million (ppm) or, in a few examples, as parts per ten thousand (‱, mainly Cl). Data on the 71 artefacts measured and their geochemical compositions can be found in Table A1. The data is not normally distributed. For standardization and general statistical estimation of data variability the geochemical data was transformed into z-scores (Table 1A). All statistical comparisons and data representation were done with the aid of Excel and R.

The Comparative Materials

General whole rock geochemical analyses of the various types of carving coals (Textbox 1) used in jewellery and art are, as yet, few and fragmented as the focus in publications is more generated towards developing ways of separating and sourcing these material types by their microstructures and organic chemistry[3]. This is not yet possible through simple, non-destructive and semiquantitative pXRF methods for estimating the general geochemical composition of these organic rich materials. This is a problem, as very often these artefacts are small, rare and priceless, so destructive methods like thin sectioning, sample powdering and acid digestion methods are very rarely an option and always must be the last resort. pXRF measurements can, however, give an important starting point for further analyses and important suggestions pertaining to the level of

Dark Organic Rich Materials Used in Beads, Pendants, Rings, Bands and Armlets

Shale

Dark colored, fine grained, clastic sedimentary rock (mudrocks), fine lamination, common shale types are e.g. black/carbonaceous (organic C rich, often associated with coal), siliceous (Si rich), ferruginous (Fe rich), clay-rich/alum shale (Al rich) and calcareous (mineralic $CaCO_3$ rich). SiO_2 content of shale can vary greatly, between 10-90%, generally between 40-70%.

- *Oil Shale:* dark-colored, organic rich, typical TOC often 2-15%, can reach 30%. Commonly CaO rich. SiO_2 can be as low as 12-20% but generally ranges from 35-65%.

Common sources: e.g. Kimmeridge in Dorset and Whitby in Yorkshire, Great Britain.

Coal

Brownish black to glossy black, metamorphosed plant matter often forming coal seams, classified as sedimentary rock. Content of organic (C, H) and lithic (mainly Si, Fe, Al and Ca among a myriad of trace elements) compounds can vary greatly.
Lignite/brown coal: 25-35% carbon, ash content 5-20%, its composition commonly 15-45% SiO_2, 20-25% Al_2O_3, 4-15% Fe_2O_3 and 15-40% CaO, LOI 0-5%

- *Jet/svartaraf/azabache/jais/gagat:* lignite type, dark brown to black, metamorphosed wood, hard (C compression and salt water) and soft (C compression and fresh water). Mineral fraction largely <20%. Can contain pyrite (FeS_2) inclusions. Common sources: e.g. Kimmeridge and Whitby, GB and Asturias and Montalbán, Spain, and Batalha, Portugal.

Subbituminous coal: 35-45% carbon, ash content 5-20%, its composition commonly 40-60% SiO_2, 20-30% Al_2O_3, 4-10% Fe_2O_3 and 5-30% CaO, LOI 0-3%
Bituminous coal: 45-86% carbon, most common, ash content 6-12%, composition commonly low in Ca (<5%), high in Si, Al and Fe.

- *Cannel/Candle coal:* sapropelic coal, very organic rich (C+H), micro-lamellar coal mainly derived from microscopic plant spore debris accumulated in oxygen-deprived aquatic environments. Strong resemblance to oil shale. Inorganic components very fine, mainly clays, carbonates, sulfide minerals and/or silicates.

Anthracite coal: 86-98% carbon, ash content can be high up to +30%, composition of bituminous and anthracite coal ash commonly 20-60% SiO_2, 5-35% Al_2O_3, 10-20% Fe_2O_3 and 1-12% CaO, LOI 0-15%.

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[3] SEM, chromatography, FTIR spectra, stable isotope analysis etc. See e.g. Watts et al., 1998, Allason-Jones and Jones, 2001, Suárez-Ruiz et al. 2006, Brock et al. 2020; Demény et al, 2024.

material purity and possibly include or exclude potential raw material sources. This can be used as a platform to direct further in-depth studies of the artefacts.

The comparative data and geochemical analyses targeted at carving coal raw materials and artefacts consulted in this report mainly come from Pollard et al.[4], Harding and Healy[5], Plather[6] and Menéndez Menéndez[7] (Figures 3-4 and 12-13). The main locations of origins of artefacts and raw materials of coals, shales and jets discussed in this report are demonstrated in figure 2. The works of e.g. Watts et al.[8], Hunter et al.[9] and Brock et al.[10] are also consulted for support. The elemental patterns presented here are directed by the analysis of Menéndez Menéndez. Major elements are expressed as oxides (SiO_2 to P_2O_3) and trace elements inn ppm or ‰ (Cl, Ni, Ba, Cr, Pb, Sr, V, Zr, Zn and/or Cu; see e.g. figures 4 and 6) as this is how geochemical compositions are most often quoted in publications where chemical compositions of shales, coals and/or jets are discussed.

Other data and publications consulted for examples of general geochemistries of coals, black shales and slates for this report come mainly from Atar et al.[11], The BGS database[12], Ofili et al.,[13] Pearce et al.[14], Rotaru and Boboc[15], Wani and Mondal, 2011, Wagner et al.[16], Wang et al.[17] and Tang et al.[18] (Figures 5-10).

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[4] Pollard et al., 1981.

[5] Harding, J. and Healy, F. (eds.), 2011, p. 399. EDXR analysis.

[6] Plather 2011, p.132-139. EDXR and pXRF analyses.

[7] Menéndez Menéndez 2023, pp. pXRF analysis with a Niton XL5.

[8] Watts et al. 1997.

[9] Hunter et al. 1993.

[10] Brock et al. 2020. Jet.

[11] Atar et al. 2020. Kimmeridge Clays.

[12] BGS database, 2025. NERC Grant NE/M010953/1. Coals and black shales in Great Britain.

[13] Ofili et al. 2022. Black shales, Northern Euruope.

[14] Pearce et al. 2010. Kimmeridge Clays.

[15] Rotaru and Boboc 2010. Fly ash, the uncombustable component of coal.

[16] Wagner et al. 1997. Roofing slate examples, e.g. from Europe, Great Britain, Skandinavia.

[17] Wang et al. 2015 and 2024. Black shales, China.

[18] Tang et al. 2018. Black shales, China.

Figure 3. *Locations of sourced raw materials (lignites and jets) and artefacts discussed in this text (map based on Muller 1987, Kokowska 2012 and Menéndez Menéndez 2023).*

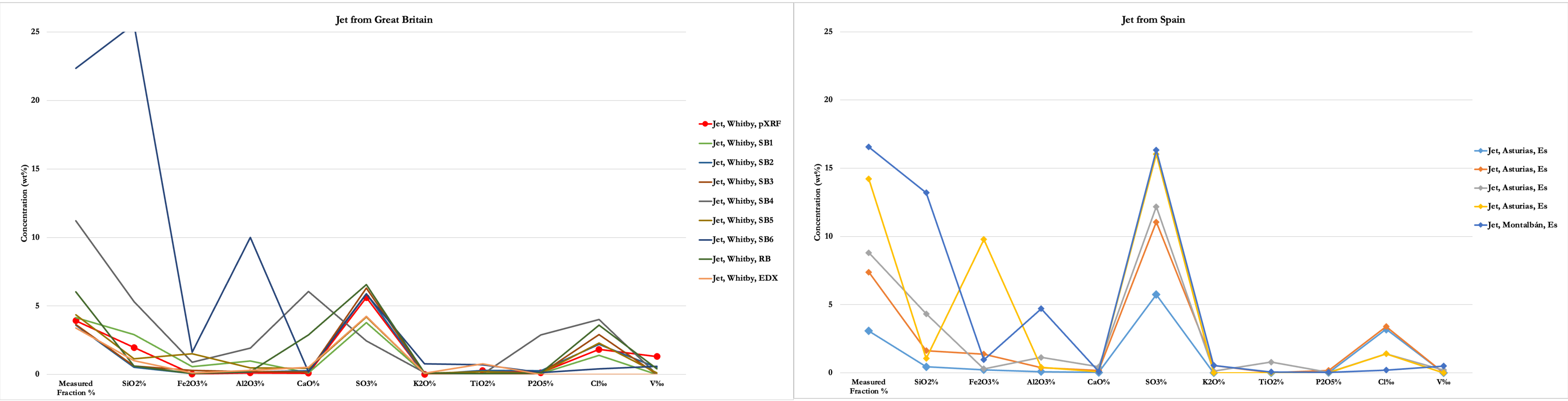

Figure 4. *Published compositions of main elements in jet from Whitby in Great Britain (Saltwick and Runswick Bays) and Asturias and Montalbán in Spain (Harding and Healy (eds.) 2011 (p.396); Menéndez Menéndez 2023). Detailed compositions for trace elements were limited in these publications. One jet sample (red line) from Whitby (SSI.10) was analysed with the Niton XL5 Plus pXRF during this project for comparison.*

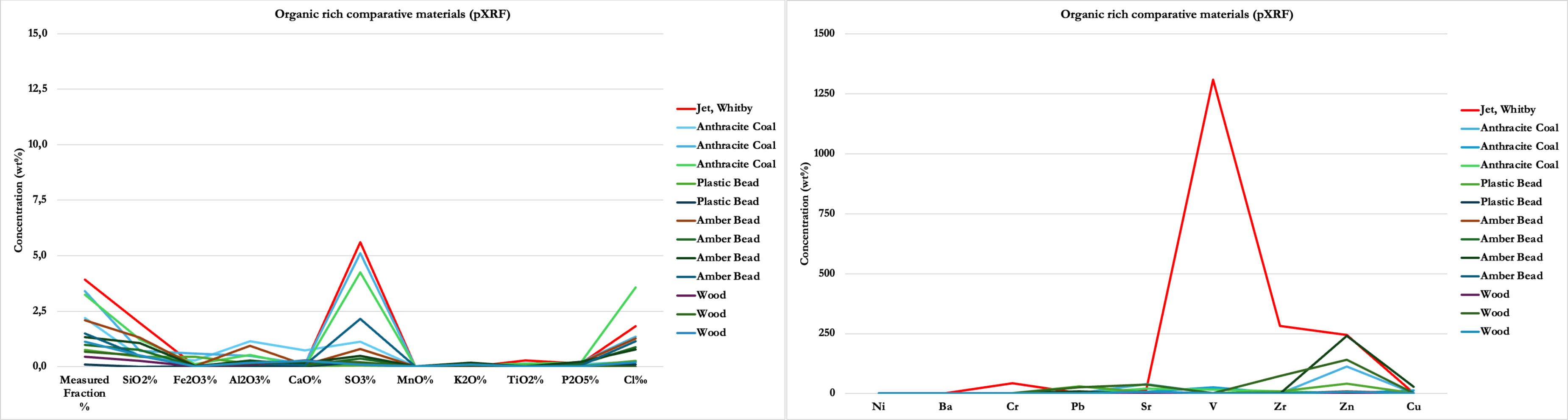

Figure 5. *Organic rich and synthetic materials (coal, amber and wood, plastic) measured in Reykjavík, Iceland with the Niton XL5 Plus pXRF for general comparison.*

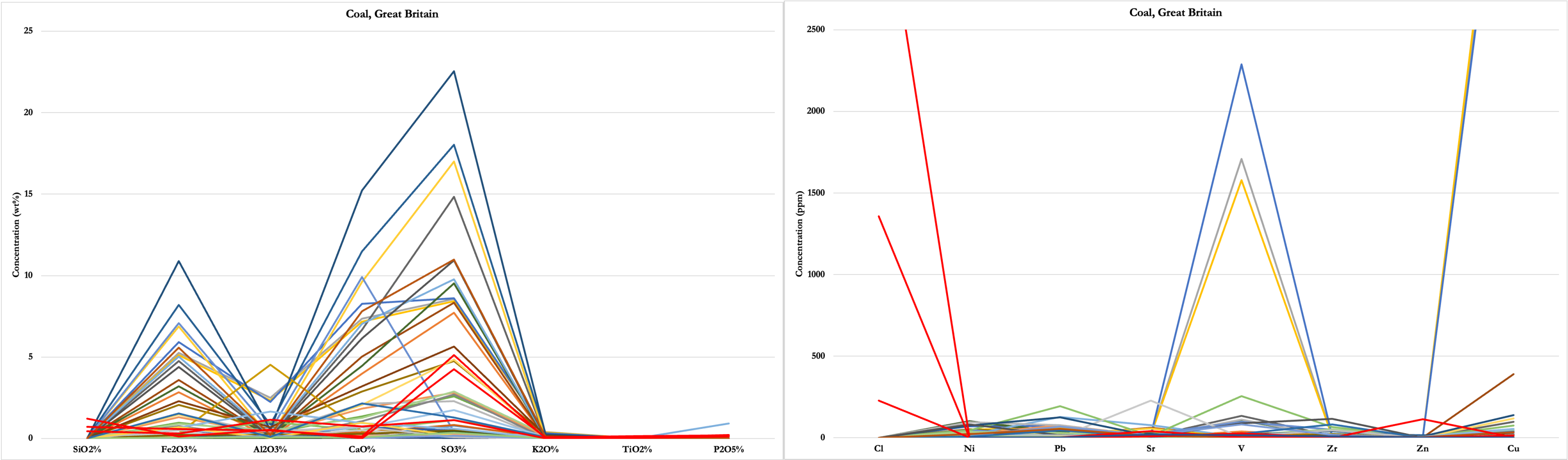

Figure 6. *Examples of compositions of various types and locations of British coal (BGS, 2025). SiO_2% and Cl concentrations were not published in the BGS data. Three samples of anthracite coal (bright red lines) found in Iceland and analysed with the Niton XL5 Plus are included here for comparison. SiO_2 concentration is commonly low in coals, but it depends on their purity. British coal with high SO_3 concentrations (>5%) tend to have high CaO% concentrations as well.*

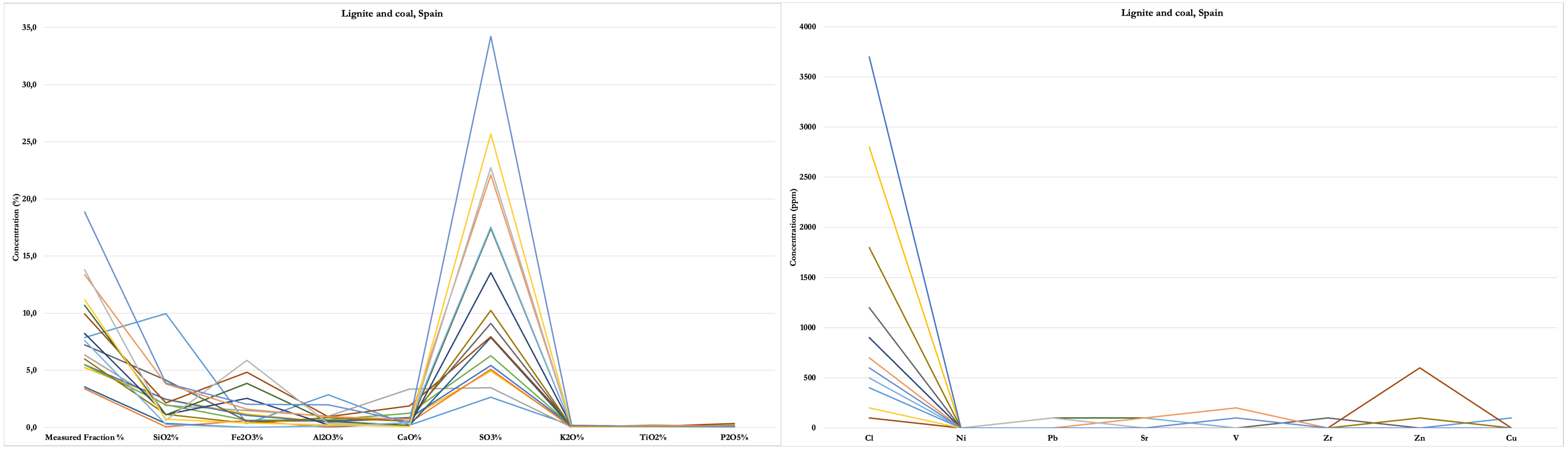

Figure 7. *Compositions of seventeen Spanish examples of lignite and coal (Menéndez Menéndez 2023, pXRF). Concentrations of trace elements excepting Cl were low, making fairly flat trace elemental patterns with faint peaks of Pb, Sr, V, Zr, Zn and Cu. Note that SO_3% concentrations >10-20% can be detected in lignite and coal samples both from Spain and Great Britain.*

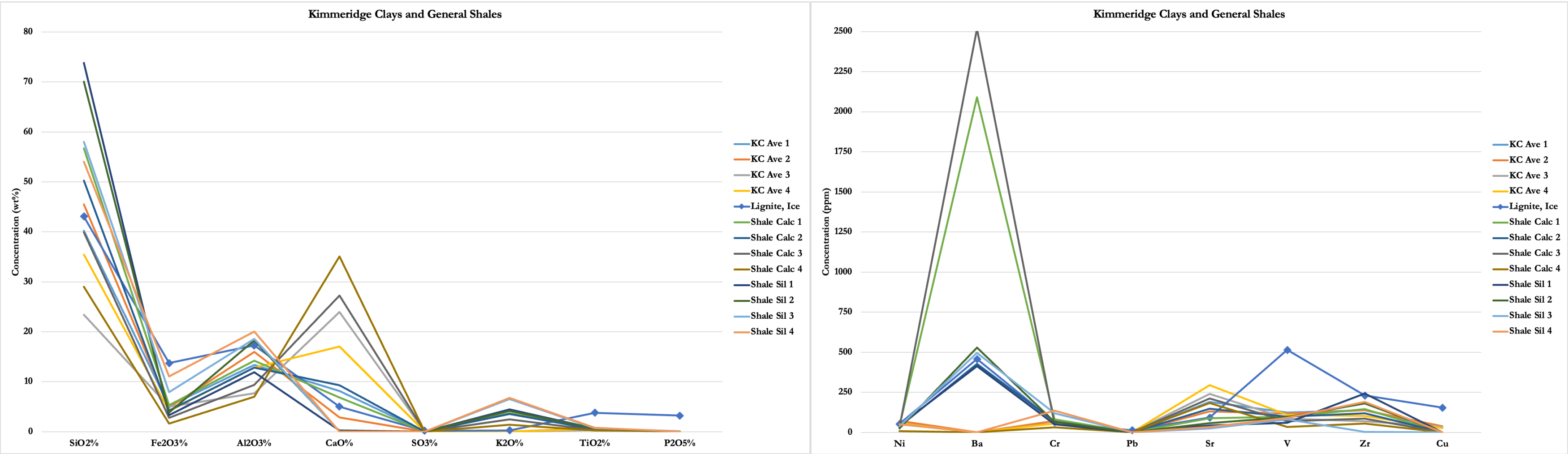

Figure 8. *Average chemical compositions of main and trace elements in general shales (both Ca and Si rich, Wani and Mondal 2011) and clays from Kimmeridge in Great Britain. Compositions of S, K, P, Cl, Ba and Pb were not included in the publication of Kimmeridge Clay concentrations (Pearce et al. 2010). An example of mineral rich Icelandic lignite from Heinaberg in Snæfellsnes was measured by the Niton XL5 pXRF and is included for comparison.*

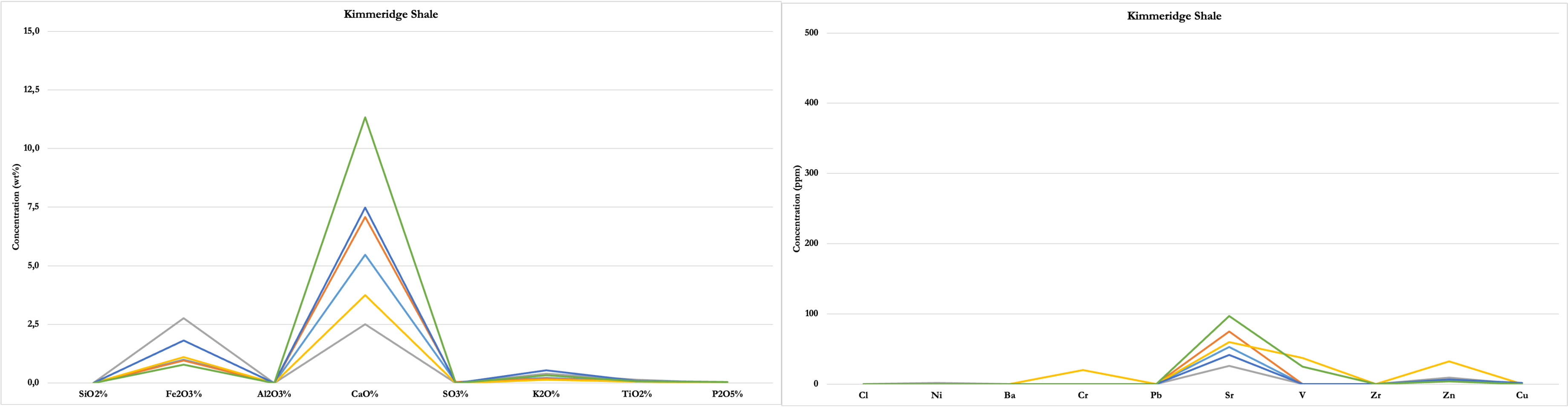

Figure 9. *Chemical compositions of six samples of Kimmeridge Shale published in Pollard et al 1981. Note that concentrations of SiO_2 and Al_2O_3 were not included in the main elemental analysis and only coarse trace element concentrations of Cr, Sr, V and Zn (ppm) were published.*

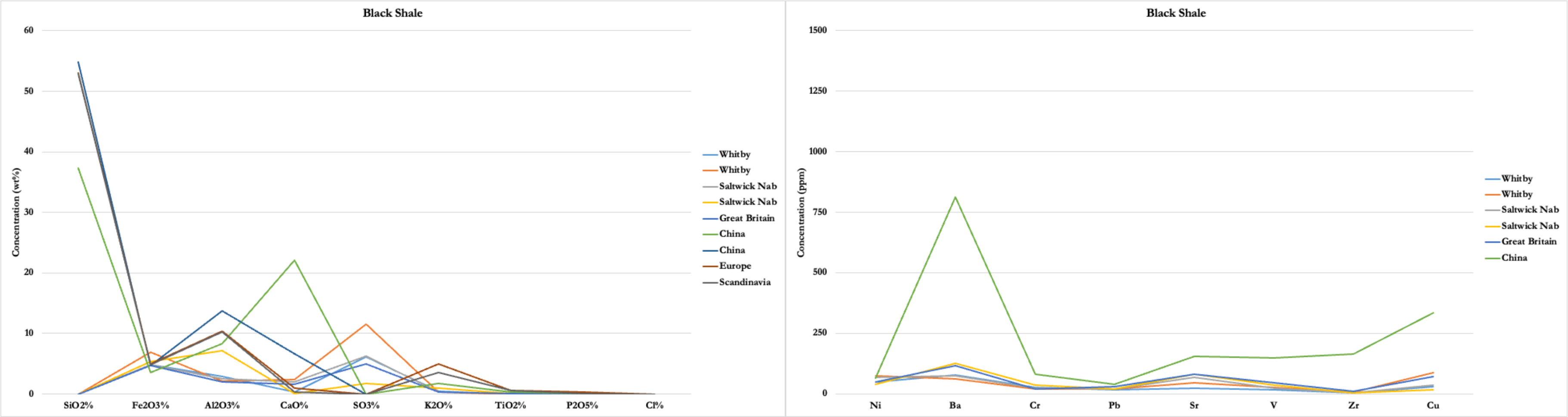

Figure 10. *Published average chemical compositions of main and trace elements in black shales from Whitby, Great Britain (BGS, 2025). Compositions of Si and Cl were not published. For comparison are examples of average compositions of black shales from Great Britain (BGS, 2025), China (Tang et al. 2018), Europe and Skandinavia (Ofili et al. 2022). Concentrations of SiO$_2$ in black shales can commonly range from 35-75%. SO$_3$% can range from <1% up to 20%.*

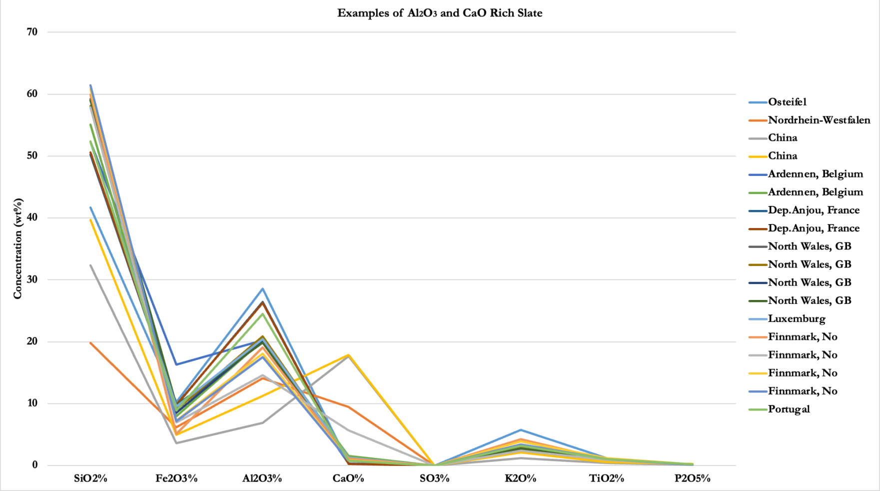

Figure 11. *Examples of published chemical compositions of main elements in Si poor and Al and Ca rich roofing slates from Skandinavia, Great Britain, Europe and China (Wagner et al., 1997, sulphur (S) and trace element compositions were not published). Slate commonly contains >20% SiO$_2$, >10% Al$_2$O$_3$ and low CaO%. When SiO$_2$% is low the CaO% is commonly higher.*

