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Mapping and Study of Possible Chemical Contamination from Military Material Found in Dumping Site in the Trondheimsfjord

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Summary

This thesis has revolved around a dumping site at approximately 600 m depth in the Trondheimsfjord containing military material from the Second World War. Both water and sediment samples have been taken in and around the dumping site, where the main objective has been looking for metal(loid) contamination and the presence of organic explosives. Certain elements in the periodic table are toxic to aquatic organisms, and are therefore unwanted in the aquatic environment. Lead, mercury, and partly cadmium are the three main non-essential metals known, but copper is also very dangerous to aquatic organisms. A heightened presence of either one of these metals is therefore undesirable in the aquatic environment.

Acid digestion using nitric acid (HNO_3) and UltraCLAVE have been used with Inductively Coupled Plasma – Mass Spectrometry (ICP-MS) to find the element concentrations in the samples. Liquid Chromatography – tandem Mass Spectrometry (LC-MS/MS) and Gas Chromatography – Mass Spectrometry (GC-MS) have been used to look for the organic explosives 2,4,6-trinitrotoluene (TNT) and 1,3,5-trinitro-1,3,5-triazacyclohexane (Research Department Explosive, RDX).

The water samples have been found to contain relatively high concentrations of both copper (0.805 µg/L) and zinc (61.9 µg/L) in the surface water, which decreases to acceptable levels for copper after 50 m (0.439 µg/L). Copper is also found at harmful concentrations (> 55 µg/g) in several sediment samples according to a guideline created by the former Climate and Pollution Agency. This guideline uses total element concentrations, meaning the bioavailable concentration is not known. Potential adverse effects on organisms in the area can therefore not be confirmed based on the guideline values alone.

No TNT or RDX have been found in the sediment samples tested, indicating no noticeable spreading from the dumping site. TNT and RDX have not been looked for inside the dumping site, making the state of the military material unknown. However, no major iron enrichment has been observed in the water column or the sediment which is believed to indicate the explosive ammunition might still be intact.

The lack of biological data makes the potential danger of the copper and zinc concentrations difficult to assess. Monitoring the dumping site by taking several water and sediment samples per year both inside and around it is thought to be the best course of action. Biological studies are also thought to be a good way of determining the potential danger posed by toxic elements found in the area.

Sammendrag

Denne hovedoppgaven har tatt for seg et dumpingfelt i Trondheimsfjorden som inneholder militært materiale fra andre verdenskrig. Både vann- og sedimentprøver har blitt tatt i og rundt området, hvor hovedmålet har vært å se etter metall(oid)kontaminering og potensiell tilstedeværelse av organisk sprengstoff. Visse elementer i periodesystemet er giftige for vannlevende organismer, og er derfor uønsket i vannmiljøet. Bly, kvikksølv, og delvis kadmium er kjent for å være tre svært giftige metaller som ikke er essensielle for organismer. I vannmiljøet er kobber også svært giftig, som gjør at forhøyede konsentrasjoner av disse fire metallene er uønsket.

Syrefordøying med salpetersyre (HNO_3) og UltraCLAVE har blitt brukt med Induktivt Koplet Plasma – Massespektrometri (ICP-MS) til å finne elementkonsentrasjoner i prøvene. Væskekromatografi – tandem Massespektrometri (LC-MS/MS) og Gasskromatografi – Massespektrometri (GC-MS) har blitt brukt til å se etter de organiske eksplosivene 2,4,6-trinitrotoluen (TNT) og 1,3,5-trinitro-1,3,5-triazasykloheksan (Research Department Explosive, RDX).

Vannprøvene har blitt funnet å inneholde relativt høye konsentrasjoner av kobber (0,805 µg/L) og sink (61,9 µg/L) i overflatevannet, der kobberkonsentrasjonen synker til et akseptabelt nivå etter omtrent 50 m (0,439 µg/L). Kobber er også funnet ved høye konsentrasjoner (> 55 µg/g) i flere av sedimentprøvene ifølge en retningslinje laget av klima og forurensningsdirektoratet (klif, nå del av miljødirektoratet). Denne retningslinjen oppgir den totale elementkonsentrasjonen, som betyr at den biotilgjengelige konsentrasjonen ikke er kjent. Derfor vil potensielt skadelige effekter på organismer i området ikke kunne bekreftes basert på retningslinjen alene.