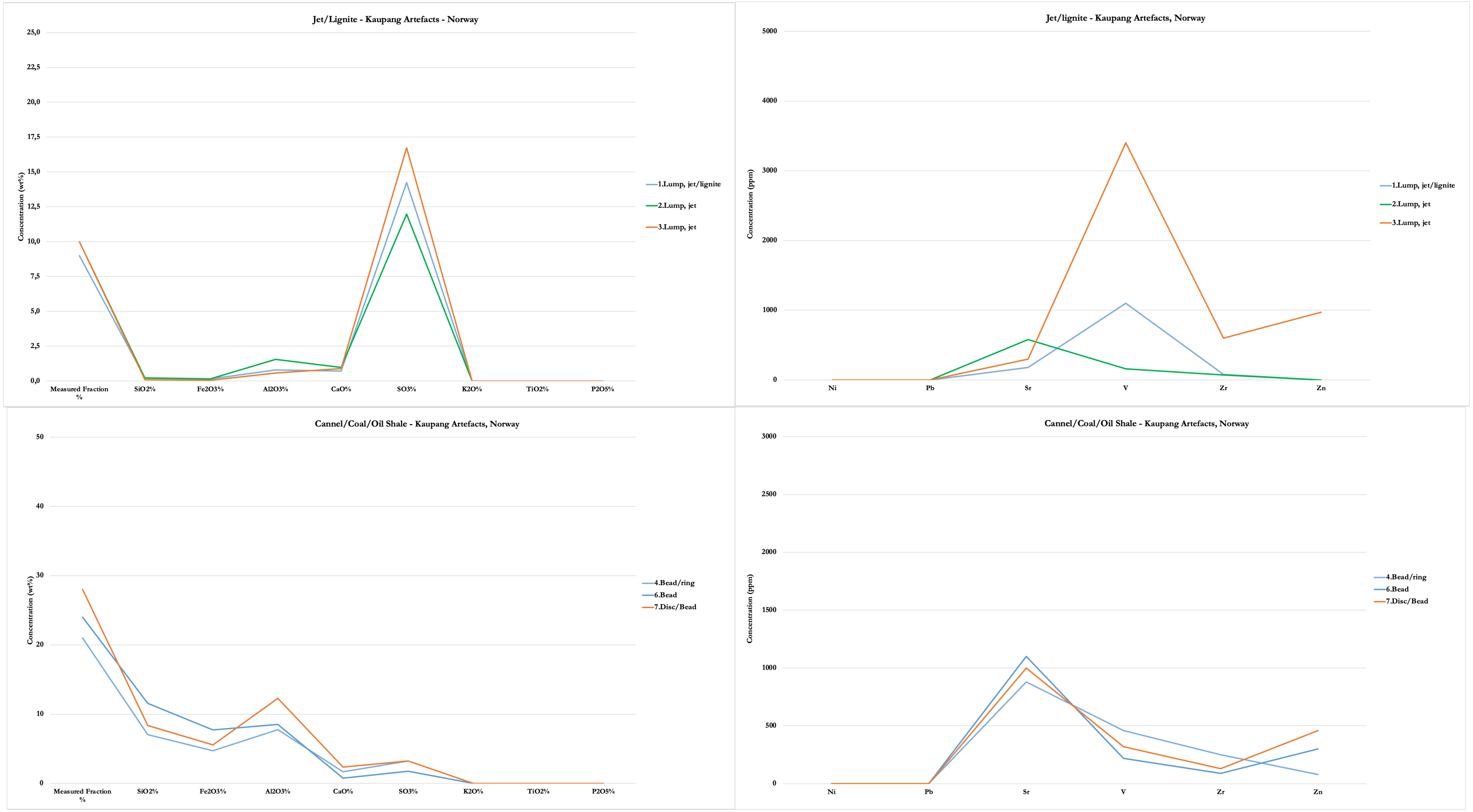

Figure 12. *Examples of Kaupang Artefact elemental patterns of carving coals published in 2011 (Plather 2011, pp.138-139). K, Ti, P and Cl concentrations were not published. Comparing the elemental patterns to Menéndez Menéndez (2023) the jet fragments found in Kaupang are more likely to be from Asturias in Spain (e.g. Villaverde and Acantilados), rather than Whitby in Great Britain, but this needs further analysis for confirmation.*

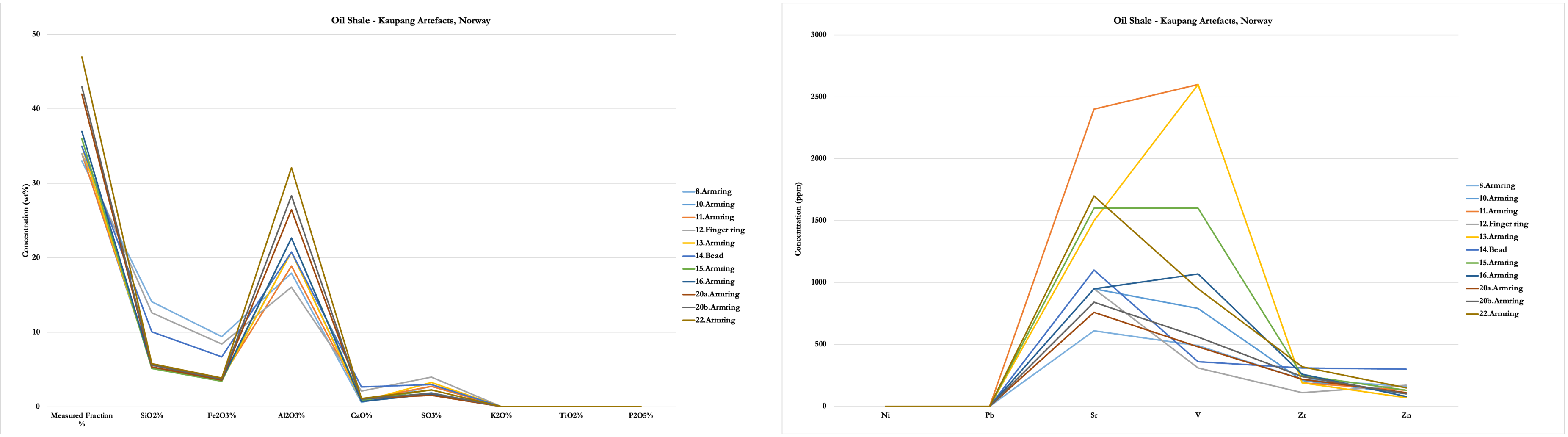

Figure 13. *Examples of Kaupang Artefact elemental patterns likely made of oil shales published in 2011 (Plather 2011, pp.138-139). K, Ti, P and Cl concentrations were not published.*

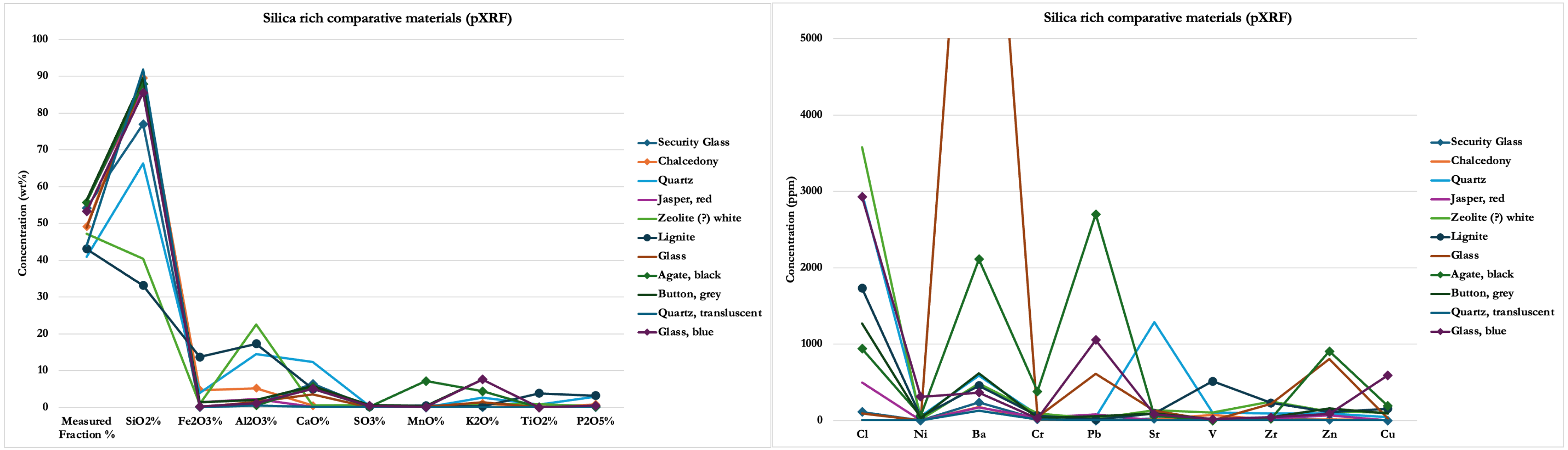

Figure 14. *Examples of elemental patterns of natural Icelandic silica rich raw materials and beads of glass and quartz analysed with the Niton XL5 Plus pXRF for general comparison.*

Results

Basic Data Analysis

The data was analysed and finds manually grouped with the aid of Excel and R. All 71 artefacts were analysed 2-3 times and where they were broken, both inner and outer surfaces were analysed. In a few artifacts measured, inner and outer elemental patterns showed slight variations (see e.g. elemental patterns in Figures 17-19, and the Grónes armlet in Figure 21) but in the majority of cases each beads' elemental patterns were very similar to each other or almost identical and their differences not statistically significant (e.g. see Figure 16). The elemental concentrations in table A1 are averages of all measurements for each artefact.

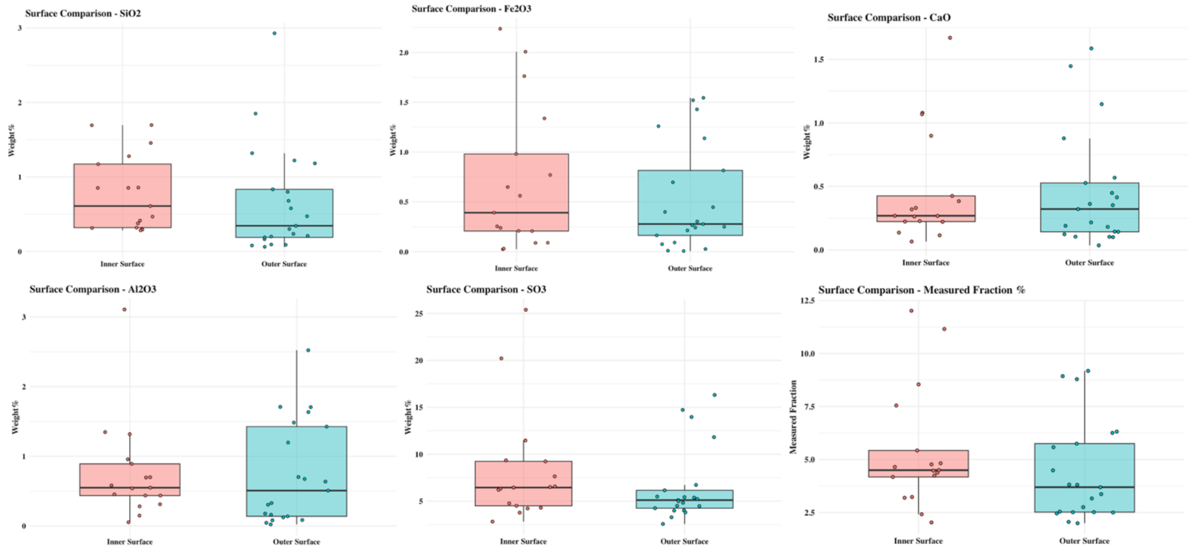

Figure 15. *All the finds were analysed 2-3 times and where beads were broken both inner and outer surfaces were analysed. In a few artifacts measured, inner and outer elemental patterns showed slight variations, especially in iron and aluminum concentrations, but in the majority of cases the differences between measurements were not statistically significant (see also figures 16-19).*

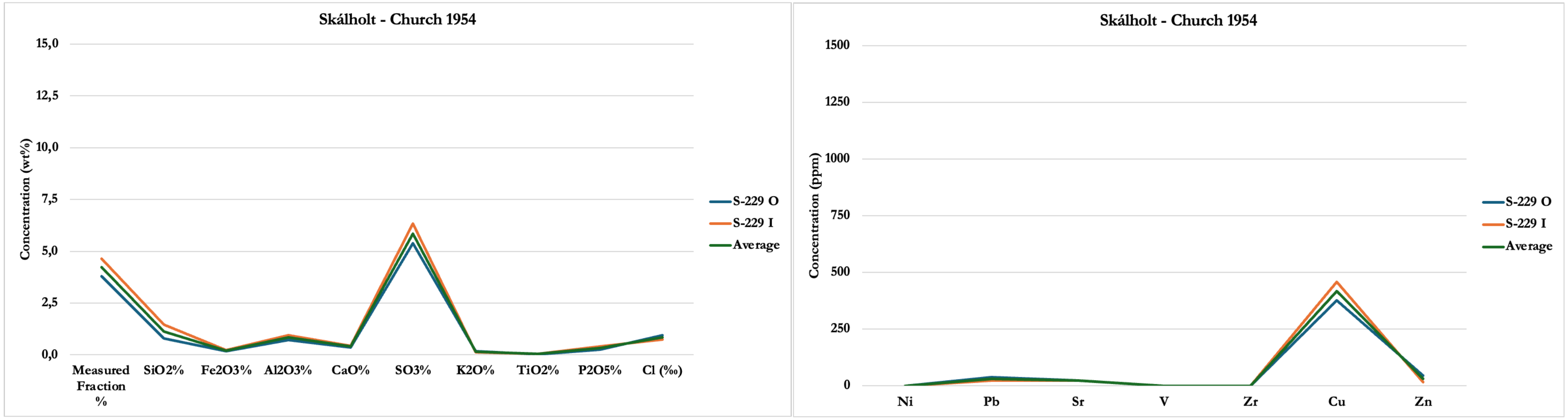

Figure 16. *Variation of concentrations between the inner and outer surfaces of bead S-229 from the Skálholt church exavations in the mid 20th century.*

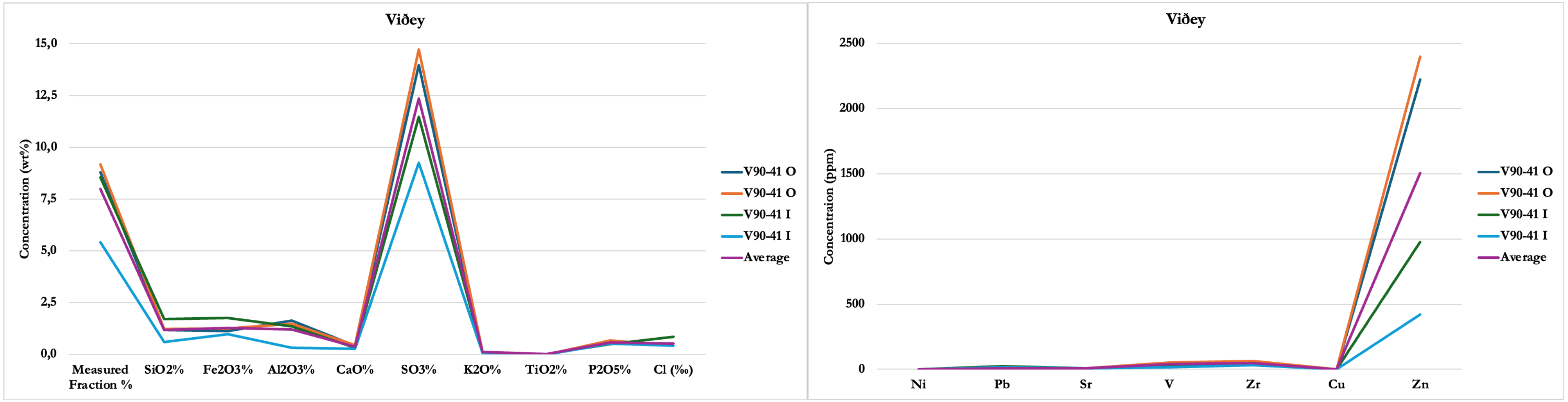

Figure 17. *Variation of concentrations within bead V90-41 from Viðey. The bead was measured twice both at the outer and inner surfaces.*

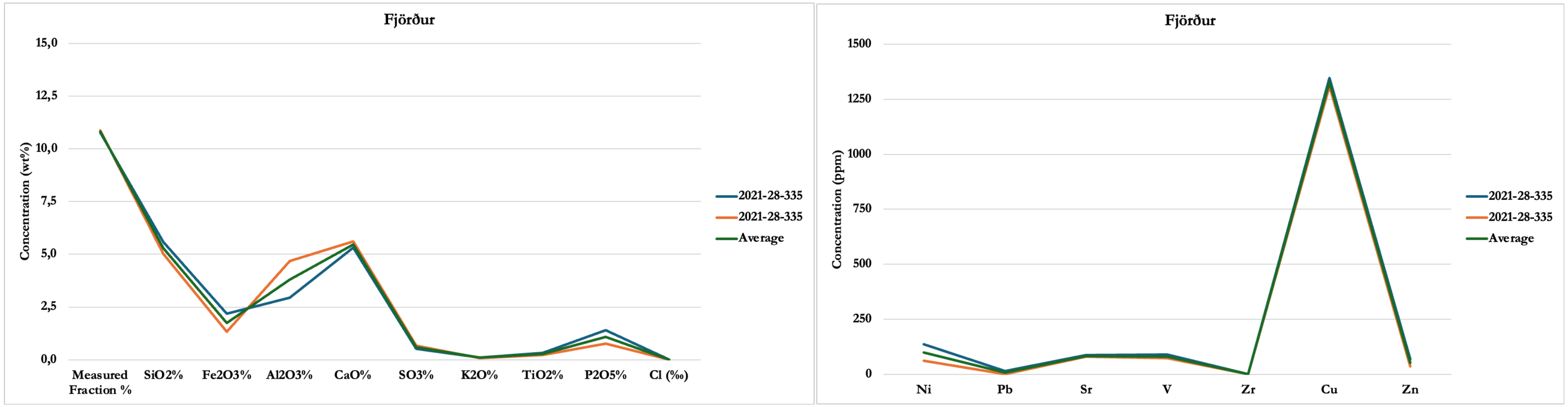

Figure 18. *Variation of elemental concentrations of bead 2021-28-335 from Fjörður. The bead was measured twice at its outer surface.*

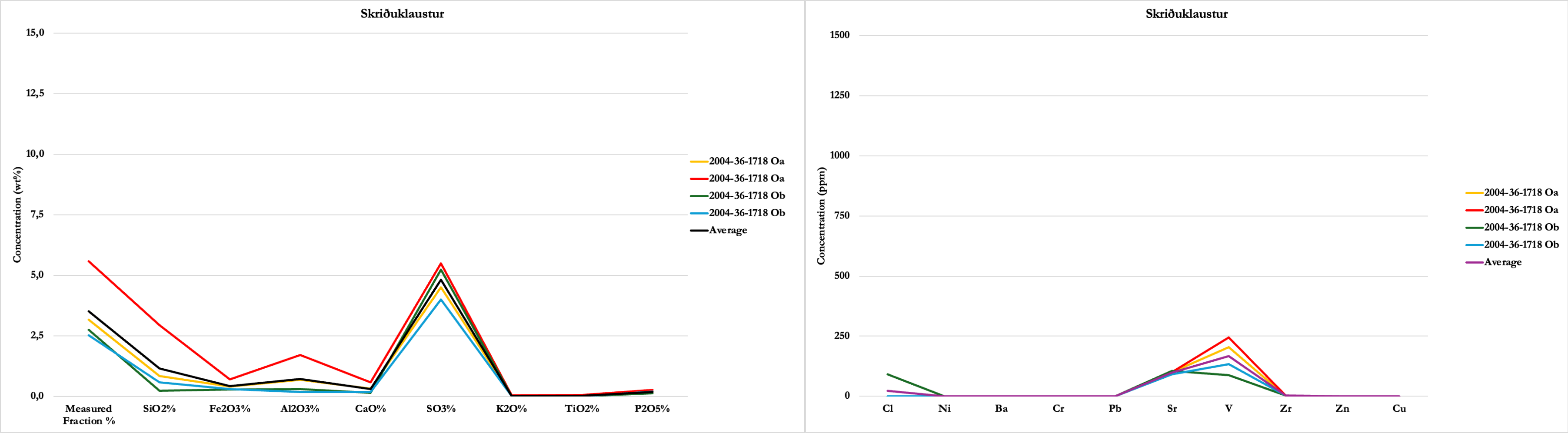

Figure 19. *The outer surface of bead 2004-36-1718 from Skriðuklaustur was measured twice at its outer surface, on two separate days.*

The Artefact Groups

The 71 artefacts in the assemblage were split into four main groups I-IV according to their iron (Fe), calcium (Ca), silica (Si), aluminium (Al) and sulphur (S) concentrations (Fig. 20, Table 1). The geochemical differences between the four groups are statistically significant (Table A1)[19]. Group I encompassed five finds that contained >5% SiO_2+Al_2O_3. Group II included eight artefacts that contained >8% SO_3. Group III only comprised two beads from Fjörður with Fe_2O_3+CaO >5%. This value is largely due to significantly higher CaO content. Group IV included the remaining 56 analysed artefacts measured with <5% SiO_2+Al_2O_3, <8% SO_3 and <8% Fe_2O+CaO_3.

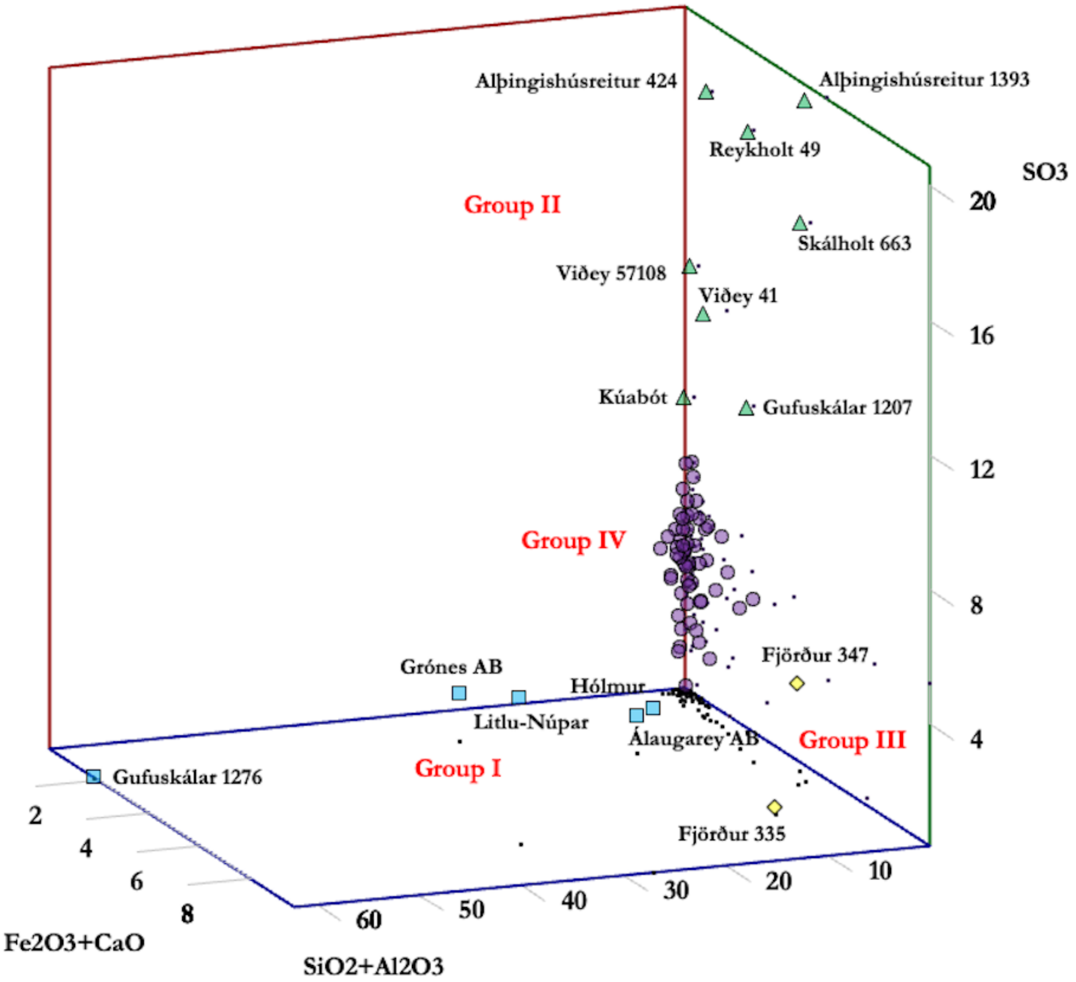

Figure 20. *The assemblage was split into four groups I-IV according to their iron (Fe), silica (Si), aluminium (Al) and sulphur (S) concentrations. Group I (SiO_2+Al_2O_3 >5%, squares), group II (>9% SO_3 triangles), group III (>5% Fe_2O+CaO, diamonds) and group IV (SiO_2+Al_2O_3 and Fe_2O+CaO <5% and <8% SO_3 circles). Group I - SiO_2+Al_2O_3 >5%*

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[19] Z-scores >1,645-1,96, for over 90-95% confidence for SiO_2, Fe_2O_3 and/or SO_3 .

The five artefacts in group I are armlets from Grónes (2021-46-046) and Álaugarey (Þjms. 11565) (~8 cm), a bead from Hólmur (2001-34-060, wheel), a large pendant from Litlu-Núpar (2007-141, thin wheel) and an unusual bead from Gufuskálar (2013-36-1276) with triangular decoration. The artefacts were manually separated into four subgroups Ia-d based on their varied elemental patterns (Fig. 21-24).