Hverken TNT eller RDX har blitt funnet i de testede sedimentprøvene, hvilket indikerer at det ikke har kommet noen spredning fra området. Ettersom TNT og RDX ikke har blitt analysert etter i prøver fra innsiden av feltet, kan ikke tilstanden til det militære materialet bekreftes. Da ingen signifikant jernanrikning har blitt oppdaget i hverken vann- eller sedimentprøvene, er det antatt at den eksplosive ammunisjonen kan være intakt.

Mangelen på biologisk informasjon gjør det vanskelig å avgjøre den potensielle faren kobber- og sinkkonsentrasjonene utgjør. Overvåking av dumpingfeltet der det tas flere vann- og sedimentprøver i året virker å være det beste alternativet. Biologiske studier kan også tenkes å gi en god oversikt over faren området utgjør for vannlevende organismer som bor der.

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Abbreviations

AET	Apparent Effects Threshold
CAD	Confined Aquatic Disposal
CDF	Confined Disposal Facility
CWA	Chemical Warfare Agent
EF	Enrichment Factor
GC-MS	Gas Chromatography – Mass Spectrometry
HPLC	High Performance Liquid Chromatography
ICP-MS	Inductively Coupled Plasma – Mass Spectrometry
LC-MS/MS	Liquid Chromatography – Tandem Mass Spectrometry
NTNU	Norwegian University of Science and Technology
PETN	Pentaerythritol Tetranitrate
POP	Persistent Organic Pollutant
RDX	Research Department Explosive
ROV	Remotely Operated Vehicle
RSD	Relative Standard Deviation
SD	Standard Deviation
TDP	Thermal Desorption Probe
TNT	Trinitrotoluene

1 Introduction

In the early 1950's explosive ammunition from the Second World War was dumped into the deepest part of the Trondheimsfjord. In recent years, this dumping site has received attention from the media and serious environmental questions have been raised. Several expeditions have been completed, where both the Norwegian Defense Research Establishment (FFI) and NTNU have sent down remote controlled submarines with video feed. The videos and images taken from the dumping site show several heavily corroded objects on the seafloor. In addition to Second World War ordnances, several ship wrecks have been identified, owing to the site's role as a ship cemetery in the 1900's. Apart from ordnances and ship wrecks, other items such as plastic and non-ordnance metal objects have also been observed.

The following figure shows the location of the dumping area. It is found close to Agdenes and the Trondheimfjord's outlet.

Figure 1.1. The location of the dumping site, provided by google maps.

The purpose of the thesis is checking for contamination inside the site, and whether this potential contamination originates from the dumping site itself. Possible contamination spread to the surroundings will also be assessed. Sediment samples will be taken around the dumping site, as well as inside the site. Water samples will also be taken, and the results compared with values supplied by the Climate and Pollution Agency (now the Norwegian Environment Agency), a Norwegian organ for the reduction of pollutants. They published a guideline in 2007 containing the acceptable and unacceptable concentration levels of specific periodic table elements and organic pollutants in both water and sediment.

The sediment samples will also be evaluated using enrichment factor (EF) values with the purpose of discovering anthropogenic contamination.

In addition to analyzing for elements, some of the samples will be analyzed for 2,4,6-trinitrotoluene (TNT) and 1,3,5-trinitro-1,3,5-triazacyclohexane (Research Department Explosive, RDX), two explosives used during the Second World War. This is to assess the state of the ordnances. If traces of explosive compounds are found it would mean the grenade shells have yielded to corrosion and discussion of remedial methods will be appropriate.

Several remedial methods for reducing environmental risk exist but, depending on where the contaminated area is, can be difficult to implement. The dumping site of interest is found at approximately 600 meters depth where strong currents are a problem due to the river Selva situated nearby. As some of the anthropogenic objects found in the area are believed to be grenades from the Second World War safety has to be prioritized. This is especially important to remember as the state of the grenades at this point in time is unknown, making them dangerous to remove.