Subgroup Ia

The Grónes armlet (2021-46-046) is broken. The material is hard and brittle, mottled and of light gray colour. It might possibly be made of shale. The armlet was found in a late Viking Age context during a rescue excavation of a settlement site in the Westfjords[20] (Fig. 2). The armlets' elemental pattern (Fig. 21, measured fraction (MF%) ~16%) shows that SiO_2 content (~15%) is moderate, Fe_2O_3 is low and the material is rich in Al_2O_3 (>10%). Trace element levels are low, with only small peaks of Ni, Sr and Zn (ppm) and very little Cl. It was one of the few artefacts measured that showed a clear difference in concentrations of Si and Al between the inner and outer surfaces, but the overall elemental pattern was unchanged. Comparison to known analysed material examples shows that the Si content is too high for most samples of *Whitby* jet, except one sample analyzed by Menéndez Menéndez from *Saltwick Bay* (SB6, MF% ~23%). Its elemental pattern is similar, but the Si and S content is slightly higher and shows a large peak in V. Another similar elemental pattern is from a sample taken from the *Saltwick Nab Alum Quarry* (sample id. STORM 637A, here marked no. 1), published by the British Geological Service (BGS, 2025). It shows similar peaks in Al and S but unfortunately the Si and Cl concentrations for that sample were not published. The trace elemental pattern is similarly weak and shows small peaks in Sr and Zn. CaO% is incompatible with known samples of Kimmeridge clays as it is much too low (Fig. 8-9)[21]. The result of the comparative work suggests a possible origin of this material is the Saltwick Nab Area in Whitby, Great Britain. This needs more detailed geochemical and microstructural analysis for solid confirmation.

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[20] Kristín Sylvía Ragnarsdóttir and Margrét Hrönn Hallmundsdóttir 2022, pp. 39.

[21] Pollard et al. 1981; Pearce et al. 2010.

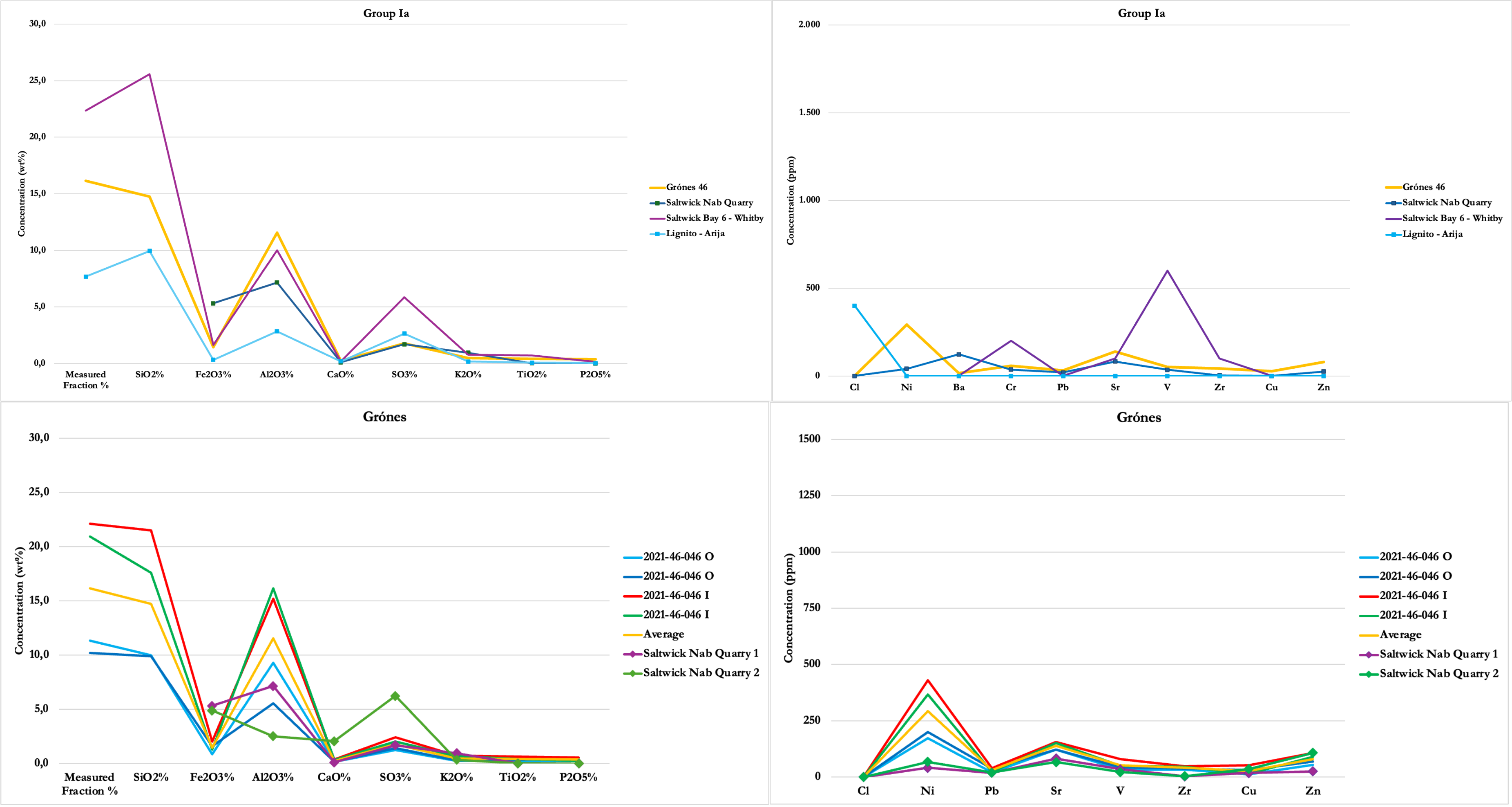

Figure 21. *The Grónes armlet raw material is pale mottled grey, fine grained, cold and brittle and resembles shale in appearance and touch. The closest geochemical similarities were found in an example of alum shale from Saltwick Nab Quarry (sample 1), from Whitby in Great Britain. The raw material has too low CaO% content to be Kimmeridge Shale. Most likely it is a type of organic and clay rich shale, possibly from the Saltwick Nab area in Whitby, Great Britain.*

Subgroups Ib and Ic

The artefacts in subgroups Ib and Ic comprise the Álaugarey armlet (Þjms. 11565) [22], beads from Litlu-Núpar (2007-141)[23] and a single bead from Hólmur[24] (2001-34-60). Álaugarey and Litlu-Núpar fall within group Ib and the Hólmur bead in Ic (Fig. 22-23). All the artefacts are whole and come from late Viking Age contexts. The armlet is shiny black with a greasy lustre, whole and plain, ~77 mm in diameter, and was found in a disturbed female grave. The beads are both atypical. The bead from Litlu-Núpar is large (~27 mm in diameter), dark gray to black, with a weak greasy lustre. It is in the shape of a wheel and was found in a boat burial (no. 5). The bead from Hólmur is a bit smaller but similarly shaped (~18mm in diameter), dark grey and matted. All three finds had to be partly cleaned of soil and iron contamination after burial. The sites at Hólmur and Álaugarey are less than 10 km apart in the Hornafjörður area, Southeast Iceland. Litlu-Núpar are in Aðaldalur in Northeast-Iceland (Fig. 2).

The armlet from Álaugarey and the Litlu-Núpar bead have very similar elemental patterns (Fig. 22) and are very likely made from similar material. They have high Al_2O_3% and moderate SO_3% concentrations which are similar to shales, but moderate SiO_2% concentrations which are relatively low and make it unlikely for it to be general shale. CaO% is also likely too low to be Kimmeridge shale. The trace elemental patterns are very similar. Their low concentrations make a flat pattern but with a small peak in Sr (ppm) and large peak in Cl (ppm), which the Grónes armlet does not have. The closest geochemical similarities were found in an example of Whitby jet from Saltwick Bay (S6[25]) and three finds from Kaupang[26] in Norway, but the fit is still imperfect. The elemental pattern with the closest fit is armlet C52519/9619 from Kaupang, but its V, Sr and Zr (ppm) concentrations are too high. The raw material in the two artefacts is likely to be mineral rich coal or very organic rich shale, possibly from Whitby. The Hólmur beads' elemental pattern is similar to group Ib, but the concentrations of Si, Fe and Al are significantly lower. The pattern only shows similarities to two samples of pXRF analysed Spanish lignite[27] (Fig. 22-23), but this cannot be interpreted further than that its raw material is most likely to be mineral rich coal. The actual source is unclear. These interpretations need more detailed geochemical and microstructural analysis for solid confirmation and further interpretation.

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[22] Kristján Eldjárn 2016, pp. 240-241.

[23] Kristján Eldjárn 2016, pp. 499-501; Guðrún Alda Gísladóttir 2012, pp. 81-82.

[24] Bjarni F. Einarsson 2002, Appendix 1, p. 52, no. 404.

[25] Menéndez Menéndez 2023, pp. 777-778.

[26] Plather 2011, pp. 133-140.

[27] Menéndez Menéndez 2023, pp. 777-778.

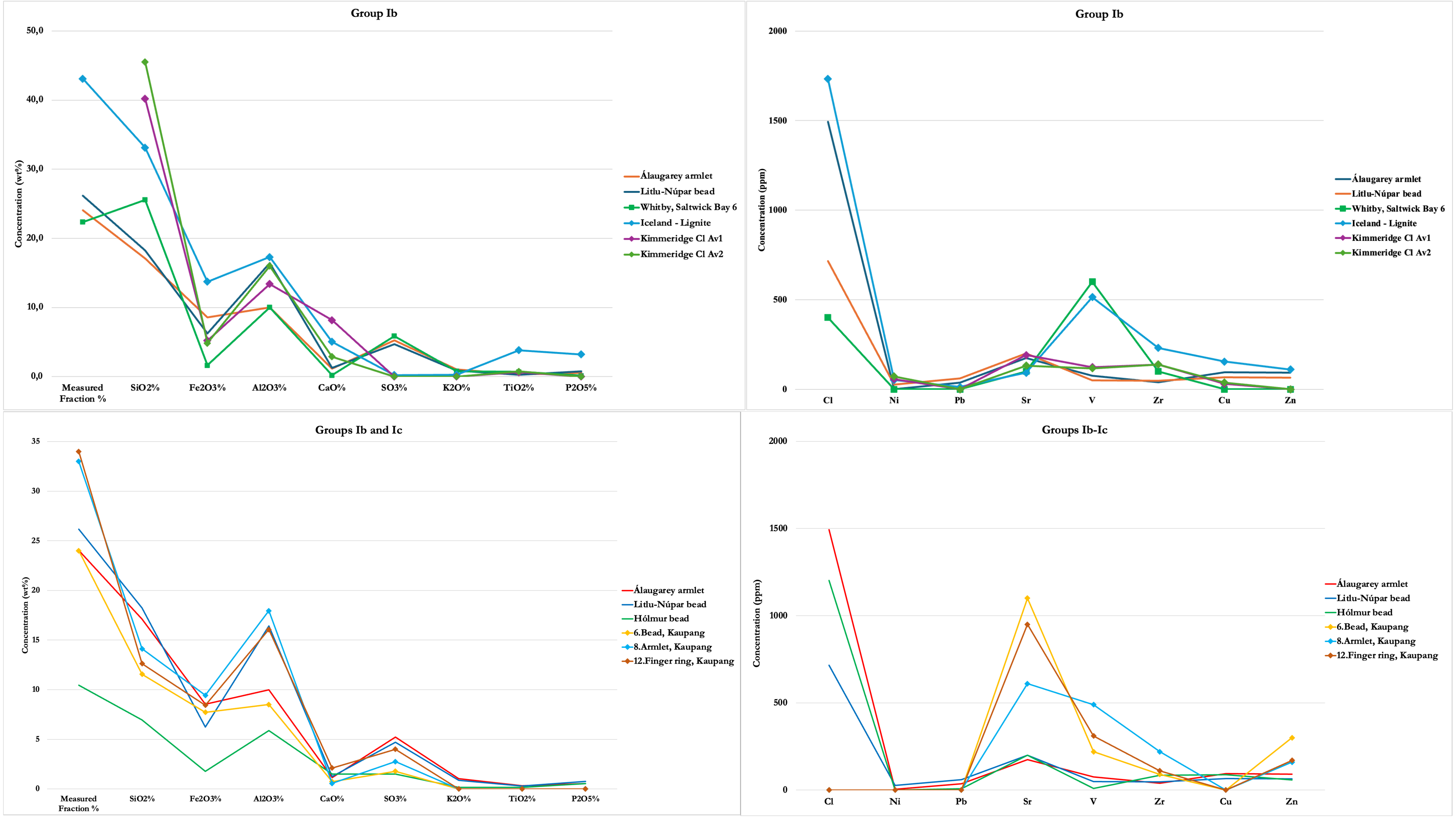

Figure 22. *The Álaugarey armlet and the Litlu-Núpar bead are both dark gray to black and greasy in appearance. Geochemical similarities were found in an example of Whitby jet from Saltwick Bay (S6), clay rich Kimmeridge Clays (too high Si and Ca) and three finds from Kaupang in Norway, but the fit is still imperfect. The elemental pattern with the closest fit is armlet C52519/9619 from Kaupang, but its V, Sr and Zr are too high. The raw material in the two artefact is likely to be shale or Si-rich coal, possibly from Whitby.*

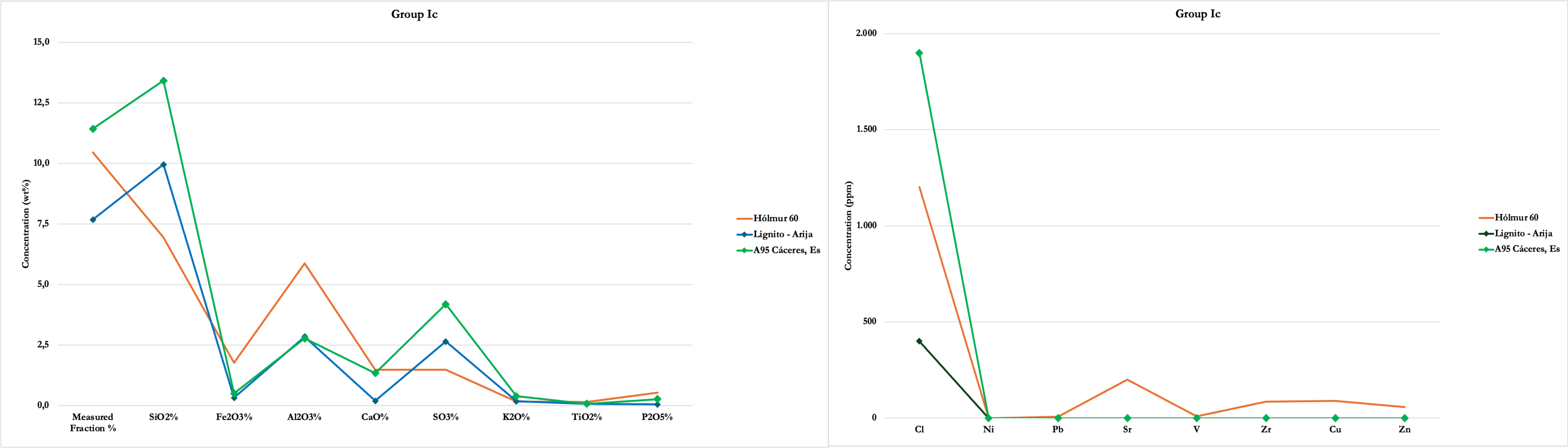

Figure 23. *The Hólmur beads' elemental pattern is similar to group Ib (Fig. 22), but the concentrations of Si, Fe and Al are much lower. The raw material is likely to be Si rich coal.*

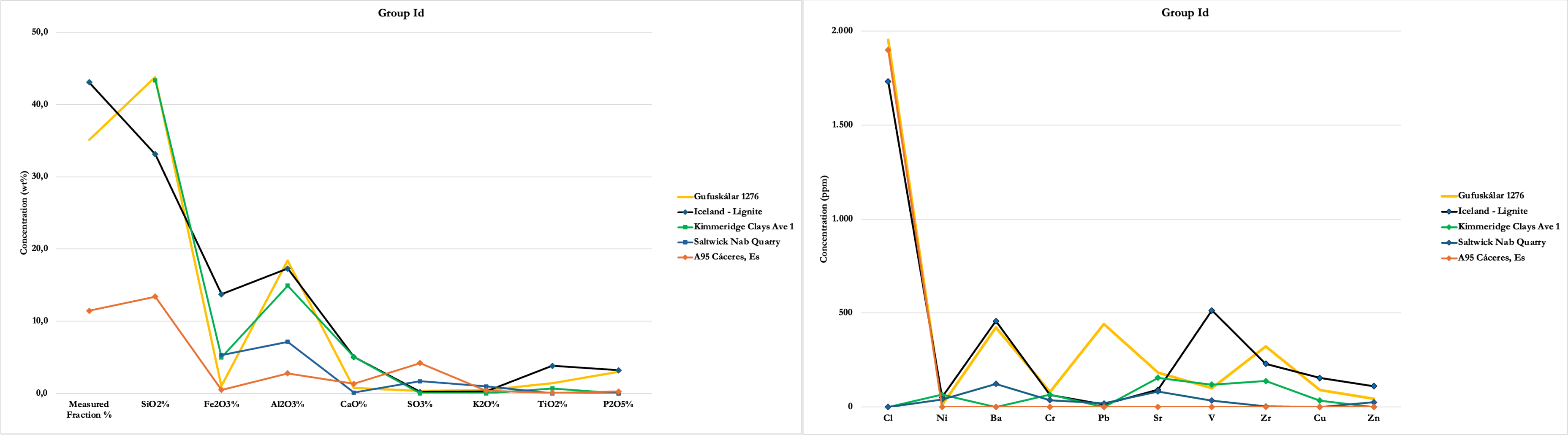

Figure 24. *The unusual bead from the Gufuskálar fishing station is possibly made from Si-rich Icelandic lignite or some form of clay rich shale.*

Subgroup Id - The Gufuskálar Triangle Bead

The Gufuskálar beads (Table 1) originate from 15th-19th century deposits excavated at an Icelandic fishing station at the western tip of Snæfellsnes (Fig.1) in Western Iceland. Bead 2013-36-1276 is black, matted and irregularly rounded with an unusual triangular decoration. It was found in trench 5 excavated into the side of Drottningarhóll[28] in deposits dated to the early 15th century[29].

The bead has a high MF% (~35%) and a much busier elemental pattern than all the other artefacts analysed (Fig. 24, Table A1). It has high concentrations of SiO_2% and Al_2O_3%, peaks of Cl, Ba, Pb and Zr (ppm) and elevated concentrations of TiO_2%, P_2O_5% and Sr, V and Cu (ppm). The closest similarity to foreign materials was to the elemental pattern of Kimmeridge clays with low CaO% content, but the fit is still poor. A raw material sample of Icelandic lignite sourced at Heinaberg in northern Snæfellsnes was analysed for comparative purposes and its elemental pattern is also very busy. It shows clear similarities in high MF% (>40%), SiO_2, Al_2O_3 and Cl and elevated CaO%, TiO_2% and P_2O_5%, Ba, V, Zr, Cu and Zn (ppm). This is not a clear fit to the material from Heinaberg, but the bead type and the material elemental pattern together could suggest a possible local lignite source, rather than an imported one. Although, the Fe_2O_3% concentration is conspicuously low. These interpretations need more detailed geochemical and microstructural analysis for solid confirmation and further interpretation.

Group II - >9% SO_3

Subgroup IIa - SO_3 >15%

Group IIa constitutes four beads where SO_3% measured higher than 15% (Fig. 25). These are two beads (99-424 and 2009-32-1393) from an urban activity site in Reykjavík (Alþingishúsreitur, unstratified), one from the ecclesiastical site in Skálholt (2002-64-663), and one from the excavation of the farm in Reykholt (2000-6-49) (Tables 1 and A1). Bead 663 from Skálholt was found in the floor of the pantry/study and library (V) in an early 18th century context[30]. Twelve beads were found at the ecclesiastical site of Reykholt during excavations of the church and farm sites. Bead 2000-6-49 is the only one found at the farmhouse site, dated to an 18th century context[31]. They have varied shapes. The beads from Reykjavík are a plain round bead (1393) and a bead with a scallop decoration (424) while interestingly, the Skálholt and Reykholt beads are both flat beads with bevelled ends.

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[28] English translation "The Queens Mound".

[29] Lilja Björk Pálsdóttir 2016, pp.108-114.

[30] Elín Ósk Hreiðarsdóttir 2024, pp. 244-245.

[31] Guðrún Sveinbjarnardóttir 2012, pp. 189-190; 2016, pp. 35-36, 136-137 and 158 and Appendix 11.

The four beads all show very high SO_3% (~16-21%, Fig. 25) relative to the other beads analysed, along with moderately to highly elevated levels of Fe_2O_3 relative to Al_2O_3 content and peaks of Cl and V. In main elements the Skálholt 663 and Alþ 1393 beads are more similar but in trace elements the Skálholt and Reykholt beads are more similar. With regard to V (ppm) concentrations, the Alþingishúsreitur beads are very similar (141 and 144 ppm), as are the Skálholt and Reykholt beads (258 and 251 ppm).

The materials of these four beads (Fig. 25) show similarities to Spanish jet from the Asturias region and artefacts originating from Léon and Lugo in Spain. They also show similarities to lignite from Valle de Valdeberzana in Spain and artefacts excavated in Kaupang, Norway, but the Kaupang artefacts exhibit too low SO_3% and significantly higher peaks of Sr and V, respectively. The closest fits are samples from the Asturias area (Bocamina) and an artefact from Léon (sample G) in Spain, but the fit is still rather poor. This shows that the material from this artefact can not be allocated a possible source through pXRF but further analyses should be directed towards Spanish raw materials as a starting point.

Subgroup IIb - SO_3 ~9-15%

In Group IIb are four artefacts that have a SO_3% concentrations between 9-15%. The beads come from an ecclesiastical site in Viðey near Reykjavík (V90-41 and 1989-153-57108), a fishing station at Gufuskálar (2013-36-1207) in Snæfellsnes and a church foundation at Kúabót farm (1975-615-46/884) in Southern Iceland. The beads from Viðey are one that is oval with a leaf decoration (41) while the other is a ridged, barrel shaped bead (57108). The dating of these beads is likely medieval[32]. The Gufuskálar bead 1207 is an oval bead with a spiral decoration. It was found in the floor of room 1025 in fishing hut 1213[33], possibly from 15th-19th century contexts. The Kúabót bead 46 is round and plain, and it was found in a disturbed context within the church foundations, just inside its eastern wall but the site was abandoned in the 15th century[34].

The material is likely coal, potentially from Spain, but what type of coal is unclear. It cannot be ruled out that the bead from Gufuskálar could be from Icelandic lignite.

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[32] Margrét Hallgrímsdóttir 1993, bls. 26-27 and 47.

[33] Lilja Björk Pálsdóttir 2015, pp. 12-13.

[34] Gísli Gestsson og Lilja Árnadóttir 1987, p. 90; Lilja Árnadóttir 1987a, pp. 57-62; Lilja Árnadóttir 1987b, pp. 97-99.