The sedimentation rate in the Trondheimsfjord is tough to determine. One might argue that the strong current found in the area from the river Selva will promote erosion which may lower the sedimentation rate, but at the same time Selva will deposit particulates that will aid sedimentation. This contradiction makes it difficult to come up with a speculated sedimentation rate. Nevertheless, the main observation after studying the footage from the area is that the explosives have not been buried. This exposure increases the corrosion rate which may lead to the introduction of metal ions and perhaps explosive organics directly into the water column where they may affect the aquatic environment. Another concern is the area's proximity to land, making it possible for unwanted metals and dangerous organic toxicants to reach the shore.

If the sediments and surrounding waters are indeed contaminated, one might argue that an in-situ remedial method like capping (sediment burial) is the safest alternative as it does not involve moving the explosives. However, introducing clean sediment to a dumping site at 600 m depth appears quite challenging.

2 Theory

The outmost consequence of environmental pollution is the destruction of important habitats and harm to organisms, most notably humans. [1] It is therefore important to regularly monitor environmentally dangerous locations such as dumping sites, mines and industrial sites. Depending on the source, a number of contaminants exist throughout the world, ranging from simple periodic table elements to complex organic compounds. Dumping sites can host a plethora of contaminants, ranging from metals and organic compounds, to organometals such as tributyltin. [2, 3] This makes monitoring dumping sites by retrieving samples for analyses on a regular basis important.

2.1 Chemical contaminants in water and sediment

Water and sediment are two mediums that come into contact and may transfer elements to each other. Sediment tends to act as a contaminant sink, meaning most contaminants will eventually end up in the sediment where they are stored. [4] The main reason for this is most contaminant's affinity for particle adsorption which over time will sink and settle in the sediment. While in the sediment contaminants tend to be quite stable. However, it is worth noting that benthic organisms living in the sediment may be exposed to the contaminants. If bottom feeders predate on the exposed benthic living organisms the contaminants may end up being transferred up the food web. Regardless of this transport route, it has been recognized that contaminants will be most damaging while in the water phase. [5] There they may harm water dwelling organisms directly. The sediment sink effect can therefore be seen as a desirable attribute.

New particles are introduced to aquatic systems continuously, meaning contaminated sediment will eventually be buried by natural sedimentation if left undisturbed. Therefore, if a point source contaminates sediment, said contamination may be buried and further stabilized if the sedimentation rate is high enough and if the source of contamination is removed. Two stabilization factors in both the water column and sediment are complexation and precipitation chemistry. These will be different in estuarine systems compared to the open ocean. This is because the input of fresh water in estuarine systems can affect the chemical species found by changing the salinity as well as other physical factors. [6] As sediment may be disturbed and undergo changes in chemistry, it can go from being a sink for contaminants to a source of contaminants. [7, 8] Contaminants can diffuse from the sediment into groundwater, or contaminant bearing particles may be re-suspended into the water column via turbulence caused by boat traffic or underwater landslides. [9, 10] A river will cause erosion and turbulence in its outlet, which may also result in sediment resuspension.

These factors should be considered both when handling contaminated sediment, and discussing methods for remediating areas believed to be contaminated. [11]

Contaminant sources can be of both natural and anthropogenic origin. Examples of natural sources of metal contamination are volcanic ash, underwater currents, atmospheric input, weathering, and hydrothermal vents. Anthropogenic sources are for instance road runoff, fossil fuel combustion, atmospheric input, industry, sewage, military material and operations, and mining. [12, 13, 14] In Norway there is no volcanic activity (apart from the volcano Beerenberg on the island Jan Mayen), and hydrothermal vents are nonexistent, making these natural sources of contamination a negligible factor. It is therefore plausible that the most important contamination factor in Norwegian fjords is anthropogenic. [15, 16]

Anthropogenic sources may release metals and/or organic contaminants, such as Persistent Organic Pollutants (POP's). [17] Oil is an example of a natural product containing both harmful organic substances (such as aromatic compounds) and metals. [18] Oil tends to be inadvertently released during oil well blowouts and oil tanker accidents, which may lead to the death of many aquatic living organisms depending on the oil type spilled. Oil is also regularly released from the shipping industry when doing routine operations, such as loading cargo. [19, 20]

2.1.1 Metals

Anthropogenic releases may potentially increase the sediment concentration of certain metals. This is thought to be a consequence of most metals' affinity for particle adsorption as well as the increased human metallurgical activity over the last centuries. [21] This, coupled with sediment's high layer stability, gives the possibility of studying a particular depth and correlating it with a specific century (memory records), which can help locate the source. However, physical processes may transfer metals up and down the surface sediment column giving the possibility of misinterpreting the observed patterns. [22] Regardless, depth profiles are often helpful when wanting to discover potential similarities and differences between sediment columns. The ability to get depth profiles is partially due to the generally low sedimentation rate observed on the seafloor, meaning a short sediment profile may contain information from several centuries ago depending on the location.