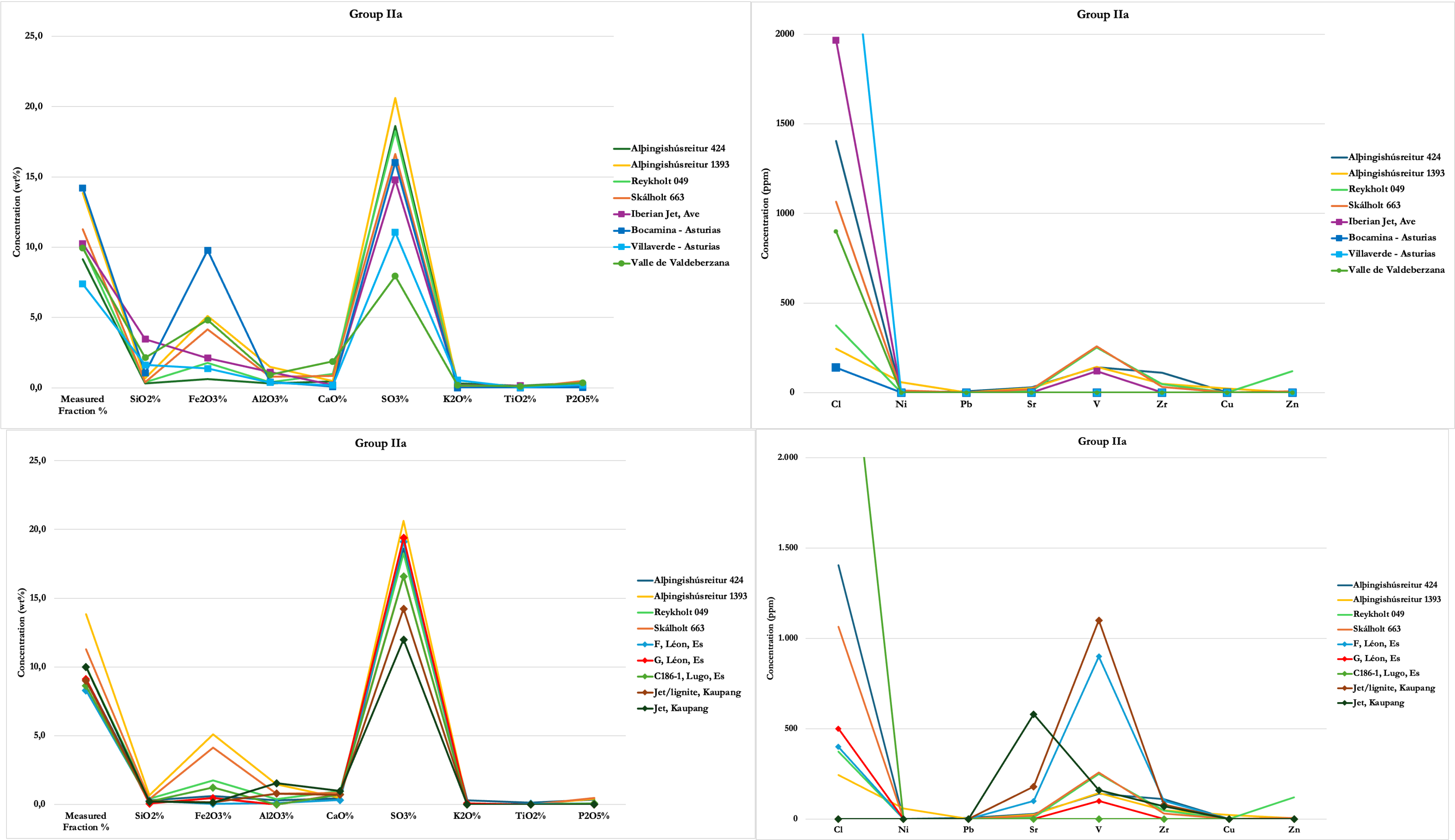

Figure 25. *Group IIa constitutes artifacts where* SO_3 *measured higher than 15%. The materials of these four beads show similarities to Spanish jet from the Asturias area, lignite from Valle de Valdeberzana and artefacts originating from Léon and Lugo in Spain. The closest fits are a sample from the Asturias area (Bocamina) and an artefact from Léon (sample G) in Spain.*

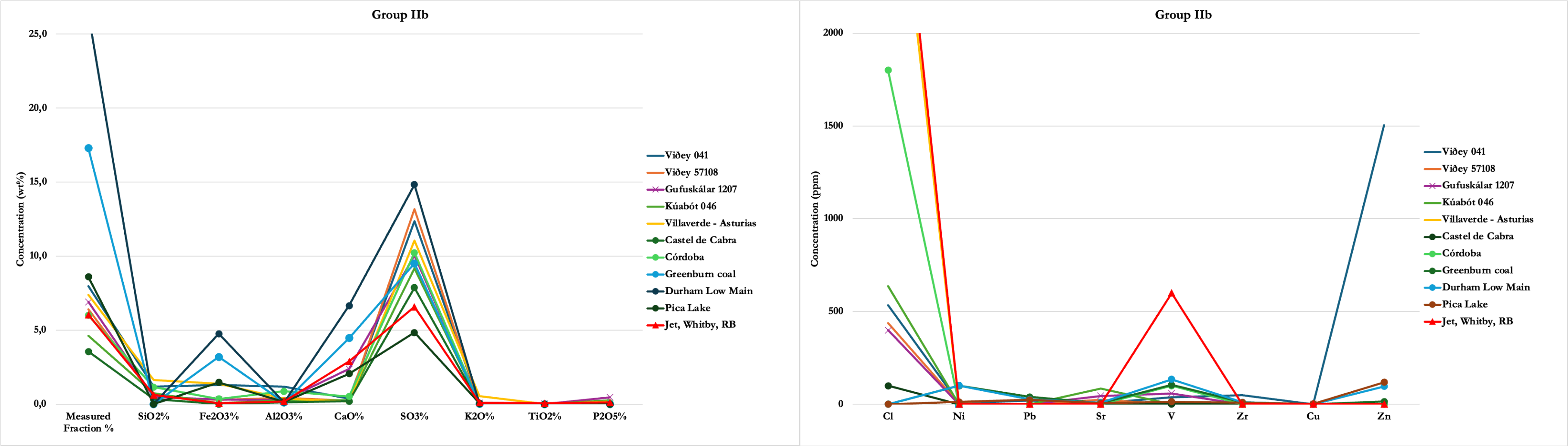

Figure 26. *Group IIb constitutes artifacts where SO_3 measured between 9-15%. The material is likely coal, potentially from Spain, but what type of coal is unclear.*

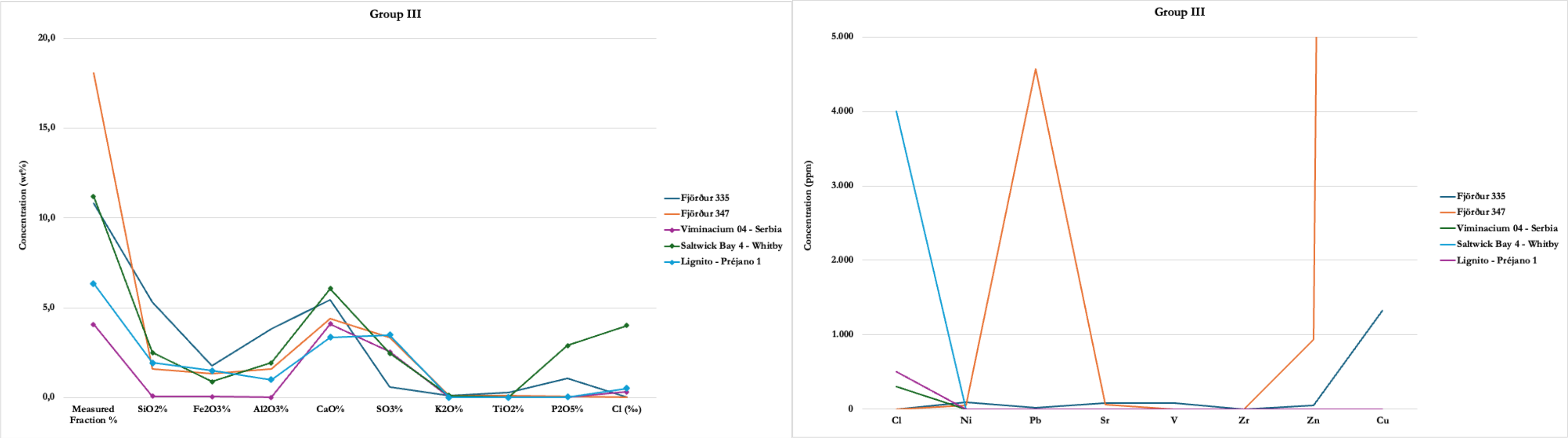

Figure 27. *In the initial grouping the two Fjörður beads landed in two separate groups based on their varied SiO_2 and Al_2O_3 concentrations. On further analysis of their elmental patterns they were placed together in a separate subgroup III based on their elevated CaO% concentrations.*

Group III - >5% Fe_2O_3+CaO

Two, badly preserved plain oval beads (2021-28-335 and -347) came from Fjörður in Seyðisfjörður, East Iceland (Fig. 1, Table 1) both from late Viking Age contexts. Bead 335 was found in situ in a disturbed boat grave and bead 347 was unearthed in a female grave with 10 other beads and close to two oval brooches[35]. The beads are of similar size, matted grey and they are both somewhat cracked. The geochemical measurements were taken at surfaces where the beads were least worn.

The beads were assigned to a separate group due to their high CaO% (4,4-5,5%) and moderate SiO_2 and Al_2O_3 concentrations (Fig. 27), compared to all the other measured artefacts. The elevation in CaO% content is statistically significant (Table A1). Both beads show peaks of Cu (ppm) but very low SO_3. Their Cl concentrations are below the limit of detection (<22 ppm). Bead 2021-28-347 was measured twice and both measurements showed unusually high peaks of Zn, Pb and Cu (~950, ~4500 and ~10000 ppm respectively). The beads are found in two different contexts and only bead 347 was found close to two metal brooches. Potentially the bead has been contaminated by the copper alloy in the brooches (Cu, Pb, Zn).

The main elemental patterns of oxides show geochemical similarities to an artefact from Viminacium in Serbia and raw materials from both Préjano in Spain (lignite) and Whitby in Great Britain (jet), but their trace elemental patterns show little resemblance (Fig. 27). This shows that the material from this artefact cannot be allocated a possible source through pXRF. Coal examples analysed by the BGS (2025) suggest that Cu can reach peaks of at least ~4500 ppm in coal, but in those samples Zn and Pb are relatively low and rarely reach ~100 ppm. It is likely that the two beads are made of coal, but a clear source cannot be determined. The possibility that the beads were made from Seyðisfjörður lignite cannot be ruled out.

Group IV - <5% $SiO_2+Al_2O_3$ and Fe_2O+CaO, *and <8%* SO_3

No statistical significance is detected between general elemental distributions of artefacts in group IV, but the samples have been manually split into subgroups directed by their elemental patterns for clarity and discussion. The artefacts were allocated three main subgroups IVa-c (Fig. 28). Group IVa encompasses artefacts with a slightly elevated Al_2O_3/Fe_2O_3% ratios and moderate SO_3%. Artefacts in group IVb have low Al_2O_3/Fe_2O_3% and CaO%. Group IVc has artefacts with CaO% concentrations >0,65%.

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[35] Ragnheiður Traustadóttir, 2026. Email communication regarding unpublished data for Fjörður, East-Iceland.

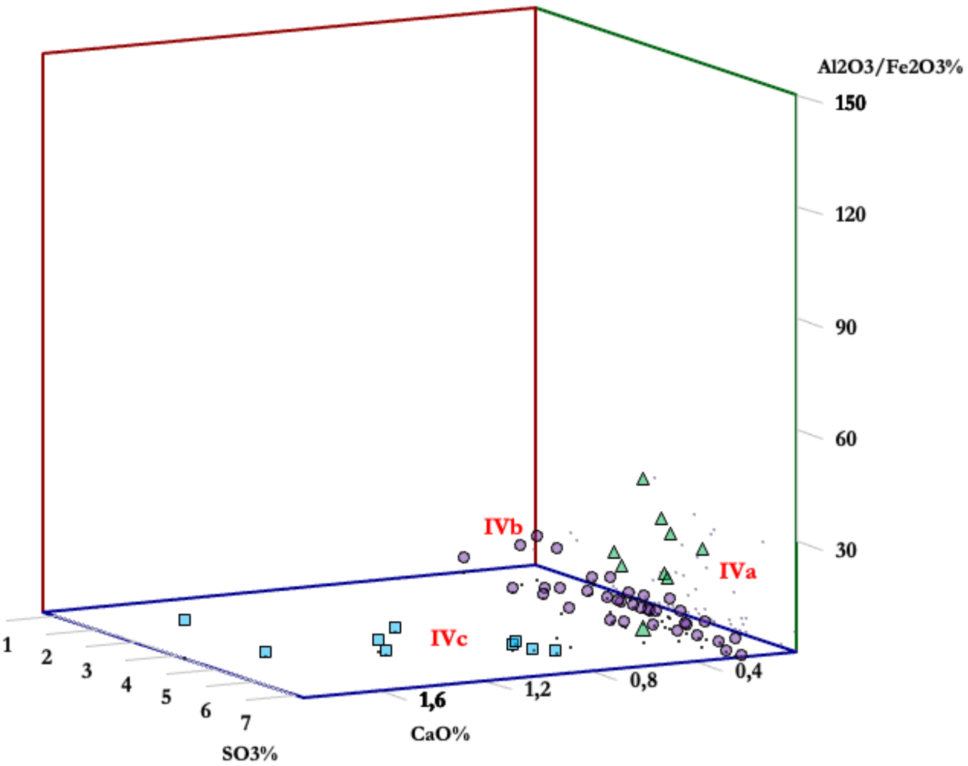

Figure 28. *Subgroups IVa-c. No statistical significance is detected between element distributions within artefacts in group IV, but the samples have been manually split into groups from their elemental patterns for clarity. Group IVa encompasses artefacts that most have slightly elevated Al2O*$_3$*/Fe*$_2$*O*$_3$*% ratios and moderate SO*$_3$*% (green triangles). Artefacts in group IVb have low Al2O3/Fe2O3% and CaO% (purple circles) but a wide range of SO*$_3$*% concentrations. Group IVc has artefacts with CaO% concentrations >0,65% (pale blue squares).*

Subgroup IVa

Group IVa encompasses beads with a slightly elevated Al_2O_3/Fe_2O_3% ratios and moderate SO_3% (Fig. 29). In this group are beads from Árbær (2021-20-71), two from Ásbúðarsafn (Ásb-1 and 4) and Reykholt (2003-25-91 and 2004-25-308), Staðarhóll (2021-52-1a), Kirkjubæjarklaustur (2002-70), Skálholt (S229) and three beads from Hólar (2002-37-1368, 2009-37-11224 og -11790). The Skálholt 229 bead was moved into this group despite a lower Al_2O_3/Fe_2O_3% ratio as it did not fit well anywhere else.

The bead from Árbær (71) is a faceted oval from a 18th-19th century farm midden[36]. The Ásb-1 and -4 beads from Ásbúðarsafn are also both faceted but rounder. The artefacts from Ásbúðarsafn do not have a recorded context and were all old artefacts without clear origin that were donated to the Icelandic National Museum. The beads are likely from 1500-1900 AD context, as were the beads that was found in the farm mound at Staðarhóll without clear context. Bead 1b is a simple bead but bead 1a is a round bead with a flower decoration.

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[36] Sólrún Inga Traustadóttir et al. 2022, pp. 29-30.

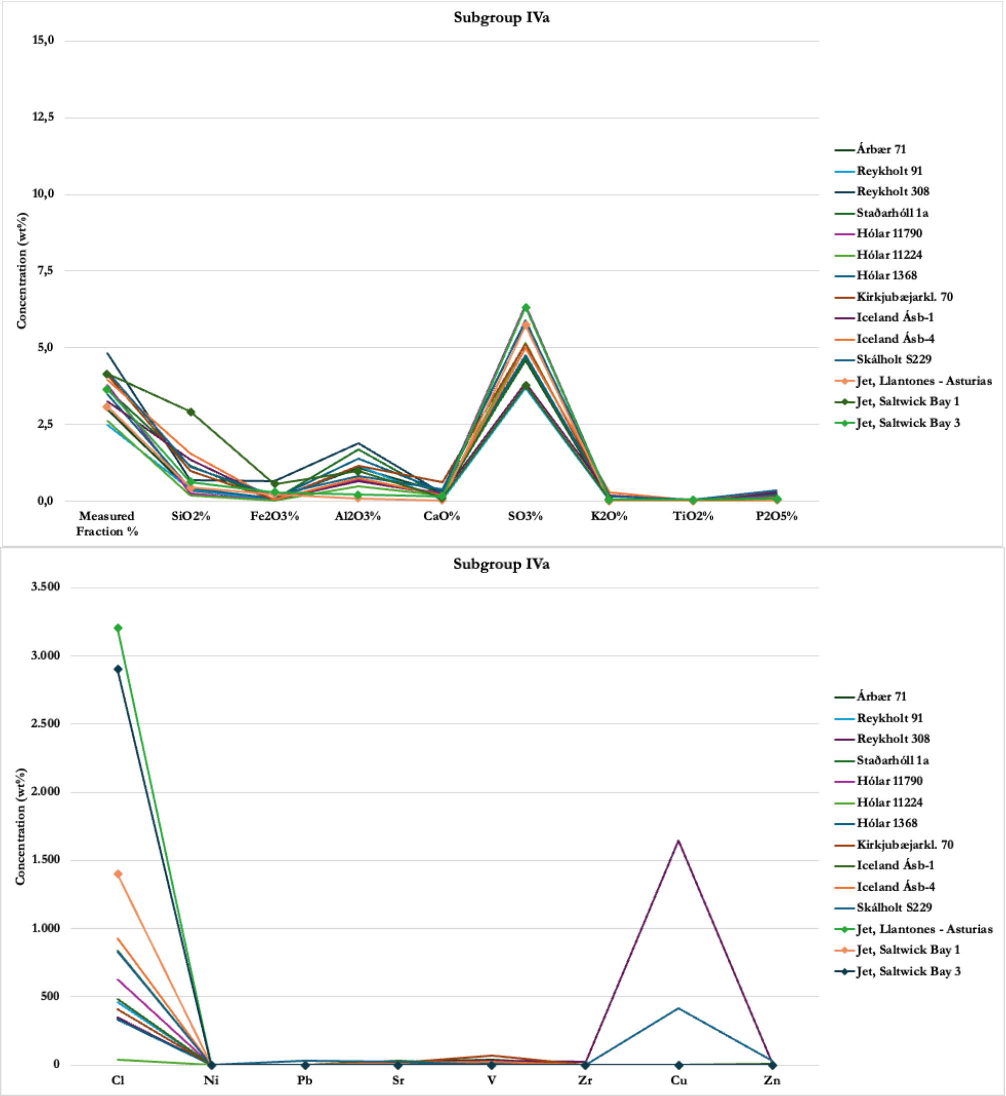

Figure 29. *All artefacts in group IVa. With regard to the main elements the artefacts in group IVa are similar to jet samples from Saltwick Bay 1-3, jet sample from Whitby analysed with the Niton XL5 plus and jet from Llantones in the Asturias area in Spain. However, the artefacts' Cl concentrations are too low (<1000 ppm). Only beads S229 and Reykholt 308 have an elevated Cu peak.*

Skálholt, Kirkjubæjarklaustur, Hólar and Reykholt are all ecclesiastical sites. The Kirkjubæjarklaustur bead (70) is a plain oval dated to 1600-1700 AD context. Reykholt bead 91 is an oval bead with a scallop decoration, found in the excavation of the church ruins in a context dated to 1778-1835 AD[37]. Reykholt bead 308 is a faceted oval, possibly a bead reused as a button, dated to 1500-1800 AD. The three Hólar beads have unclear contexts and are as yet undated. Two of the beads are plain rounded (11790) and oval (11224), and one is a faceted oval (1368). Finally, the Skálholt bead (S229) is from the church excavation 1954-1958[38]. It is a plain oval without clear context or age.

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[37] Guðrún Sveinbjarnardóttir 2012, pp. 189-190; 2016, pp. 35-36, 136-137 and 158 and Appendix 11.

[38] Kristján Eldjárn et al., 1988, pp. 28-32 and 76-77.

The main element patterns of the artefacts in group IVa are similar to jet samples from Saltwick Bay 1 and 3, and jet from Llantones in the Asturias area in Northeastern Spain. However, the artefacts' Al_2O_3 concentrations are elevated compared to Fe_2O_3, which fits badly with all Whitby samples but Saltwick Bay 1 (although there the SiO_2 content is too high), and artefact Cl concentrations are too low (<1000 ppm). Only beads S229 from Skálholt and 308 from Reykholt have an elevated Cu peak similar to beads in groups IVb - C and IVc - A.

Subgroup IVb

Artefacts in subgroup IVb have low Al_2O_3/Fe_2O_3% ratio and CaO% but a wide range of SO_3% concentrations (Fig. 30-31). They have been manually split into five branches A-E based on their elemental patterns for clarity and discussion. Within branch A (Fig. 32) there are beads that have trace element concentrations with peaks in Sr, V and Zr (ppm). Within B (Fig. 33) there are beads that have high Cl peaks (>1500 ppm). Branches C-D (Figs. 34-35) are beads that have a range of SO_3% and moderate Cl concentrations, with faint peaks in in Fe_2O_3% and/or Al_2O_3, Cl and Sr, but otherwise fairly flat elemental patterns. Branch E (Fig. 36) has low concentrations of both main and trace elements.

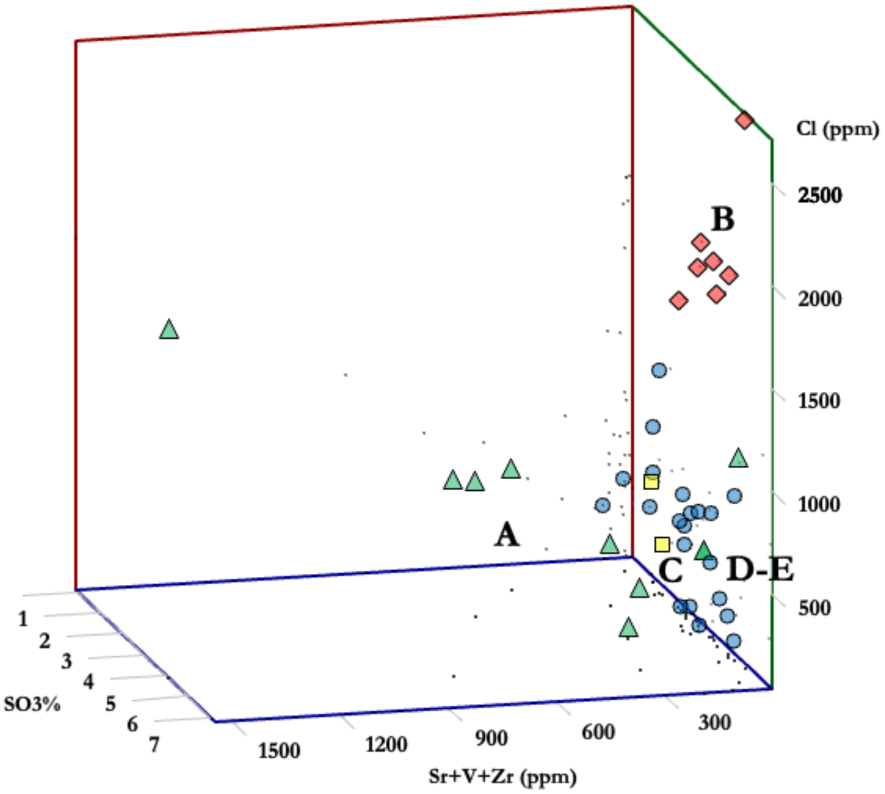

Figure 30. *All samples in subgroup IVb. No statistical significance is detected between the main element distributions within artefacts in group IV, but they have been manually split into five branches A-E (A green triangles; B red diamonds; C yellow squares; D-E blue circles) based on their elemental patterns for clarity and discussion.*

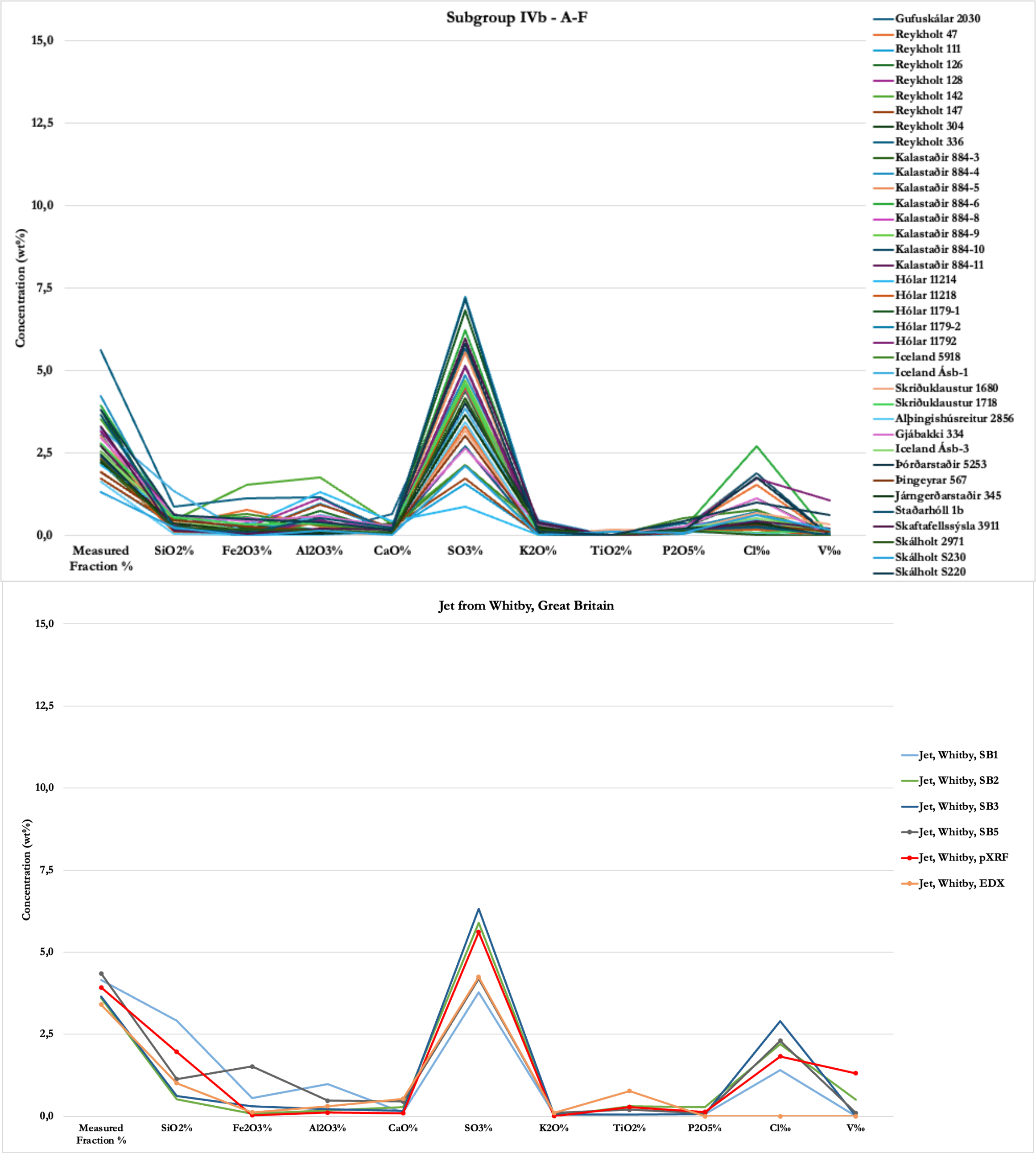

Figure 31. *General comparison of the chemical compositions of beads in group IVb and jet from Whitby, Great Britain (Menéndez Menéndez 2023, Harding, J. and Healy, F. (eds.), 2011, pXRF this project). The majority of beads in this group could potentially be from the Whitby area, but more detailed analysis is needed to defute or confirm this.*

Branch A

Within branch A (Fig. 32) are two beads from the Skálholt church excavations 1954-1958 (S220 and S230), one of unknown origin found within Skaftafellssýsla (Þjms. 3911), two from the ecclesiastical site at Hólar (1179-2 and 2009-37-11792) and one from Þingeyrar (2018-28-567). All the beads are plain and round or barrel shaped.

The two Skálholt beads have different contexts. The S220 bead is round and plain and was found within the filling of the stone coffin of bishop Þórður Þorláksson (1637-1697) and therefore

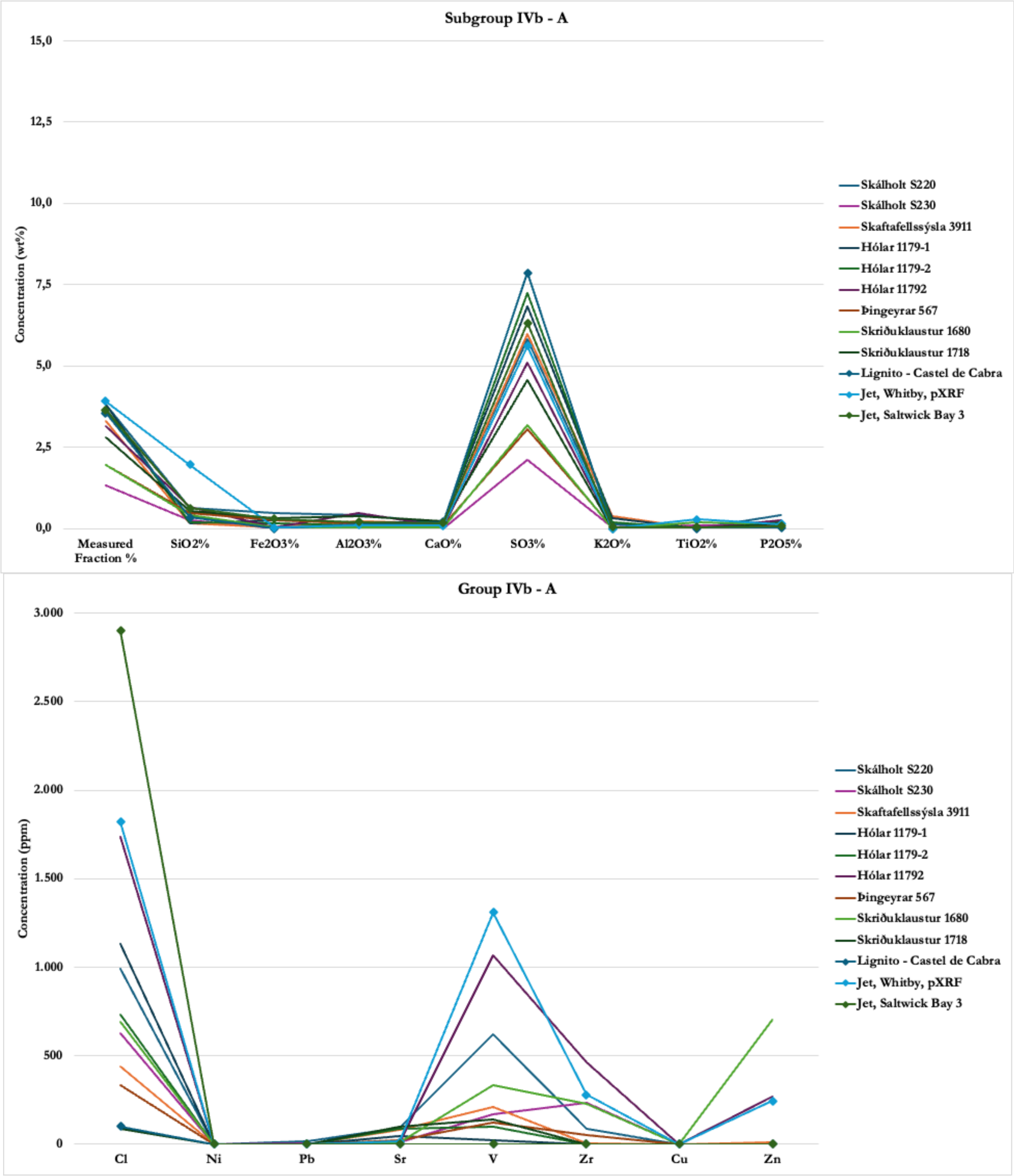

Figure 32. *Subgroup IVb - branch A. The beads on branch A all have elevated levels of Sr, V, Zr and/or Zn. The main elemental patterns resemble jet samples from Saltwick Bay 3 in Whitby and Spanish lignite (Castel de Cabra). However, the Saltwick sample has to high Cl levels and an otherwise flat trace element pattern while the lignite overall has very low trace element concentrations. The jet sample from Whitby analysed by the Niton XL5 Plus (pXRF) has similar main and trace elemental patterns, excluding the higher* SiO_2*% content.*

can be allocated a time period around 1600-1700 AD. Bead S230 is plain and barrel shaped but has an unclear context[39]. Bead 567 from Þingeyrar is plain and round but also has an unclear context[40] and can only be allocated a wide time period of 1100-1800 AD. The two Skriðuklaustur

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[39] Kristján Eldjárn et al., 1988, pp. 28-32 and 76-77.

[40] Sigrún Hannesdóttir 2026, email communication regarding unpublished excavation data.

beads 1680 and 1718 are from a medieval ecclesiastical site and likely dated to 1493-1554 AD[41]. The beads are both plain and barrel shaped. Bead 3911 from Skaftafellssýsla is also plain and barrel shaped, but a loose find that was donated to the Icelandic National Museum without a clear chronological or spatial context beyond a possible area[42]. Finally, the two Hólar beads 1179-2 and 11792 are plain barrel and oval beads of unknown context and can only be allocated a wide time period of 1100-1800 AD, at the present time.

The beads within branch A all have elevated levels of trace elements Sr, V, Zr and/or Zn (ppm). The main elemental patterns have the closest resemblance to jet samples from Saltwick Bay 3 in Whitby and Spanish lignite (Castel de Cabra). However, the Saltwick sample has too high Cl levels and an otherwise flat trace element pattern, while the lignite overall has very low trace element concentrations and high SO_3% (~8%). The jet sample from Whitby analysed by the Niton XL5 Plus (pXRF) for comparison has similar main and trace elemental patterns, excluding the higher SiO_2% content. Only Hólar 11792 and Skálholt S220 have V levels higher than 500 ppm.

Branch B

Within branch B (Fig. 33) are seven beads from Kalastaðir (884-4 to 6 and 10-11), one from Reykholt (2004-25-047), one from Hólar (1179-1) and one from Þórðarstaðir (Þjms. 5253).

The Kalastaðir beads are loose finds without context that were grouped together in a band and donated to the Icelandic National Museum[43]. The beads are all plain ovals and have been allocated a likely period between 1500-1900 AD. The Þórðarstaðir bead 5253 was also a stray find donated to the museum without clear context or chronology beyond the location. The bead is a large, bevelled rectangle, which is unusual. Reykholt bead 47 is a faceted oval found during the Reykholt church excavation and dated to 1500-1800 AD[44].

The samples have very similar flat main elemental patterns with a SO_3% peak, and high Cl concentrations (>1500 ppm), but otherwise flat trace elemental patterns. Only Kalastaðir bead 884-4 has an unusually high peak of Zn similar to Reykholt bead 336 in branch C and Iceland 5918 in branch E. The closest similarities are seen in samples from Saltwick Bay 3 in Whitby and the Asturias area in Spain (Llantones). However, these jet samples have very high Cl concentrations (>2500 ppm), which only Kalastaðir bead 884-6 matches.

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[41] Sarpur 2026; Steinunn Kristjánsdóttir 2004, bls. 19-21.

[42] Sarpur 2026.

[43] Sarpur 2026.

[44] Guðrún Sveinbjarnardóttir 2012, pp. 189-190; 2016, pp. 35-36, 136-137 and 158 and Appendix 11.

Branch C

Within branch C (Fig. 34) are only two beads (2002-25-142 and 2005-25-336) from the Reykholt church ruins. Bead 142 is an oval scallop from 1778-1835 AD contexts while bead 336 is a ridged oval from 1400-1600 AD[45].

Branches C and D (Figs. 34-35) are beads that have a range of SO_3% and moderate Cl concentrations, with faint peaks in Fe_2O_3% and/or Al_2O_3%, Cl and Sr, but otherwise fairly flat elemental patterns. Reykholt beads 142 and 336 have very similar elemental patterns with similarly elevated levels of Al_2O_3% and Fe_2O_3% and very low SO_3%. Bead 142 has a peak of Cu and 336 has a high peak of Cu and Zn. The closest elemental patterns are Saltwick Bay 5 from Whitby and peat from Tarragona in Spain, but the fit is by no means good.

Branch D

Within branch D (Fig. 35) there are tweleve beads in total. Those include five beads from Kalastaðir (884-3 and 8-9), two from Reykholt (2005-25-126 and 2006-25-304) and one from Gufuskálar (2015-40-2030), Staðarhóll (2021-52-1b), Hólar (2009-37-11218), Skálholt (2003-64-2971), Alþingishúsreitur (2009-2856), Járngerðarstaðir (Þjms. 345) and Ásbúðarsafn (Ásb-3).

The beads from Kalastaðir 884-3 and 8-9, are two plain ovals (3 and 9) and one faceted oval (8). Like all the other Kalastaðir beads they are without clear context and likely from 1500-1900 AD. Skálholt bead 2971 is round and faceted. It was found in a drain in the foundations of the early 20th century haybarn but is likely from an older disturbed context connected to the school dormitory (XX)[46]. The bead from Ásbúðarsafn (Ásb-3) is also round and faceted but without clear context (likely from 1500-1900 AD). The two Reykholt beads are both ovals with a scallop decoration dated to ~1200-1500 AD (304, distrubted contexts, sondage/post pit through graves) and 1400-1600 AD (126)[47]. Járngerðarstaðir 345 is also an oval with a scallop decoration but it is a stray find without context or date that was donated to the National Museum of Iceland[48]. The other four beads are all plain and round but without clear context. The Gufuskálar bead 2030 was found at a fishing station and likely dated to 1400-1800 AD[49] while the others from Hólar (11218, ecclesiastical site), Alþingishúsreitur (2856, urban activity site) and Staðarhóll (1b, loose find from an eroded section into the Staðarhóll farm mound) only have a wide, uncertain age range.

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[45] Guðrún Sveinbjarnardóttir 2012, pp. 189-190; 2016, pp. 35-36, 136-137 and 158 and Appendix 11.

[46] Elín Ósk Hreiðarsdóttir 2024, pp. 244-245.

[47] Guðrún Sveinbjarnardóttir 2012, pp. 189-190; 2016, pp. 35-36, 50-52, 136-137 and 158 and Appendix 11.

[48] Sarpur, 2026.

[49] Unpublished data.

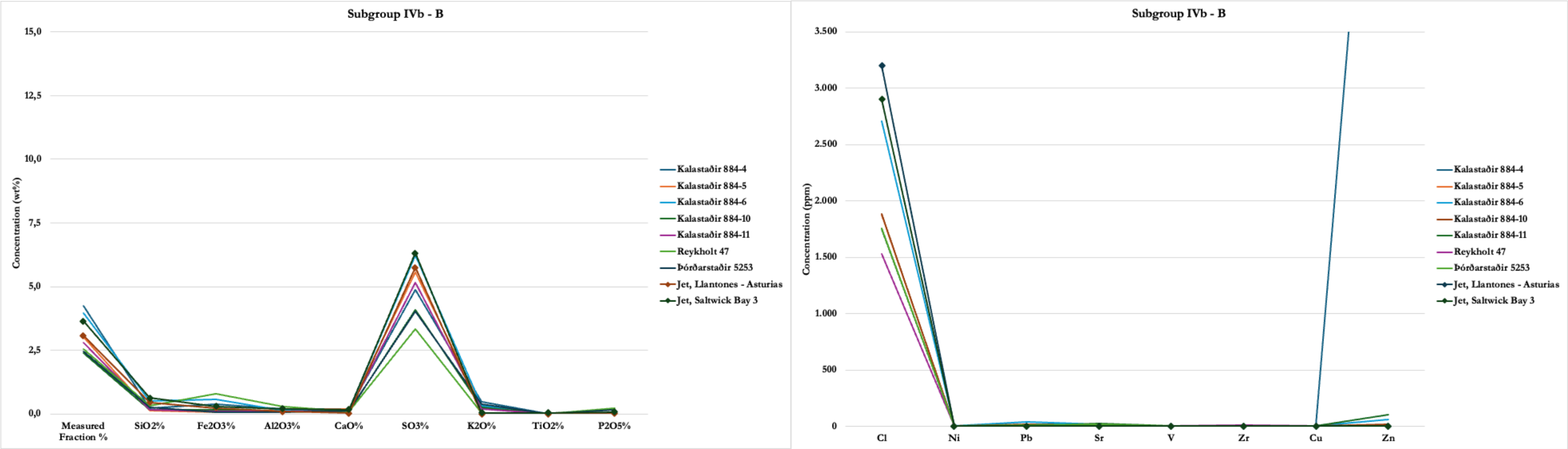

Figure 33. *Subgroup IVb - branch B. The beads have very similar main elemental patterns and high Cl concentrations, buth otherwise flat trace elemental patterns. Only Kalastaðir bead 884-4 has an unusually high peak of Zn similar to Reykholt bead 336 and Iceland 5918 in branch C.*

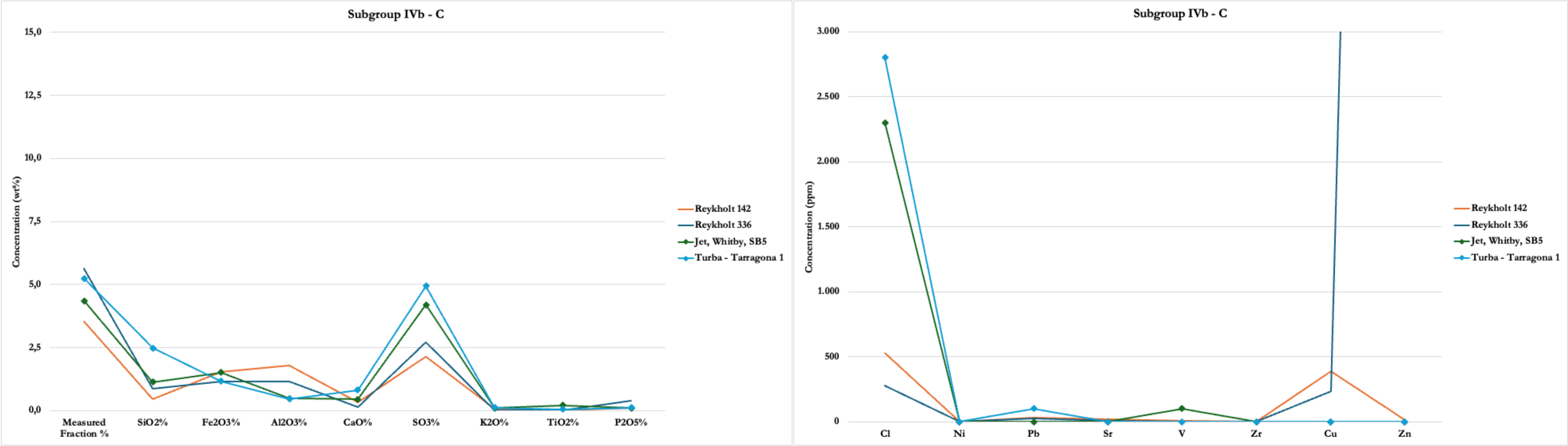

Figure 34. *Subgroup IVb - branch C. Reykholt beads 142 and 336 have very similar elemental patterns, although 336 shows a high peak of Zn. The closest elemental patterns are Saltwick Bay 5 from Whitby and peat from Tarragona in Spain, but the fit is by no means good.*

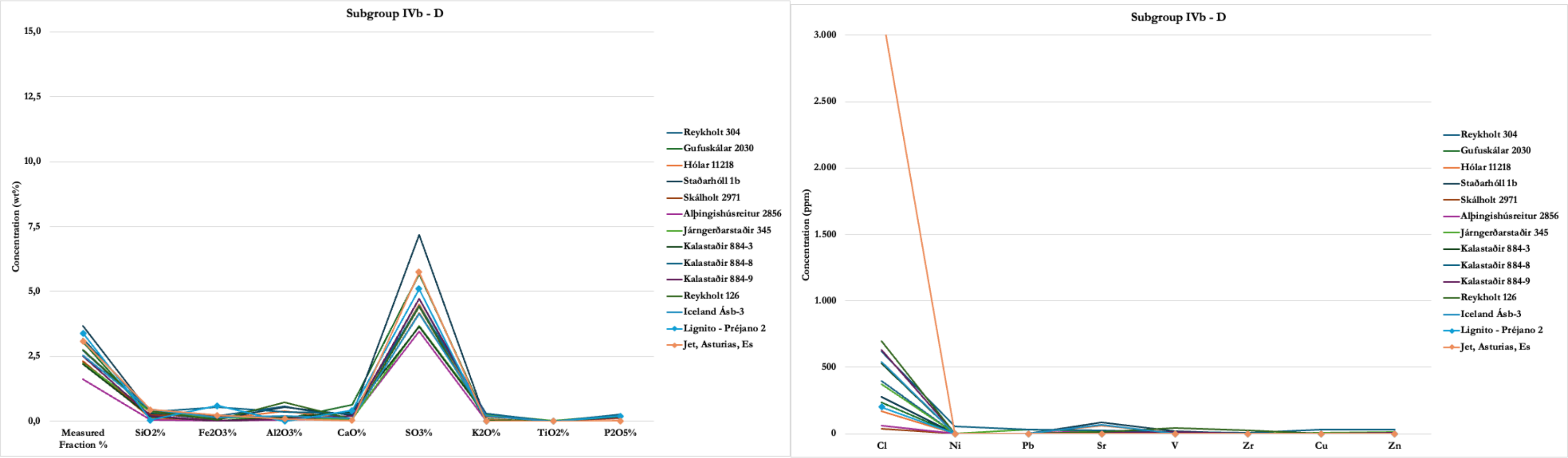

Figure 35. *Subgroup IVb -branch D. The beads have flat elemental patterns with peaks of* SO_3*% and Cl. Some have faint elevations of* Al_2O_3*% and Sr (ppm). The closest elemental patterns are jet from Asturias (Llantones) and lignite (Préjano) from Spain. Both raw material samples have lower* Al_2O_3*% and the jet sample has too high Cl concentrations (ppm).*

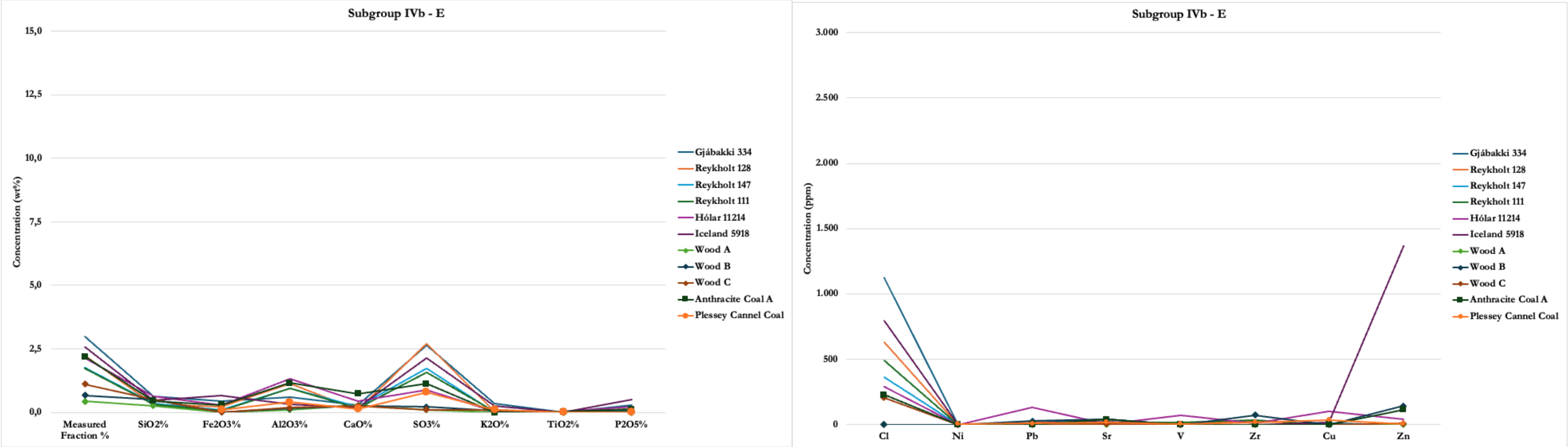

Figure 36. *Subgroup IVb - branch E. The beads are very organic rich (<3% MF) and have low concentrations of both main and trace elements. Only bead 5918 has a peak of Zn and Hólar bead 11214 has small elevations of Pb, V and Cu. The raw material elemental patterns with the closest similarities are anthracite (A) and Plessey cannel coal.*

Branches C and D (Figs. 34-35) are beads that have a range of SO_3% and moderate Cl concentrations, with faint peaks in Fe_2O_3% and/or Al_2O_3%, Cl and Sr, but otherwise fairly flat elemental patterns. The closest elemental patterns are jet from Asturias (Llantones) and lignite (Préjano) from Spain. Both raw material samples have lower Al_2O_3% concentration, and the jet sample has too high Cl (ppm).

Branch E

Within branch E (Fig. 36 are three beads from Reykholt (2004-25-111, 2004-25-128 and 2003-25-147), one from Gjábakki (Þjms. 334) and Hólar (2009-37-11214), and one with an unclear origin in Iceland (Þjms. 5918).

All the beads are ovals with scallop decorations, except the Hólar bead 11214 which is plain and round with an unclear context (1000-1800 AD). The beads from Gjábakki and Iceland (334 and 5918) are stray finds without context or date that were donated to the Icelandic National Museum. The Reykholt beads are all from the church foundations from contexts dated to 1500-1800 AD (111 and 128) and 1778-1835 AD (147).

The beads within branch E are all very organic (<3% MF) and have low concentrations of both main and trace elements. Only bead 5918 has a peak of Zn and Hólar bead 11214 has small elevations of Pb, V and Cu. The raw material elemental patterns with the closest similarities are examples of anthracite (A, pXRF) and Plessey cannel coal[50].

Subgroup IVc

Subgroup IVc (Fig. 38) has slightly elevated CaO concentrations of >0,65%. The subgroup was manually split into three branches A-C (Fig. 39-41) for clarity and comparison.

Branch A (Fig. 39) includes two beads from Skálholt (S217 and S218), one from Árbær (2019-36-026) and one from Reykholt (2006-25-181). The two Skálholt beads come from a medieaval church foundation excavated in the mid-20th century[51], in the north-western and southern parts of the choir. The beads are a plain oval and a round faceted, dating likely pre-16th century. The Árbær bead 26 is also round and faceted but comes from a farm mound midden likely dated to the 19th century, possibly slightly older. The Reykholt bead was found in the filling of a grave dated to 1778-1835 AD. The bead is oval with a scallop decoration and may be older than the grave.[52] The beads have similar main elemental patterns, but three beads all have elevated levels of Pb and Cu (ppm). The Árbær 26 is the

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[50] BGS Britain, 2025.

[51] Kristján Eldjárn et al., 1988, pp. 28-32 and 76-77.

[52] Guðrún Sveinbjarnardóttir 2012, pp. 189-190; 2016, pp. 35-36, 136-137 and 158 and Appendix 11.

only one that does not. Elemental patterns show similarities to examples of lignite from Spain and Whitby jet from Saltwick Bay, but the fits are imperfect.

Branch B (Fig. 40) includes two beads from Skálholt (2003-64-2392) and the Kalastaðir Group (884-1). The Skálholt bead is round and plain and was found in a floor layer of the dining room and chambers (IV), dated to 1760-1780 AD[53]. Bead K884-1 is also round and plain but it is a stray find, possibly from 1500-1900 AD. All the Kalastaðir beads are loose finds without clear context that were at some point looped together on a band and donated to the Icelandic National Museum[54]. Their main elemental patterns are fairly similar, with low levels of all the main elements, except SO_3%. The Skálholt bead shows elevated levels of Sr in its trace elemental pattern, while the K884-1 bead has faintly elevated levels of V and Zr. The patterns are similar to e.g. general anthracite coal, Spanish lignite and Whitby jet (Saltwick Bay 2 and 3), but the fits are imperfect.

Branch C (Fig. 41) includes another bead (2021-20-043) from the Árbær farm midden, one from Skriðuklaustur (2003-36-400) and one from Gufuskálar (2011-253). The Árbær 43 bead is round and faceted. The Skriðuklaustur bead 400 is from a medieval ecclesiastical site and likely dated to 1450-1600 AD. The bead is oval with a scallop decoration[55]. Finally, the Gufuskálar bead 253 was found in an excavated midden deposit outside a fishing hut, that likely dates to 1400-1800 AD[56]. This bead is also round and plain. Branch C has slightly elevated levels of SiO_2 and CaO% but a farily flat trace elemental pattern, except the elevated Cl (ppm). The elemental patterns show similarities to Spanish lignite (Léon) and Whitby jet from Runswick Bay in Great Britain, but the fit is imperfect as Cl and V levels are too low, at least compared to the Whitby jet.

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[53] Elín Ósk Hreiðarsdóttir 2024, pp. 244-245.

[54] Sarpur.is, 2026.

[55] Sarpur 2026; Steinunn Kristjánsdóttir 2004, bls. 14-15.

[56] Lilja Björk Pálsdóttir and Óskar Gísli Sveinbjarnarson 2011, pp. 21-23 and 32.