When comparing sedimentation rates in estuarial areas such as fjords with the open sea, a higher sedimentation rate in the estuarial areas is observed. [23] This is due to the abundance of particles transported by rivers that increase the sedimentation around the outlet.

Regardless, sedimentation tends to be slow enough to observe memory records if the sediment column is believed to be undisturbed. An example where memory records might be useful is when studying volcanic eruptions over the centuries. A high concentration of mercury may be found in the part of a sediment layer formed after a volcanic eruption. Another example is observing a heightened lead concentration in sediment during the mid-late 1900's showing the increased use of lead during the oil bonanza. [24, 25] Analyzing a sediment core from before the oil bonanza started to the present day will show major differences in lead concentration. This concentration increases dramatically for a few decades and decreases again after the leaded gasoline ban came in effect in several developed countries in the late 1980's. [22]

Several metals in seawater tend to be chemically immobilized when reacting with ligands such as oxygen (O), sulfur (S), carbonate (CO_3^{2-}), and organic substances, forming insoluble and stable compounds. This is made possible by the mildly alkaline environment found in seawater. Metal solubility is generally greatest in an acidic environment, where hydronium ions (H_3O^+) will compete with the metal for the ligand. [26, 27, 28] In mildly alkaline conditions however, the concentrations of both hydronium and hydroxide ions (OH^-) are sufficiently small so that metal complexes are able to exist. These complexes can adsorb to particles found in the water column and sink with them, making sediment an appropriate sink for several metal contaminants. [29]

This sink is dependent on the oxygen saturation in the upper sediment and bottom water, where an oxygen deficiency will lead to anoxic conditions (oxygen deprived environment). Where in the sediment/water column the anoxic zone begins varies greatly from location to location. Several factors influence the formation of an anoxic zone, such as inflow of oxygen rich water from another water basin and amount of organic matter found. [30] An anoxic zone will have differing redox properties than oxygen saturated mediums, which will affect metal solubility. A study showed that copper (Cu) and cadmium (Cd) will stabilize and accumulate in an anoxic water column, while manganese (Mn) and iron (Fe) experience enhanced solubility. [31] This shows that metal enrichment is affected by the redox properties found in the area of interest, which in turn is affected by the oxygen saturation level. [32] Additionally, as manganese and iron oxides are important metal adsorption species, their dissolution may lead to the enhanced solubility of several other metals, such as lead. [33]

Metal enrichment in the sediment is often observed where human activity is high, such as mining areas and harbors. [34] Sources such as rivers transport particles that end up settling in the outlet area. If mining activity is found upstream high metal concentrations may be observed in the outlet. It is also important to remember that rivers are important sources of metals found in seawater. The strong current brings particles from the riverbed which are then transported downstream and ends up in the sea. [35, 36] This can lead to metal enrichment in the sediment. Another source of metals worth mentioning is industrial activity, like smelters, constantly supplying the surrounding area with contaminants through smoke and runoff. [37] Metal enrichment in sediment can be confirmed by comparing a polluted sediment sample with a clean reference sample, and using a normalization element to calculate the enrichment factor (EF), explained in chapter 2.1.2.4. [38] The advantage of using a normalization element when looking for anthropogenic contamination becomes apparent when comparing different particle types.