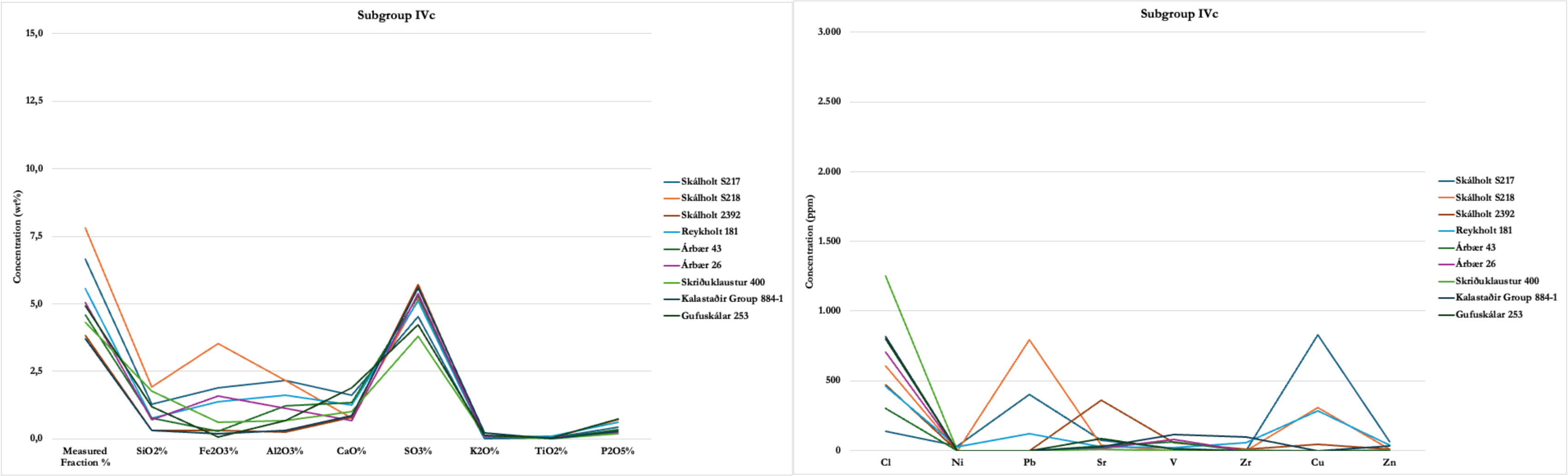

Figure 38. *Subgroup IVc has slightly elevated CaO concentrations of >0,65%. The group was manually split into three branches A-C (Fig. 39-41) for clarity and comparison.*

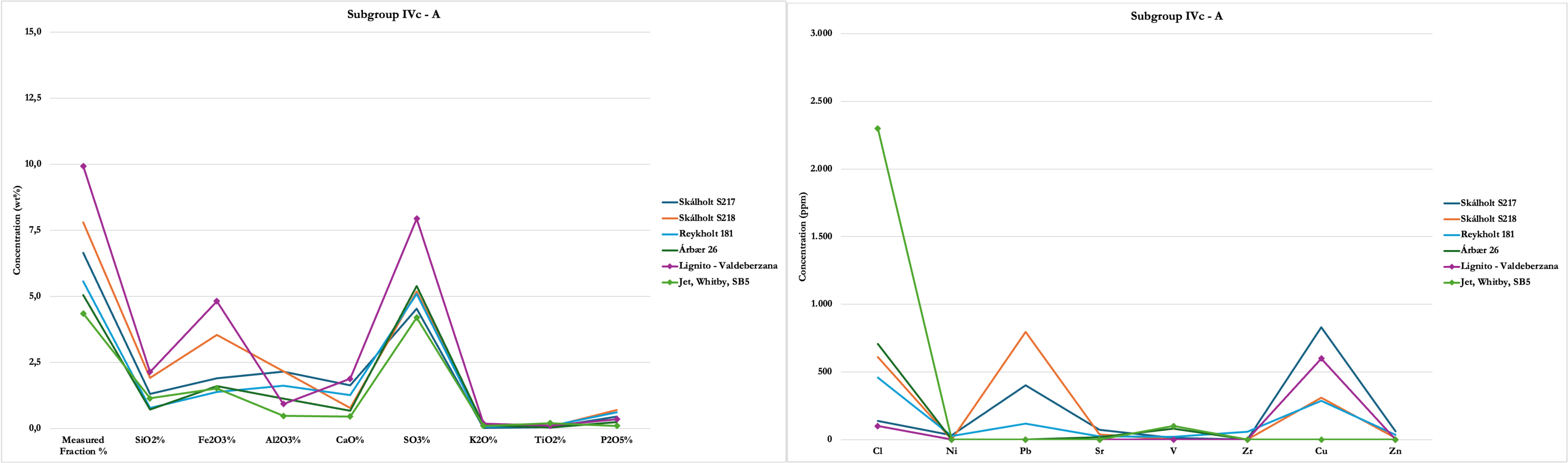

Figure 39. *Group IVc - branch A. The beads have similar main elemental patterns, but three beads have elevated levels of Pb and Cu (ppm). The Árbær 26 is the only one that does not. Elemental patterns show similarities with examples of lignite from Spain and Whitby jet from Saltwick Bay, but the fits are imperfect.*

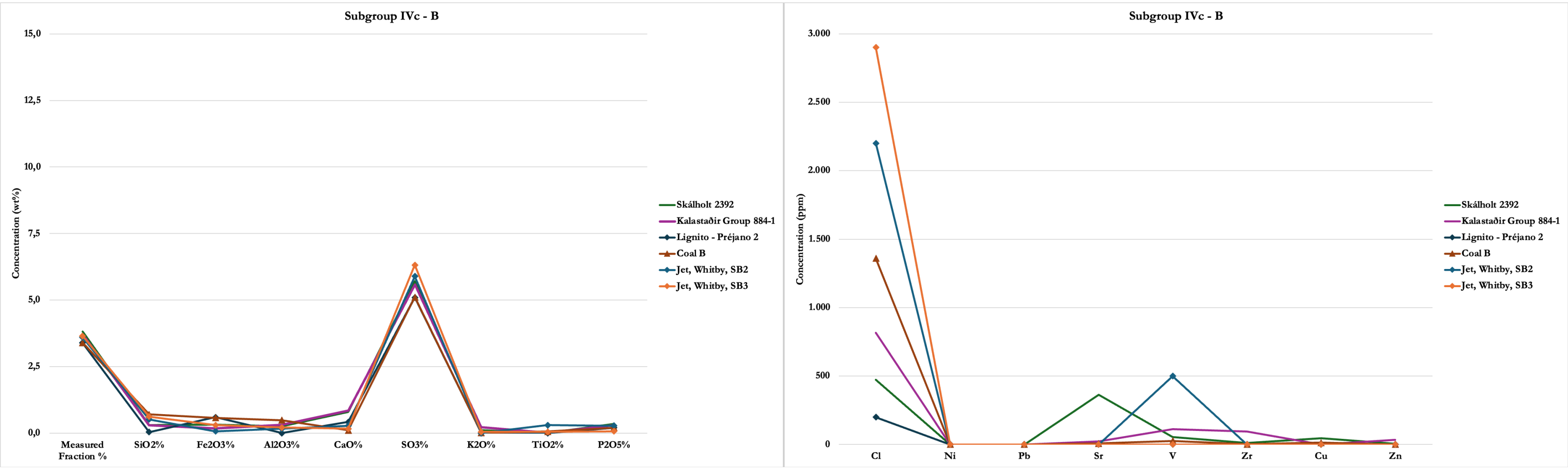

Figure 40. *Subgroup IVc - branch B. The main elemental patterns of the Skálholt 2392 and K884-1 beads are fairly with low levels of all elements except* SO_3*%. The Skálholt bead shows elevated levels of Sr while the K884-1 bead has faintly elevated levels of V and Zr. The elemental patterns are similar to e.g. general anthracite coal, Spanish lignite and Whitby jet (Saltwick Bay 2 and 3) but the fits are imperfect.*

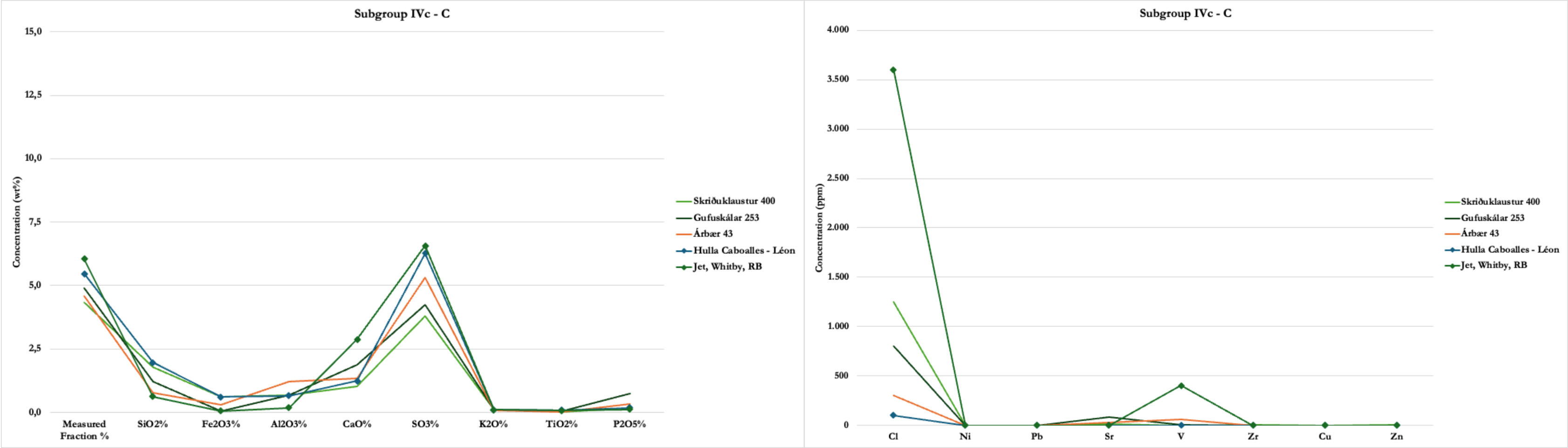

Figure 41. *Subgroup IVc - branch C has slightly elevated levels of* SiO_2 *and CaO% but a farily flat trace element pattern, excepting the elevated Cl. The elemental patterns show similarities to Spanish lignite (Léon) and Whitby jet from Runswick Bay, but the fit is imperfect as Cl and V levels are too low, at least compared to the Whitby jet.*

The Trace Elements

The trace elements that had clear and consistent concentrations and potentially useful variations were chlorine (Cl), nickel (Ni), lead (Pb), strontium (Sr), vanadium (V), zircon (Zr), copper (Cu) and zinc (Zn), along with barium (Ba), rubidium (Rb) and mercury (Hg). Comparisons of trace elemental patterns are often difficult. Published research does not always include all elemental concentrations needed for helpful comparisons of raw materials and in pXRF they must be interpreted with caution and considered semiquantitative at best. The distributions of published jet sample concentrations from Spain and Whitby are not very accurate as their finer trace elemental patterns are unclear.

It is unclear whether Cl concentrations can be used in any way to separate or identify specific raw materials. They seem to have a wide range both within and between shales, coals and jets. Combined trace element concentrations of Ba, Sr and Rb vs V and Hg (ppm) can be used to demonstrate how artefact materials in group I are more likely to be shales, rather than coals or jets (Fig. 42). There the Grónes armlet and one sample (STORM 635) from Saltwick Nab Quarry land close together again, which strengthens the idea that the armlet raw material originates from there.

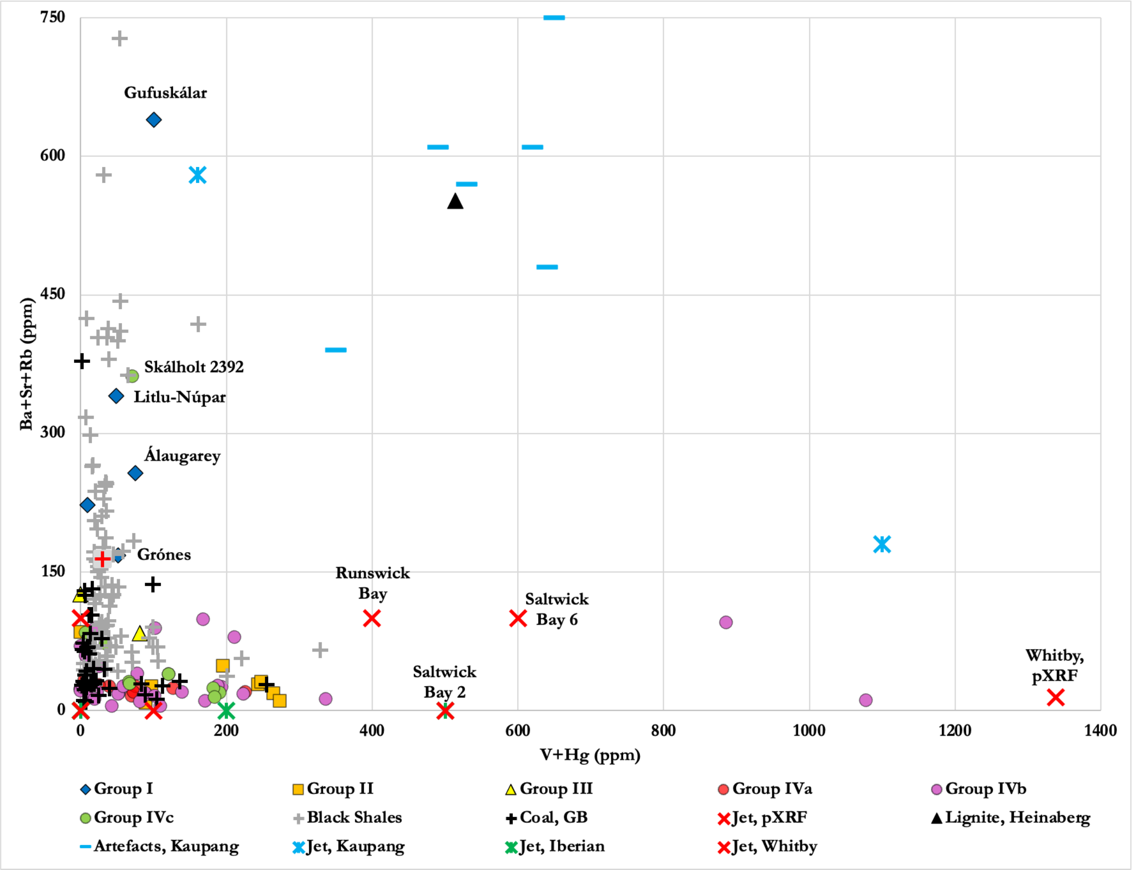

Figure 42. *Trace element concentrations of Ba, Sr and Rb vs V and Hg (ppm) can potentially be used to demonstrate how materials in group I are more likely to be shales, rather than coals or jets. Note how the Grónes armlet and a sample from Saltwick Nab Quarry (STORM 635; red cross with light grey background) land close together. Distributions of the jet samples are not very accurate as pXRF data on trace elemental patterns are unclear.*

Only artefacts in group I show elevated levels of Ba (>50 ppm) and Sr (>100 ppm), again suggesting mineral rich materials. Bead 2392 from Skálholt also (and only) exhibits a high peak of Sr (>350 ppm). The bead is found in a floor layer in the Skálholt dining room so a potential reason for this singular Sr peak is unclear.

British coals and shales commonly have low concentrations of V (<150 ppm, Fig. 42) while concentrations above that are rarer, but they can reach at least 4500 ppm in coals. The artefact collection generally exhibits V concentrations <150 ppm common to both coals and shales, but a few demonstrate higher peaks. This could potentially suggest that they are more likely to be coals, but this needs further testing. Two beads from Skálholt (663) and Reykholt (49) show similar levels (~255 ppm, low Hg) and judging from their elemental patterns they likely have a common source. Skálholt bead S220 has elevated levels of both V and Hg (~600 and 250 ppm respectively). Skriðuklaustur bead 1680 has >300 ppm V and Hólar bead 11792 shows a peak ~1000 ppm (very low Hg).

General trace elemental analyses of British shales and coals also suggest that peaks of Pb, Cu and Zn (ppm) likely cannot be considered unusual until they exceed at least >200 ppm for Pb, and >500 ppm for Zn and Cu (Fig. 43). A few beads demonstrated elevated peaks in Cu, Zn and/or Pb but most do not go beyond natural peaks often measured in both coals and shales. The two beads from Fjörður 335 and 347 in group III found in a late Viking Age burial, both exhibit elevated levels of Cu (>1000 ppm), and bead 347 also has unusually elevated levels in Pb and Zn. It has likely been contaminated by association with metal artefacts (e.g. brooches) within the same context. None of the artefacts analysed show any elevation (>10 ppm) in either silver (Ag) or gold (Au), except bead 335 from Fjörður that has a slight elevation in silver concentration, but it is very weak (~35 ppm). Tin (Sn) concentrations in all more organically pure beads never reach >10 ppm.

Three beads show elevated levels of both Pb and Cu: Skálholt beads S217 and S218 along with Reykholt bead 181. Bead S218 also has elevated levels of cobalt (Co, >250 ppm). Bead S229 from Skálholt, and Reykholt beads 142 and 308 have elevated levels of Cu (~400+ ppm). The only other bead with an elevated Pb level is the Gufuskálar bead 1276 (>400 ppm) in group I which is likely mineral rich Icelandic lignite. Finally, four beads have elevated levels of Zn (>700 ppm): a bead from Viðey (V90-41), Þjms. 5918 (unknown source), Skriðuklaustur (1680), Reykholt (336) and Kalastaðir bead 884-4. These trace elemental peaks in organic rich material beyond general concentrations could potentially suggest external metal contaminations from associated archaeological contexts or artefacts (e.g. other metal artefacts or jewellery fittings), although mineral enrichment of raw materials in situ prior to exploitation cannot be ruled out. It is possible that beads with elevated Cu, Zn and/or Pb concentrations may have contact traces from other metal fittings, beads or crosses (likely brass, or possibly enamels) that may have been positioned beside them on a cord or string (e.g. on a rosary).

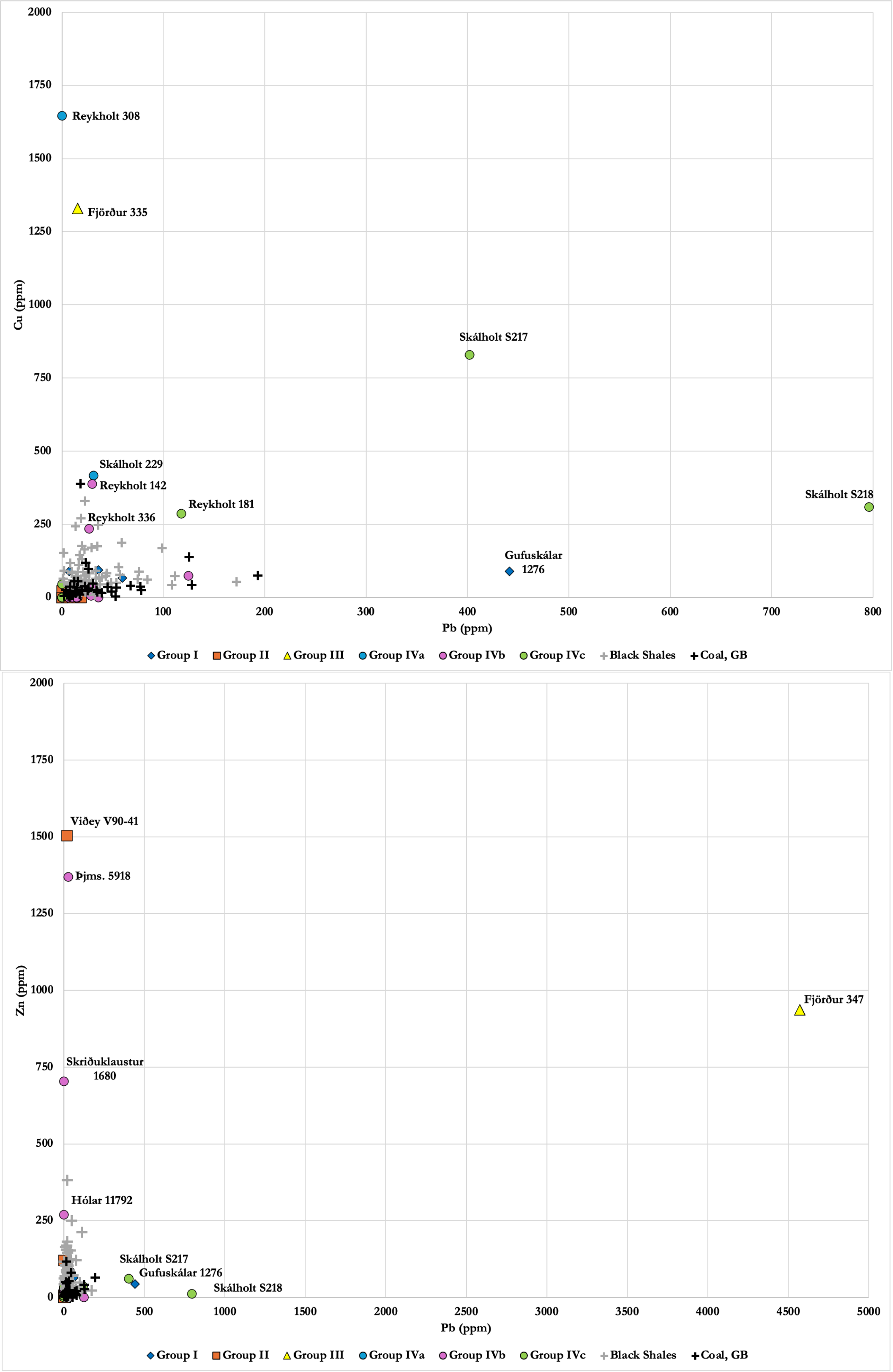

Figure 43. *Outliers within the four groups with regards to trace element concentrations of Pb, Cu and Zn (ppm). Peaks of these elements likely cannot be considered unusual until they exceed at least 200 ppm for Pb, and 500 ppm for Zn and Cu. Peaks beyond those concentrations could potentially suggest external contaminations.*

Purity and Provenance

From the studies of Plather of Kaupang artefacts[57] and Menéndez Menéndez of Spanish materials[58] it is clear that distinguishing between jets and coals only through XRF is difficult and often impossible. Examples of concentrations of the main elements (Si, Al, Fe, Ca and S) in shales, jets and generic coals can be used to separate the raw material types into organic rich, intermediate and mineral rich (Fig. 44), as a first step in determining raw material types and moving closer to possible sources. The geochemistry of generic coals and shales used here are only for demonstration, mainly to show the difference between mineral poor organic materials (jets and coals) and the more mineral rich shales, and between silica rich and calcium rich materials. Perhaps Saltwick Bay sample 6 should be classified as shale rather than jet, at least that singular jet sample is a very mineral rich outlier (Fig. 44). All Icelandic artefacts in group I are classified as intermediate to mineral rich, while groups II-IV are all organic rich.

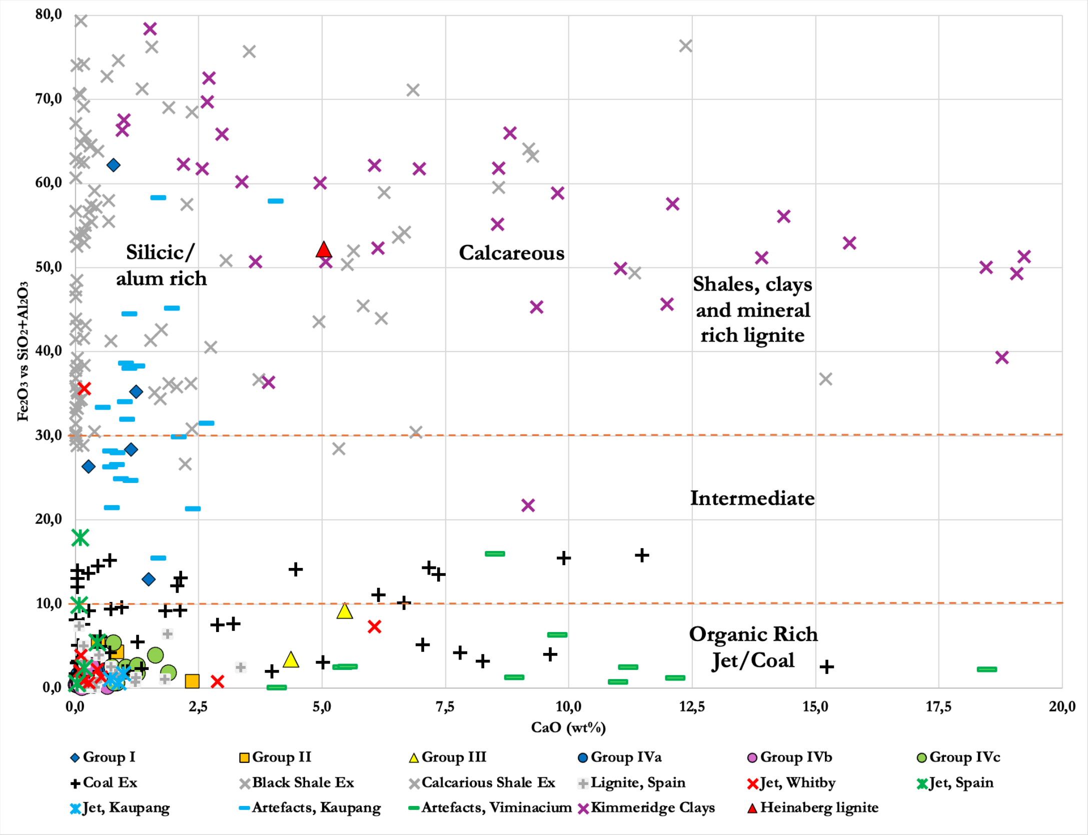

Figure 44. *Examples of concentrations of the main elements (Si, Al, Fe and Ca) in shales and clays, lignites, jets and generic coals can be used to separate the raw material types into organic rich, intermediate and mineral rich (see also Plather 2011). The geochemistry of coals, clays and shales are mainly to demonstrate visually the difference between pure organic materials and mineral rich ones.*

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[57] Plather 2011, pp. 133-134.

[58] Menéndez Menéndez 2023, bls. 760-778.

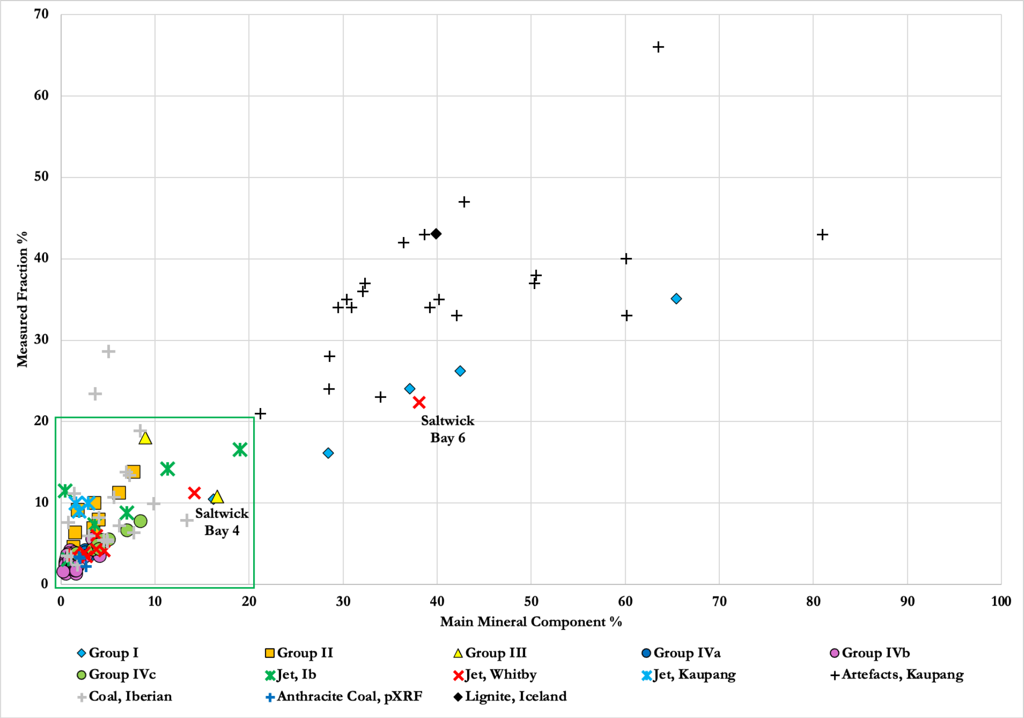

Figure 45. *General composition range of most jet (green box) from Spain, Portugal and Whitby suggests that most jet that has been analysed with pXRF analyses has both a measured fraction (%) and main mineral components (wt%) <20%.*

At this point in time general composition range of pXRF analysed jet samples from Spain and Whitby suggests that most jet has a measured fraction (%) and main mineral components (wt%) <20% (Fig. 45). Attempting to estimate the organic purity of the Icelandic material the measured fraction (%) and the main mineral component (wt%) were used to calculate a basic *purity coefficient* (P), giving the raw material a simple ranking and grouping them into zones that can be developed and honed as more samples are analysed with pXRF during preliminary geochemical research. The range of purity was evaluated using a two-parameter purity distance metric based on bulk mineral content (F) and the pXRF-derived measured fraction (M). Bulk mineral content was calculated as the sum of the main elements (SiO_2, Al_2O_3, FeO, CaO, K_2O and TiO_2 (wt%)). The pXRF measured fraction was defined as 100 minus the pXRF balance (%). Samples were ranked by Euclidean distance with a pure organic endmember (M = 0, F = 0) as a base line, with lower distances indicating higher organic purity.

F = pXRF-measured fraction (%) → *measureable elemental signal (100% - pXRF balance %)*

M = bulk mineral component (wt%) → *sum of* SiO_2*,* Al_2O_3*,* Fe_2O_3*, CaO,* K_2O *and* TiO_2

$$P = \sqrt{M^2 + F^2}$$

Fresh wood samples were analyzed as a natural organic reference material and yielded values <2. This range was used to define the lower boundary of absolute organic purity, with increasing distances reflecting progressively greater inorganic contribution (Table 2).

Table 2. *Suggested range of purity from fresh wood up to quartz minerals and glass. These ranges need fine-tuning as more data is gathered in pXRF research of jets, coals and shales used in artefact production.*

Purity Zones (P)	Classification
<2	Organic, fresh wood and pure amber (and plastic)
2–10	Very high organic purity (amber/cannel coal/best jet)
10–25	High organic purity (coal/jet)
25–50	Moderate organic purity (mineral-rich coal and jet, very organic rich shale (silicic and calcareous).
50–80	Low organic purity (oil/black shale and lignite), both silicic and calcareous
>80	Mineral-dominated sediments, rocks and mineral compounds (e.g. glass, quartz, zeolites)

Based on observed values, jet commonly occupies an organic-dominant range (P ≈ 3–25), equal to and bounded by coal at lower distances and with more mineral rich shales at higher distances. Samples with values exceeding ~25 exhibit increasing mineral fraction and are perhaps more appropriately classified as organic-rich shales and/or mineral rich coal. Compositions and concentrations of mineral matter in coal (ash)[59] can vary greatly (Text box 1). Typical oil shales

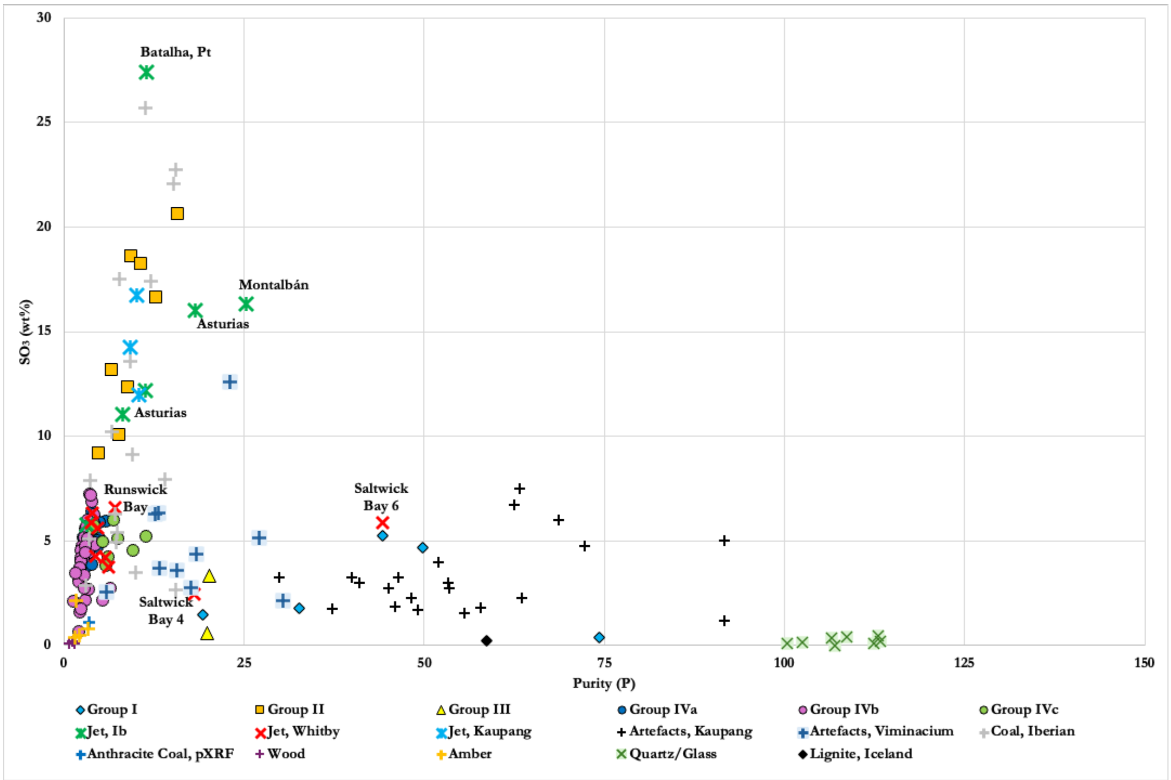

Figure 46. *Using the purity coefficient (P) and SO$_3$ (wt%) levels, jet from Whitby and Spain can easily be separated. Whitby jet generally has low S concentrations and estimated purity between 3,8-18,1 (average 6,7). Jet from Spain generally has high S concentrations and an estimated purity between 3,2-25,2 (average 13,2). As yet, only jet from Llantones in the Asturias region cannot be separated geochemically from Whitby jet by pXRF.*

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[59] Rotaru and Boboc 2010, pp. 429-430; Bhatt et al. 2019, p. 4.

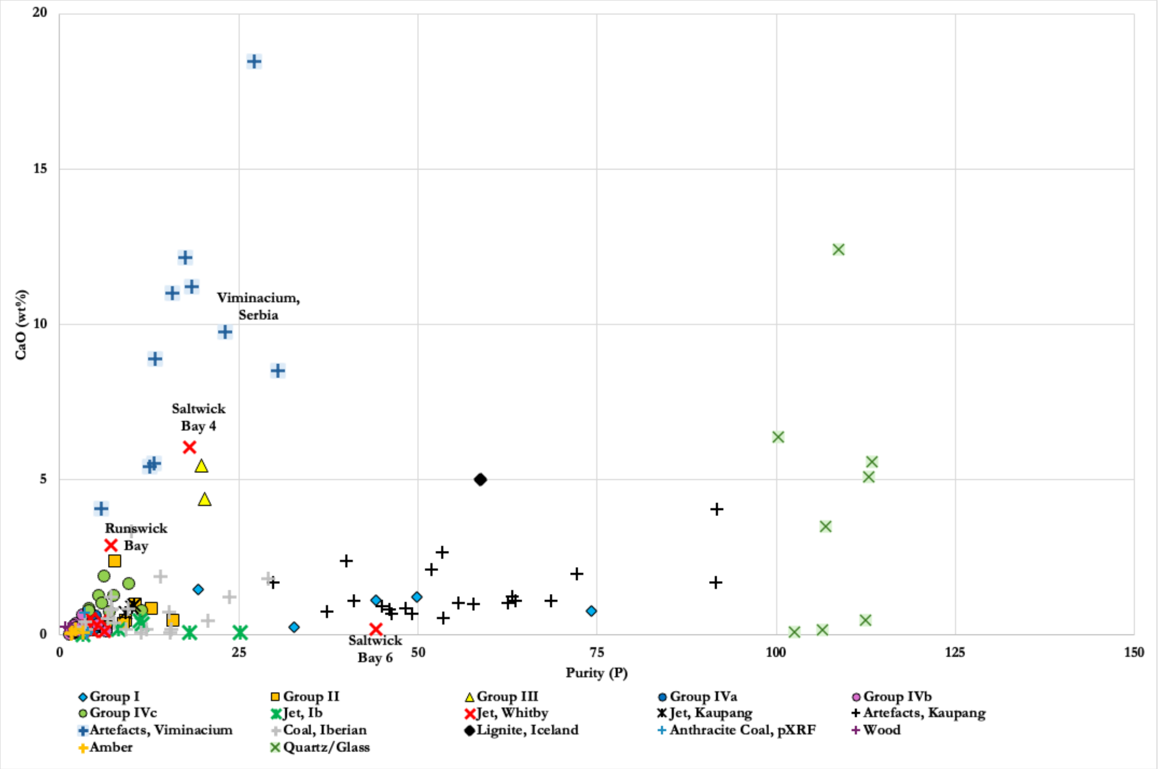

Figure 47. *Coals and shales with elevated CaO% levels can largely be separated from jets originated in Whitby in Great Britain and Asturias in Spain. Shales commonly have a higher bulk mineral component (M) and measured fraction (F) which separates them from pure coals and jets.*

(commonly marls, CaO% rich) and black shales (more silicic, SiO_2% rich) exhibit substantially higher M- and F-values, reflecting their elevated mineral content (Fig. 44), despite their higher organic fraction when compared to other sedimentary rock.

Using the purity coefficient (P) and SO_3 (wt%) levels, most jet from Whitby and Spain can easily be separated (Figs. 46). Whitby jet generally has low S concentrations and estimated purity between 3,8-18,1 (average 6,7) with one outlier (SB6 = 44,2). Jet from Spain generally has high S concentrations and an estimated purity between 3,2-25,2 (average 13,2). As yet, only jet from Llantones in the Asturias region cannot be separated geochemically from Whitby jet by pXRF, but more data is needed. Coals, oil shales and other organic materials with elevated CaO% levels can largely be separated from British and Spanish jet, as is demonstrated by Menéndez Menéndez´s[60] analysis of artefacts from Viminacium in Serbia (Fig. 47). Shales also commonly have a higher bulk mineral component (M) and measured fraction (F) which separates them from pure coals and jets (Figs. 44 and 45).

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[60] Menéndez Menéndez 2023, bls. 760-778.

Just over 80% of the Icelandic artefacts analysed can be said to be of very high organic purity (P=0-10; Fig. 49). Whether they are made of jet, cannel coal or general coal cannot be ascertained with certainty through pXRF but if they are jet, which some likely are, their primary source is most likely to be the Whitby area in Great Britain. Only the eight artefacts in Group II could potentially be Spanish jet from the Asturias region in Northeastern Spain, although generic, sulphur rich coal cannot be ruled out. This needs further testing. There is no indication that any single type of bead (round/oval/barrell etc.) has a similar or any one specific source (Fig. 48).

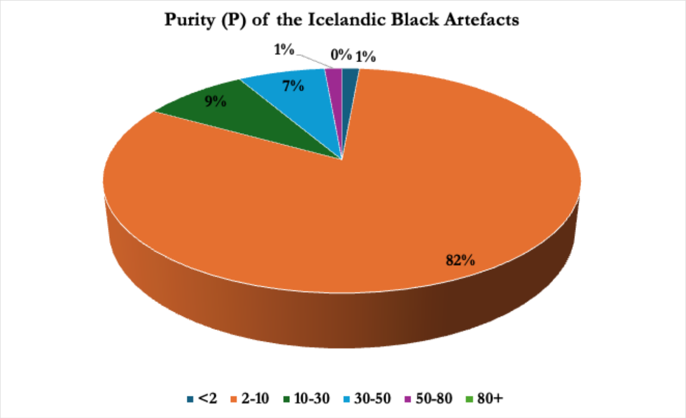

Figure 49. *Over 80% of the artefacts found in Iceland are made of materials of very high organic purity.*

Artefacts in group I are more likely to be mineral rich coal and black shale, rather than jet (Table 3). The Grónes and Álaugarey armlets, along with the bead from Litlu-Núpar, could possibly be mineral rich coal or black shale from Saltwick Bay in Whitby (SB6 P=44,2). The Álaugarey armlet and the bead from Litlu-Núpar (P=44-50) could be from the same material source and they show similarities with beads and armlets found in Kaupang in Norway. The Grónes armlet is most likely alum shale, very possibly from Saltwick Nab in Whitby. The Hólmur bead could be coal (P=19) and shares similarities with samples from Whitby, but also with lignite from Northern Spain. The Gufuskálar bead also shows similarities to lignite from Northern Spain.

The beads in group II (P=5-16) show similarities to jet from Bocamina in the Asturias region in Northeastern Spain, but also to lignite from Valle de Valdeberzana and a single artefact from Léon, both in northern Spain. This needs further testing.

The two beads from Fjörður in group III (both P=20) are likely to be mineral rich coal, but the beads are badly preserved and likely contaminated by other artefacts and/or grave filling found in the same context. It cannot be ruled out that the Fjörður beads, along with Gufuskálar bead 1276 in group I, could be Icelandic lignite.

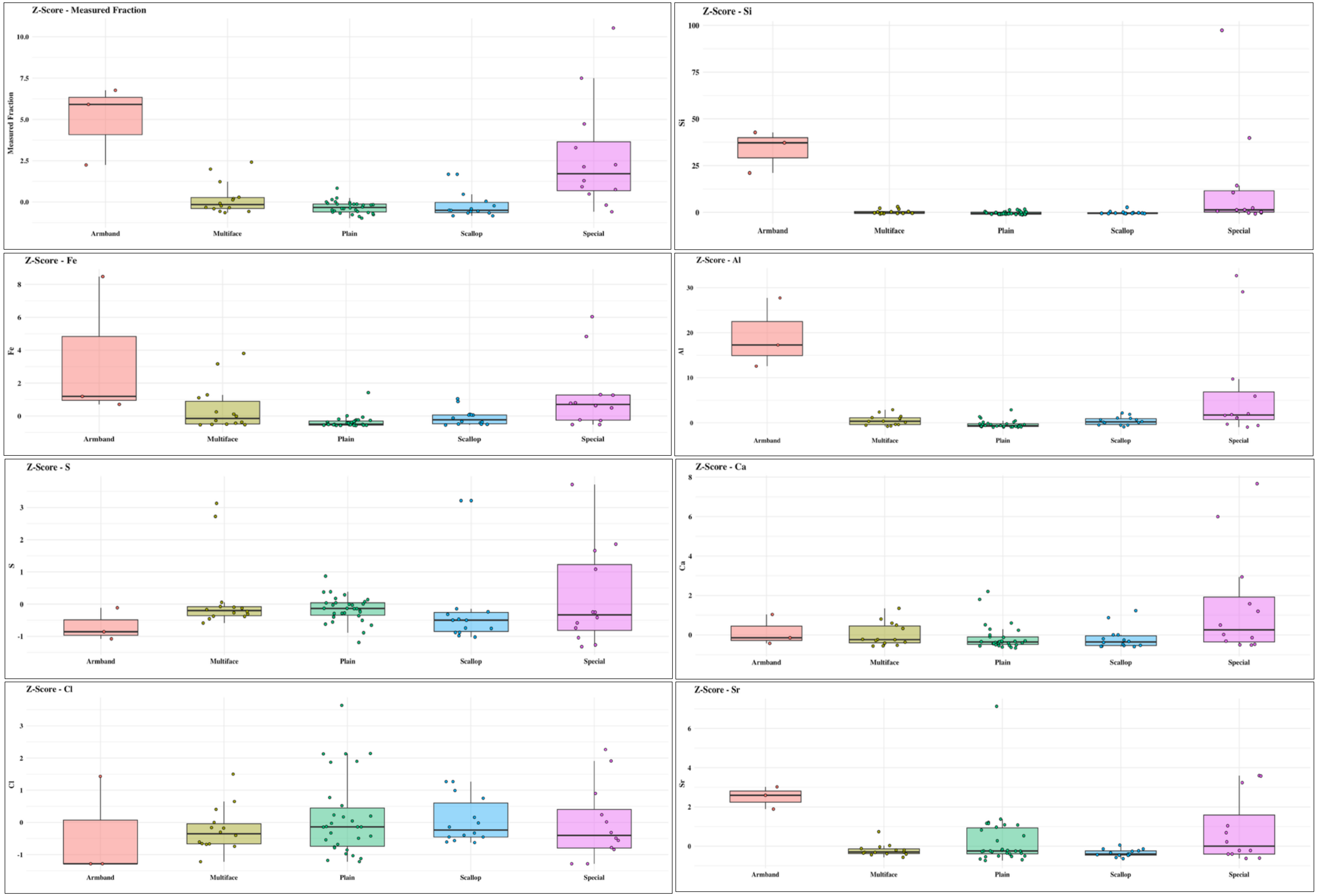

Figure 50. *Z-Score examples for the measured fraction %, some main and trace elements and how they are distributed between the main artefact types. There is no indication that any single type of bead has a similar or specific source that has a clearly different chemical composition from any other source.*

Table 3. *Summary of similarities and potential sources for the Icelandic artefacts. More detailed analyses are needed to refine and refute or confirm these suggestions.*

Location	Finds no.	Group	Similarities and Potential Sources
Grónes	2021-46-046	Ia	Likely source is Saltwick Nab, Whitby, Great Britain.
Álaugarey	Þjms. 11565b	Ib	Material similar to Litlu-Núpar bead 141. Possible source Saltwick Bay, Whitby. Shows similarities with artefacts from Kaupang, Norway.
Litlu-Núpar	2007-141	Ib	Material similar to the Álaugarey armlet. Possible source Saltwick Bay, Whitby. Shows similarities with artefacts from Kaupang, Norway.
Hólmur	2001-34-60	Ic	Similarities to Spanish lignite from Arija (sample 1) and an artefact (A95) from Casa del Monte, Cáceres.
Gufuskálar	2013-36-1276	Id	Unique elemental signal, could be Icelandic lignite, also shows certain similarities to Kimmeridge clays but the fit is poor.
Reykjavík, Alþingishúsreitur	2009-32-1393	IIa	Closest similarities to jet from Bocamina in the Asturias region and an artefact from Léon (G), both in Northeastern Spain.
Reykjavík, Alþingishúsreitur	1999-424	IIa	Closest similarities to jet from Bocamina in the Asturias region and an artefact from Léon (G), both in Northeastern Spain.
Skálholt	2002-64-663	IIa	Closest similarities to jet from Bocamina in the Asturias region and an artefact from Léon (G), both in Northeastern Spain.
Reykholt	2000-6-49	IIa	Closest similarities to jet from Bocamina in the Asturias region and an artefact from Léon (G), both in Northeastern Spain.
Gufuskálar	2013-36-1207	IIb	High CaO% and SO3%. Similarities to jet from Runswick Bay in Whitby but the fit is still poor. Could be Icelandic lignite.
Kúabót	1975-615-46/884	IIb	Similarities to jet from Villaverde in the Asturias region in Northeastern Spain.
Viðey	V90-41	IIb	Material very similar to Viðey 57108, likely the same source. Similarities to jet from Villaverde in the Asturias region, Northeastern Spain, but the fit is still poor.
Viðey	1989-153-57108	IIb	Material very similar to Viðey 90-41, likely the same source. Similarities to jet from Villaverde in the Asturias region, Northeastern Spain, but the fit is still poor.
Fjörður	2021-28-335	III	Poorly preserved. Likely same material as in Fjörður bead 347, contaminated with Cu. Shows similarities with lignite from Préjano in Northern Spain (P1) but a source of Seyðisfjörður lignite can not be ruled out.
Fjörður	2021-28-347	III	Poorly preserved. Likely same material as in Fjörður bead 335, contaminated with Cu and Pb. Shows similarities with lignite from Préjano in Northern Spain (P1), but a source of Seyðisfjörður lignite can not be ruled out.
Kirkjubæjarklaustur	2002-70	IVa	Closest similarities to jet from Saltwick Bay, Whitby (S1 and S3), and jet from Llantones, Asturias in Northeastern Spain.
Árbær, Reykjavík	2021-20-71	IVa	Closest similarities to jet from Saltwick Bay, Whitby (S1 and S3), and jet from Llantones, Asturias in Northeastern Spain.
Reykholt	2003-25-91	IVa	Closest similarities to jet from Saltwick Bay, Whitby (S1 and S3), and jet from Llantones, Asturias in Northeastern Spain.

Reykholt	2004-25-308	IVb	Elevated Cu. Closest similarities to jet from Saltwick Bay, Whitby (S1 and S3), and jet from Llantones, Asturias in Northeastern Spain.
Hólar	2009-37-11790	IVa	Closest similarities to jet from Saltwick Bay, Whitby (S1 and S3), and jet from Llantones, Asturias in Northeastern Spain.
Hólar	2009-37-11224	IVa	Closest similarities to jet from Saltwick Bay, Whitby (S1 and S3), and jet from Llantones, Asturias in Northeastern Spain.
Hólar	2002-37-1368	IVa	Closest similarities to jet from Saltwick Bay, Whitby (S1 and S3), and jet from Llantones, Asturias in Northeastern Spain.
Staðarhóll	2021-52-1a	IVa	Closest similarities to jet from Saltwick Bay, Whitby (S1 and S3), and jet from Llantones, Asturias in Northeastern Spain.
Skálholt 1954	S229	IVa	Elevated Cu. Closest similarities to jet from Saltwick Bay, Whitby (S1 and S3), and jet from Llantones, Asturias in Northeastern Spain.
Iceland, Ásbúðarsafn	Ásb-1	IVa	Closest similarities to jet from Saltwick Bay, Whitby (S1 and S3), and jet from Llantones, Asturias in Northeastern Spain.
Iceland, Ásbúðarsafn	Ásb-4	IVa	Closest similarities to jet from Saltwick Bay, Whitby (S1 and S3), and jet from Llantones, Asturias in Northeastern Spain.
Reykholt	2004-25-047	IVb	Closest similarities to jet from Saltwick Bay, Whitby (S3), and jet from Llantones, Asturias in Northeastern Spain.
Þórðarstaðir	Þjms. 5253	IVb	Closest similarities to jet from Saltwick Bay, Whitby (S3), and jet from Llantones, Asturias in Northeastern Spain.
Kalastaðir	884-4	IVb	Elevated Cl and peak of Zn. Closest similarities to jet from Saltwick Bay, Whitby (S3), and jet from Llantones, Asturias in Northeastern Spain.
Kalastaðir	884-5	IVb	Elevated Cl. Closest similarities to jet from Saltwick Bay, Whitby (S3), and jet from Llantones, Asturias in Northeastern Spain.
Kalastaðir	884-6	IVb	Elevated Cl. Closest similarities to jet from Saltwick Bay, Whitby (S3), and jet from Llantones, Asturias in Northeastern Spain.
Kalastaðir	884-10	IVb	Elevated Cl. Closest similarities to jet from Saltwick Bay, Whitby (S3), and jet from Llantones, Asturias in Northeastern Spain.
Kalastaðir	884-11	IVb	Elevated Cl. Closest similarities to jet from Saltwick Bay, Whitby (S3), and jet from Llantones, Asturias in Northeastern Spain.
Kalastaðir	884-3	IVb	Closest similarities to jet from Llantones, Asturias (too high Cl), and lignite from Préjano (S2) in Northern Spain. Jet from Saltwick Bay (S3) can not be ruled out.
Kalastaðir	884-8	IVb	Closest similarities to jet from Llantones, Asturias (too high Cl), and lignite from Préjano (S2) in Northern Spain. Jet from Saltwick Bay (S3) can not be ruled out.
Kalastaðir	884-9	IVb	Closest similarities to jet from Llantones, Asturias (too high Cl), and lignite from Préjano (S2) in Northern Spain. Jet from Saltwick Bay (S3) can not be ruled out.

Skálholt 1954	S220	IVb	Slightly elevated levels of Sr, V, Zr and/or Zn. Closest similarity to jet from Saltwick Bay (S3 and pXRF (V too high).
Skálholt 1954	S230	IVb	Slightly elevated levels of Sr, V, Zr and/or Zn. Closest similarity to jet from Saltwick Bay (S3 and pXRF (V too high)).
Skriðuklaustur	2004-36-1680	IVb	Slightly elevated levels of Sr, V, Zr and/or Zn. Closest similarity to jet from Saltwick Bay (S3 and pXRF(V too high)).
Skriðuklaustur	2004-36-1718	IVb	Slightly elevated levels of Sr, V, Zr and/or Zn. Closest similarity to jet from Saltwick Bay (S3 and pXRF(V too high)).
Iceland, Skaftafellssýsla	Þjms. 3911	IVb	Slightly elevated levels of Sr, V, Zr and/or Zn. Closest similarity to jet from Saltwick Bay (S3 and pXRF(V too high)).
Þingeyrar	2018-28-567	IVb	Slightly elevated levels of Sr, V, Zr and/or Zn. Closest similarity to jet from Saltwick Bay (S3 and pXRF(V too high)).
Hólar	1179-1	IVb	Slightly elevated levels of Sr, V, Zr and/or Zn. Closest similarity to jet from Saltwick Bay (S3 and pXRF(V too high)).
Hólar	1179-2	IVb	Slightly elevated levels of Sr, V, Zr and/or Zn. Closest similarity to jet from Saltwick Bay (S3 and pXRF(V too high)).
Hólar	2009-37-11792	IVb	Slightly elevated levels of Sr, V, Zr and/or Zn. Closest similarity to jet from Saltwick Bay (S3 and pXRF).
Hólar	2009-37-11214	IVb	Elevation of Pb, V and Cu.. Very organic rich, could be cannel coal or very pure jet.
Hólar	2009-37-11218	IVb	Closest similarities to jet from Llantones, Asturias (too high Cl), and lignite from Préjano (S2) in Northern Spain. Jet from Saltwick Bay (S3) can not be ruled out.
Iceland, Ásbúðarsafn	Ásb-3	IVb	Closest similarities to jet from Llantones, Asturias (too high Cl), and lignite from Préjano (S2) in Northern Spain. Jet from Saltwick Bay (S3) can not be ruled out.
Skálholt	2003-64-2971	IVb	Closest similarities to jet from Llantones, Asturias (too high Cl), and lignite from Préjano (S2) in Northern Spain. Jet from Saltwick Bay (S3) can not be ruled out.
Staðarhóll	2021-52-1b	IVb	Closest similarities to jet from Llantones, Asturias (too high Cl), and lignite from Préjano (S2) in Northern Spain. Jet from Saltwick Bay (S3) can not be ruled out.
Reykjavík, Alþingishúsreitur	2009-2856	IVb	Closest similarities to jet from Llantones, Asturias (too high Cl), and lignite from Préjano (S2) in Northern Spain. Jet from Saltwick Bay (S3) can not be ruled out.
Járngerðarstaðir	Þjms. 345	IVb	Closest similarities to jet from Llantones, Asturias (too high Cl), and lignite from Préjano (S2) in Northern Spain. Jet from Saltwick Bay (S3) can not be ruled out.
Gufuskálar	2015-40-2030	IVb	Closest similarities to jet from Llantones, Asturias (too high Cl), and lignite from Préjano (S2) in Northern Spain. Jet from Saltwick Bay (S3) can not be ruled out.
Reykholt	2005-25-336	IVb	Very similar to Reykholt 142. Peak of Zn. Closest similarities to jet from Saltwick Bay, Whitby (S5).
Reykholt	2002-25-142	IVb	Very similar to Reykholt 336. Peak of Cu. Closest similarities to jet from Saltwick Bay, Whitby (S5).

Reykholt	2006-25-304	IVb	Closest similarities to jet from Llantones, Asturias (too high Cl), and lignite from Préjano (S2) in Northern Spain. Jet from Saltwick Bay (S3) can not be ruled out.
Reykholt	2005-25-126	IVb	Closest similarities to jet from Llantones, Asturias (too high Cl), and lignite from Préjano (S2) in Northern Spain. Jet from Saltwick Bay (S3) can not be ruled out.
Reykholt	2004-25-111	IVb	Very organic rich, could be cannel coal or very pure jet.
Reykholt	2004-25-128	IVb	Very organic rich, could be cannel coal or very pure jet.
Reykholt	2003-25-147	IVb	Very organic rich, could be cannel coal or very pure jet.
Iceland	Þjms. 5918	IVb	Peak of Zn. Very organic rich, could be cannel coal or very pure jet.
Gjábakki	Þjms. 344	IVb	Very organic rich, could be cannel coal or very pure jet.
Kalastaðir	884-1	IVc	Elevated CaO >0,65%. Closest similarities to jet from Saltwick Bay, Whitby (S2 (too high V) and S3), lignite from Préjano (S2) in Northern Spain and generic coal (B).
Skálholt	2003-64-2392	IVc	Elevated CaO >0,65%, peak of Sr. Closest similarities to jet from Saltwick Bay, Whitby (S2 (too high V) and S3), lignite from Préjano (S2) in Northern Spain and generic coal (B).
Gufuskálar	2011-253	IVc	Elevated SiO2% and CaO%. Closest similarities to jet from Runswick Bay in Whitby (RB, too high V) and lignite from Léon (S7) in Northeastern Spain.
Skriðuklaustur	2003-36-400	IVc	Elevated SiO2% and CaO%. Closest similarities to jet from Runswick Bay in Whitby (RB, too high V) and lignite from Léon (S7) in Northeastern Spain.
Árbær, Reykjavík	2021-20-043	IVc	Elevated SiO2% and CaO%. Closest similarities to jet from Runswick Bay in Whitby (RB, too high V) and lignite from Léon (S7) in Northeastern Spain.
Árbær, Reykjavík	2019-36-026	IVc	Elevated CaO >0,65%, Pb and Cu. Closest similarities are lignite from Valdeberzana in Northern Spain and jet from Saltwick Bay, Whitby (S5, Cl too high).
Reykholt	2006-25-181	IVc	Elevated CaO >0,65%, Pb and Cu. Closest similarities are lignite from Valdeberzana in Northern Spain and jet from Saltwick Bay, Whitby (S5, Cl too high).
Skálholt 1954	S217	IVc	Elevated CaO >0,65%, Pb and Cu. Closest similarities are lignite from Valdeberzana in Northern Spain and jet from Saltwick Bay, Whitby (S5, Cl too high).
Skálholt 1954	S218	IVc	Elevated CaO >0,65%, Pb and Cu. Closest similarities are lignite from Valdeberzana in Northern Spain and jet from Saltwick Bay, Whitby (S5, Cl too high).

Many of the artefacts in group IV show similarities to jet from Saltwick Bay, mainly sample 3, but also samples 1, 2 and 5 and the Runswick Bay sample, in Whitby. Samples 2, 6 and RB can possibly be excluded from their high V content, so that leaves only Saltwick Bay samples 1, 3 and 5 as possible matches. However, a few also show similarities to jet from Llantones in the Asturias region and lignites from e.g. Préjano and Léon, all in Northern and Northeastern Spain. A few could be very organic rich coal and there are similarities to cannel coal, e.g. from Plessey in Northumberland, Great Britain. These areas cannot be treated as possible sources without further analyses, but they are a place to start.

Conclusions

The Icelandic assemblage subjected to XRF analysis in this study comprised 71 artefacts, of which 69 were beads and two were armlets; they have been split into groups I-IV based on their main and trace elemental concentration patterns. The assemblage spans a broad chronological range, from the late 9th century through the 20th century, with particular emphasis on finds from late Viking Age and later medieval contexts. Just over 80% of the Icelandic artefacts analysed can be said to be of very high organic purity (P=0-10) and there is no indication that any single morphological type of bead (round/oval/barrel-shaped etc.) has a consistent association with a any one specific source.

Finds in group I are all likely organic rich, silicic shales or mineral rich coals of low organic purity (average P =44). The Grónes armlet is likely made of alum shale, possibly from the Saltwick Nab area in Whitby, Great Britain. The Álaugarey armlet and the Litlu-Núpar bead are very likely made of the same organic rich shale, with a potential source in Saltwick Bay in Whitby, but the fit is poor. The two artefacts also show similarities to a few artefacts unearthed in Kaupang in Norway. The Hólmur bead is likely mineral rich coal with similarities to Spanish lignite but its source is unclear. Norwegian sources cannot be ruled out. Three beads could potentially be made of Icelandic lignite, one from Gufuskálar in Snæfellsnes (1276, group I), West Iceland, and the two CaO% rich Fjörður beads from Seyðisfjörður (335 and 347), East Iceland, in group III (P = 74 and 20 respectively). The Fjörður bead raw materials also show similarities to materials from Serbia, Whitby and Spain but they are very badly preserved so ascertaining any potential source for them will be difficult. Fjörður bead 347 could have been contaminated by association with metal (copper/bronze?) artefacts within its context.

The eight artefacts in group II had unusually high SO_3% concentrations and higher organic purity (average P=10) than groups I and III. Four of them showed similarities to jet from Bocamina in the Asturias region and one artefact from Léon, both in Northeastern Spain, but the fit is poor and sulphur rich coal cannot be ruled out. This needs further data. Two of the beads from Skálholt (663) and Reykholt (49) are very likely made from similar source material, as are the two beads from the Alþingishúsreitur in Reykjavík (1393 and 424). Two beads from Viðey, Gufuskálar bead 1207 and the Kúabót bead, are likely sulphur rich coal (either generic or jet), possibly from Spain, but more data is needed.

All 56 beads in group IV are of very high organic purity (average P = 4) and they are likely jets and/or very organicly pure coals. Whether they are made of jet, cannel coal or general coal cannot be ascertained with certainty through pXRF but if they are jet, which some likely are, their primary source is most likely to be the Whitby area in Great Britain. Many of the artefacts show

Table 4. *The datable artefacts and their groups arranged by periods.*

Time Periods	Location	Finds no.	Period	Group	P	Type	Similarities and Potential Sources
Late Viking Age (870-1000 AD)	**Grónes**	2021-46-046	870-1000 AD	Ia	33	Plain circle	Likely source is Saltwick Nab, Whitby, Great Britain.
	Álaugarey	Þjms. 11565b	870-1000 AD	Ib	44	Plain circle	Material similar to Litlu-Núpar bead 141. Possible source Saltwick Bay, Whitby. Shows similarities with artefacts from Kaupang, Norway.
	Litlu-Núpar	2007-141	870-1000 AD	Ib	50	Cylinder, plain large	Material similar to the Álaugarey armlet. Possible source Saltwick Bay, Whitby. Shows similarities with artefacts from Kaupang, Norway.
	Hólmur	2001-34-60	870-1200 AD	Ic	19	Cylinder, plain	Similarities to Spanish lignite from Arija (sample 1) and an artefact (A95) from Casa del Monte, Cáceres.
	Fjörður	2021-28-335	900-1000 AD	III	20	Oval, plain	Poorly preserved. Likely same material as in Fjörður bead 347, contaminated with Cu. Shows similarities with lignite from Préjano in Northern Spain (P1) but a source of Seyðisfjörður lignite can not be ruled out.
	Fjörður	2021-28-347	900-1000 AD	III	20	Oval, plain	Poorly preserved. Likely same material as in Fjörður bead 335, contaminated with Cu and Pb. Shows similarities with lignite from Préjano in Northern Spain (P1), but a source of Seyðisfjörður lignite can not be ruled out.
Late Medieval (1300-1600 AD)	**Kúabót**	1975-615-46/884	1300-1500 AD	IIb	5	Round, plain	Similarities to jet from Villaverde in the Asturias region in Northeastern Spain.
	Viðey	V90-41	1200-1800 AD	IIb	9	Cylinder, boat/leaf	Material very similar to Viðey 57108, likely the same source. Similarities to jet from Villaverde in the Asturias region, Northeastern Spain, but the fit is still poor.
	Viðey	1989-153-57108	1200-1800 AD	IIb	7	Barrel, ridged	Material very similar to Viðey 90-41, likely the same source. Similarities to jet from Villaverde in the Asturias region, Northeastern Spain, but the fit is still poor.
	Skálholt 1954	S217	1200-1600 AD	IVc-A	10	Oval, plain	Context very unsure. Elevated CaO >0,65%, Pb and Cu. Closest similarities are lignite from Valdeberzana in Northern Spain and jet from Saltwick Bay, Whitby (S5, Cl too high).
	Skálholt 1954	S218	1200-1600 AD	IVc-A	11	Round, faceted	Context very unsure. Elevated CaO >0,65%, Pb and Cu. Closest similarities are lignite from Valdeberzana in Northern Spain and jet from Saltwick Bay, Whitby (S5, Cl too high).
	Gufuskálar	2013-36-1207	1400-1800 AD	IIb	8	Oval, spiral	High CaO% and SO3% (~10). Similarities to jet from Runswick Bay in Whitby but the fit is very poor. High sulphur concentrations could suggest Spanish jet but could also be Icelandic lignite.
	Gufuskálar	2013-36-1276	1450-1500 AD	Id	74	Round, triangle	Unique elemental signal, could be Icelandic lignite, also shows certain similarities to Kimmeridge clays but the fit is poor.

	Skriðuklaustur	2004-36-1680	1493-1554 AD	IVb-A	2	Barrel, plain	Very similar pattern to Þingeyrar 567. Slightly elevated levels of Sr, V, Zr and/or Zn. Closest similarity to jet from Saltwick Bay (S3 and pXRF sample (V too high)).
	Skriðuklaustur	2004-36-1718	1493-1554 AD	IVb-A	4	Barrel, plain	Slightly elevated levels of Sr, V, Zr and/or Zn. Closest similarity to jet from Saltwick Bay (S3 and pXRF(V too high)).
	Þingeyrar	2018-28-567	1100-1800 AD	IVb-A	2	Round, plain	Very similar pattern to Skriðuklaustur 1680. Slightly elevated levels of Sr, V, Zr and/or Zn. Closest similarity to jet from Saltwick Bay (S3 and pXRF sample (V too high)).
	Reykholt	2005-25-126	1400-1600 AD	IVb-D	3	Oval, scallop	Main elemental pattern almost identical to Reykholt 304. Closest similarities to jet from Llantones, Asturias (too high Cl), and lignite from Préjano (S2) in Northern Spain. Jet from Saltwick Bay (S3) cannot be ruled out.
	Reykholt	2006-25-304	1200-1500 AD	IVb-D	3	Oval, scallop	Main elemental pattern almost identical to Reykholt 126. Disturbed context, sondage [2448] cut through end of post pit [2431] that cut several graves, closest similarities to jet from Llantones, Asturias (too high Cl), and lignite from Préjano (P2) in Northern Spain. Jet from Saltw.Bay (S3) cannot be ruled out.
	Reykholt	2005-25-336	1400-1600 AD	IVb-C	7	Oval, ridged	Almost identical pattern to Reykholt 142. Peak of Zn. Closest similarities to jet from Saltwick Bay, Whitby (S5).
	Reykholt	2002-25-142	1778-1835 AD	IVb-C	5	Oval, scallop	Almost identical pattern to Reykholt 336, from the 15th-16th c. The context of 142 is around 1800 AD, but it could be medieval. Peak of Cu. Closest similarit. to jet from Saltw.Bay, Whitby (S5).
	Skriðuklaustur	2003-36-400	1450-1600 AD	IVc-B	6	Oval, scallop	Elevated SiO2% and CaO%. Closest similarities to jet from Runswick Bay in Whitby (RB, too high V) and lignite from Léon (S7) in Northeastern Spain.
	Gufuskálar	2011-253	1400-1800 AD	IVc-B	3	Round, plain	Elevated SiO2% and CaO%. Closest similarities to jet from Runswick Bay in Whitby (RB, too high V) and lignite from Léon (S7) in Northeastern Spain.
Early Modern (1600-1900 AD)	**Reykholt**	2004-25-47	1500-1800 AD	IVb-B	3	Oval, faceted	Closest similarities to jet from Saltwick Bay, Whitby (S3), and jet from Llantones, Asturias in Northeastern Spain.
	Skálholt 1954	S220	1600-1700 AD	IVb-A	4	Round, plain	Slightly elevated levels of Sr, V, Zr and/or Zn. Closest similarity to jet from Saltwick Bay (S3 and pXRF (V too high).
	Reykholt	2000-6-49	1700-1800 AD	IIa	11	Flat, bevelled	Strong similarities to Skálholt 663. Closest similarities to jet from Bocamina in the Asturias region and an artefact from Léon (G), both in Northeastern Spain.
	Skálholt	2002-64-663	1800-1830 AD	IIa	13	Flat, bevelled	Strong similarities to Reykholt 49. Closest similarities to jet from Bocamina in the Asturias region and an artefact from Léon (G), both in Northeastern Spain.
	Reykjavík, Alþ.r.	2009-32-1393	Unclear	IIa	16	Round, plain	Closest similarities to jet from Bocamina in the Asturias region and an artefact from Léon (G), both in Northeastern Spain.
	Reykjavík, Alþ.r.	1999-424	1500-1900 AD	IIa	9	Oval, scallop	Closest similarities to jet from Bocamina in the Asturias region and an artefact from Léon (G), both in Northeastern Spain.

	Reykholt	2003-25-147	1778-1835 AD	IVb-E	2	Oval, scallop	Very organic rich, could be cannel coal or very pure jet. Source?
	Reykholt	2004-25-111	1500-1800 AD	IVb-E	2	Oval, scallop	Very organic rich, could be cannel coal or very pure jet. Source?
	Reykholt	2004-25-128	1500-1800 AD	IVb-E	3	Oval, scallop	Very organic rich, could be cannel coal or very pure jet. Source?
	Gjábakki	Þjms. 344	Unclear	IVb-E	4	Oval, scallop	Very organic rich, could be cannel coal or very pure jet. Source?
	Kirkjubæjarklaustur	2002-70	1600-1700 AD	IVa	5	Oval, plain	Closest similarities to jet from Saltwick Bay, Whitby (S1 and S3), and jet from Llantones, Asturias in Northeastern Spain.
	Reykholt	2004-25-308	1500-1800 AD	IVa	6	Hemisphere, faceted, split, button?	Elevated Cu. Closest similarities to jet from Saltwick Bay, Whitby (S1&S3), and jet from Llantones, Asturias in Northeastern Spain.
	Reykholt	2003-25-91	1778-1835 AD	IVa	3	Oval, faceted	Closest similarities to jet from Saltwick Bay, Whitby (S1 and S3), and jet from Llantones, Asturias in Northeastern Spain.
	Árbær, Reykjavík	2021-20-71	1800-1900 AD	IVa	3	Oval, faceted	Closest similarities to jet from Saltwick Bay, Whitby (S1 and S3), and jet from Llantones, Asturias in Northeastern Spain.
	Skálholt	2003-64-2392	1760-1780 AD	IVc-B	4	Round, plain	Main elemental pattern almost identical to Kalastaðir bead 884-1. Elevated CaO >0,65%, peak of Sr. Closest similarities to jet from Saltwick Bay, Whitby (S2 (too high V) and S3), lignite from Préjano (S2) in Northern Spain and generic coal (B).
	Kalastaðir	884-1	Unclear	IVc-B	4	Oval, plain	Main elemental pattern almost identical to Skálholt bead 2392. Elevated CaO >0,65%, peak of Sr. Closest similarities to jet from Saltwick Bay, Whitby (S2 (too high V) and S3), lignite from Préjano (S2) in Northern Spain and generic coal (B).
	Skálholt	2003-64-2971	1900-1930 AD	IVb-D	2	Round, faceted	Distrubed context in a 20th century haybarn at Skálholt. Closest similarities to jet from Llantones, Asturias (too high Cl), and lignite from Préjano (S2) in Northern Spain. Jet from Saltwick Bay (S3) cannot be ruled out.
	Kalastaðir	884-9	Unclear	IVb-D	3	Oval, plain	Kalastaðir beads 884-3 to 6 and 8 to 11 show the closest similarities to Skálholt 2971. Closest similarities to jet from Llantones, Asturias (too high Cl), and lignite from Préjano (S2) in Northern Spain. Jet from Saltw. Bay (S3) cannot be ruled out.
	Gufuskálar	2015-40-2030	1400-1800 AD	IVb-D	3	Round, plain	Closest similarities to jet from Llantones, Asturias (too high Cl), and lignite from Préjano (S2) in Northern Spain. Jet from Saltwick Bay (S3) cannot be ruled out.
	Reykholt	2006-25-181	1778-1835 AD	IVc-A	8	Oval, scallop	Elevated CaO >0,65%, Pb and Cu. Closest similarities are lignite from Valdeberzana in Northern Spain and jet from Saltwick Bay, Whitby (S5, Cl too high).
	Árbær, Reykjavík	2019-36-026	1800-1900 AD	IVc-A	7	Round, faceted	Elevated CaO >0,65%, Pb and Cu. Closest similarities are lignite from Valdeberzana in Northern Spain and jet from Saltwick Bay, Whitby (S5, Cl too high).
	Árbær, Reykjavík	2021-20-043	1800-1900 AD	IVc-B	5	Round, faceted	Elevated SiO_2% and CaO%. Closest similarities to jet from Runswick Bay in Whitby (RB, too high V) and lignite from Léon (S7) in Northeastern Spain.

similarities to jet samples from Saltwick Bay (sample 3, along with 1, 5 and RB are the strongest candidates) published by Menéndez Menéndez (2023). However, the matter is made more complicated as jet from Llantones in the Asturias region and lignites, e.g. from Préjano and Léon in Northeast and Northern Spain, in some cases also show strong similarities to the Icelandic artefacts. A few beads from e.g. Gjábakki, Hólar and Reykholt (subgroup IVb-E) have very high organic purity and could be cannel coal or very pure jet and show geochemical similarities e.g. to general anthracite coal and Plessey cannel coal in Northumberland, Great Britain. Further analysis is needed to untangle that puzzle.

Nine beads from the ecclesiastical sites of Skálholt (S217, S218, S229), Reykholt (142, 181, 308 and 336), Skriðuklaustur (1680) and Viðey (V90-41), along with two beads from unknown contexts (Þjms. 5918 and Kalastaðir 884-4) had elevated levels of Cu, Pb and/or Zn which could indicate external metal contaminations from associated archaeological contexts or artefacts (e.g. other metal artefacts or jewellery fittings). It is possible they may have contact traces from metal fittings, beads or crosses (likely brass or possibly enamels) that may have been positioned beside them on a cord or string (e.g. on a rosary).

The artefacts analysed in this report come from three main time periods (Table 4), 1. Late Viking Age (870-1000 AD), 2. Late Medieval (1300-1600 AD), and 3. Early Modern (1600-1900). No artefacts analysed come from Early Medieval (1100-1300 AD) contexts. Groups I and III are largely late Viking Age finds from materials associated with Kaupang in Norway, Whitby in Great Britain, local use of Icelandic materials and possibly Northern Spain. There does, however, seem to be a hiatus, or at least a marked dearth, of black artefacts made of organic carving coals in Iceland during the early Middle Ages, which is intriguing. This may simply reflect the limited number of excavated sites from that period in Iceland, but in the Icelandic bead assemblage as a whole (glass, stone and organic beads combined) there is a marked decline in the use of beads as adornment in Iceland in the late 11th/early 12th century.

Generally, glass beads are thought to have been imported into Scandinavia well into the 11th century, and simple bead types may even have been produced locally until around 1200 AD. However, after c. 1100-1200 AD beads become a much less visible element of dress and personal adornment. In Iceland the dating evidence suggests beads were popular in the late 10th and early 11th centuries, and their use likely continued into the 12th century. A number of Viking Age beads in Iceland date to the 11th century, and a few occur in contexts that may be later still. Overall, the finds indicate that beads continued to reach Iceland during the 11th century, that older beads were curated and reused for some time, and in rare cases perhaps much longer. Beads did not vanish entirely in Iceland during the 12th century, partly because older beads were kept and reused, and partly because simple beads could be made from local raw materials, although they were probably well out of fashion before 1200 AD. After the 12th century, bead use in Iceland appears to enter a pronounced lull, as in many other parts of Europe. From the 12th century onwards beads seem to have been rare, their materials, forms and decoration becoming much simpler than before, while organic materials, such as amber and organic carving coals, appear to make up a larger share of the Icelandic artefact flora than before.[61]

As yet, black organic carving coals only appear again in Icelandic archaeological contexts dated to the late middle ages after 1300 AD, and armlets disappear. At first there seems to be a possible slant towards Spanish sources (Kúabót, Viðey, Skálholt, Gufuskálar) along with possible Icelandic materials (Gufuskálar) around 1300-1400 AD. This could suggest that initially, such imported beads mainly came from Northern Spain (e.g. the Asturias region), very likely connected to religious practices of Catholisism (i.e. prayer beads). However, its seems that after 1400-1500 AD the artefacts' raw materials demonstrate elemental signitures that are more likely to originate in the Whitby region, on the east coast of England, with Spanish materials mixed in. When changing trading practices and the Black Death severed and redefined trade connections and production in Scandinavia and Europe to some extent in the mid 14th century and into the 15th, import of such artefacts to Iceland was also affected[62]. After the plague ravaged Iceland at the start of the 15th century the English took over a large part of trade to the island for over 60 years, which caused a large influx of English trade goods[63] like e.g. jewellery, possibly made of Whitby carving coals. This import likely never stopped, especially after it became fashionable in the late 18th/early 19th century[64]. The Early Modern period assemblage (1600-1900 AD) at least, seems to be a potential mixture of English and Spanish materials. It must be mentioned however, that jet production in the Eastern Alps (e.g. Schwäbisch-Gmünd) that was active until the Reformation[65] and the Aude department close to the southeastern border in Southern France (Fig. 3) from the 15th century onwards[66], should perhaps also be included in future research (pXRF and FTIR) of such artefacts found in Iceland. Although their geographical positions make them much less likely to be potential candidates as raw material sources, compared to material source locations and production in Whitby, England and Asturias, Northeastern Spain, which are both very close to the coast and maritime trade along the northeastern border of the North Atlantic.

There are clear examples where artefacts from two different areas or different contexts within sites exhibit very similar to almost identical elemental patterns. For example, the bead and armlet from Litlu-Núpar in Northern Iceland and Álaugarey in the Southeast (group I, late Viking Age),

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[61] Elín Hreiðarsdóttir 2005, pp. 167-170.

[62] Helgi Þorláksson 2017, pp. 93-96 and 111-119.

[63] Helgi Þorláksson 2017, pp. 143 and 157.

[64] Muller 2009.

[65] See e.g. Von Wilhelm Freh 1956.

[66] Muller 2009, p. 9; see also Prim 2025 and Evans 2024.

the two Fjörður beads (group II), the beads from Viðey (group IIb), beads 1680 and 1718 from Skriðuklaustur (group IVb-A), beads 142 and 336 from Reykholt (IVb-D) and the two flat beads from Reykholt and Skálholt (beads 49 and 663 in group IIa). The last two are from two different sites but exhibit very similar geochemical patterns, are of similar typology and both with 18th-19th century dating. These artefacts could suggest that where organic beads were imported in batches (e.g. strings of beads) that were possibly made from similar raw material sources. These batches may then have been distributed more widely, but could potentially still be identified geochemically, linking particular sites and/or time periods.

While pXRF analysis alone cannot provide definitive provenance determinations, it offers an effective non-destructive first step for grouping artefacts, excluding glaringly incompatible sources and guiding future research. Further work combining microstructural analysis, organic geochemistry and targeted destructive sampling, where permissible, is recommended to refine and support raw material identifications and source interpretations. The next steps would be to choose suitable samples from all four groups for further FTIR- (Fourier-Transform Infrared) and SEM-analyses to look closer into the microstructures of the artefacts to see whether they can be classified with more detail into types (i.e. cannel coals, generic coals or jet) and pinpoint possible material sources in more detail.

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