Sand particle sizes range from very coarse (1 mm) to very fine (0.0625 mm), whereas mud particles, such as silt and clay, are even smaller. Silt particles are found between 0.0625 mm and 0.002 mm, while clay particle sizes range from 0.002 mm to 0.0005 mm, making them the smallest sediment particle type. [39] The smaller the particle size, the larger the total surface area found. This means clay and silt particles have a larger surface area available for adsorption by contaminants. Therefore, one would expect to find more contaminants (and elements in general) in mud sediment than sand sediment. [40]

Harmful elements are not the only ones likely to find their way into the sediment. Metals such as iron will also accumulate there. [41] Dissolved iron will not be found in appreciative concentrations in seawater partly because of its low solubility, a consequence of Fe^{2+} quickly becoming Fe^{3+} in seawater, which has a lower solubility than Fe^{2+}. Iron is an essential metal where the natural tolerance in both water and sediment is quite high. However, even if a metal like iron is not dangerous in a direct sense, its ability to affect the redox chemistry in systems, and its formation of solid particles makes it important to remember. [42, 43] For instance; iron found near the sediment-water interface will regulate phosphorus (P), hindering it from reaching the surface by promoting adsorption onto iron oxide particles. [44] This is undesirable, as phosphorus is a macro nutrient essential for phytoplankton to photosynthesize. Iron itself is also an important nutrient for phytoplankton, and has been found to be a limiting factor for phytoplankton growth in multiple areas. [45]

2.1.1.1 *Corrosion*

Metal objects are constantly attacked by their surroundings which can, depending on the metal used, greatly impact the integrity and functionality of the object. For instance, iron will react with water and oxygen and form rust, a flaky orange-brown solid with greatly reduced strength. Rust can be said to be hydrated ferric oxide, $Fe_2O_3 \cdot nH_2O$, but will also consist of several other iron compounds, such as α, β, γ-FeOOH and Fe_3O_4. [46, 47] Copper on the other hand will not rust, but form a green layer called verdigris, which consists of different copper acetate compounds. [48] Compared to rust, verdigris is found to be quite stable. Two examples of verdigris covered monuments are the Statue of Liberty, found in New York, and the roof of Nidarosdomen, found in Trondheim, where both originally had a bronze-like color. Another metal with a good defense mechanism is aluminum (Al), which will react with oxygen, forming a very stable surface layer, Al_2O_3. [49]

As iron is prone to environmental attack and does not have a reliable defense mechanism, alloying it with elements which yields favorable properties has become a standard. Examples of such elements are carbon, manganese, chromium, and vanadium. The main iron alloy is called steel, and is a combination of iron and carbon. Steel also contains several other elements that will do anything from strengthening it to making it acid resistant. These properties are dependent both on the elements used, and the concentration of each element. This gives several different steel types, each specialized for a certain application. For instance, when wanting corrosion resistant steel (stainless steel) chromium is the main alloying element and the steel should contain at least 11 weight% chromium. Nickel and molybdenum (Mo) may also help enhance steel's corrosion resistance.

Corrosion can be found in several different forms. One of the most common forms is uniform corrosion. This is when a randomized corrosion pattern is observed on the whole metal surface, and is normal to see on iron based equipment. Pitting is another form of corrosion, and involves the creation of small holes in the metal. This is unfavorable if the metal acts as a container since the content may leak out. An additional form of corrosion is erosion-corrosion which can be observed when the metal is in contact with a moving liquid. This corrosion form is difficult to protect against and will affect all metal alloys exposed to it in some degree. Erosion-corrosion is often observed inside pipes due to the constant flow of liquid, but can also be seen in aquatic environments close to rivers when metal objects end up there. Furthermore, seawater is highly corrosive due to the abundance of sodium chloride. Therefore, if erosion-corrosion is observed in seawater the combined effect may attack metals with impunity. [50]

2.1.2 Elements in seawater and soil/sediment

2.1.2.1 *Main composition of seawater*

Seawater contains a preponderance of chloride (Cl^-), sodium (Na), sulfate (SO_4^{2-}), magnesium (Mg), potassium (K), calcium (Ca), bicarbonate (HCO_3^-), bromide (Br^-), and strontium (Sr). [25] These cover ~99 % of all non-H_2O constituents found in seawater, where the remaining 1 % consists of trace elements. [51] Chloride and sodium are the two elements with the highest concentration in seawater by far, a consequence of their long residence times. [25] Metals such as iron and aluminum are removed from the water much quicker than chloride and sodium. This can be explained by their low solubility in seawater, iron's role as a micronutrient, as well as aluminum's rapid particle formation, and adhesion to other particles. [52]

Whether the water column has access to oxygen or not will affect the solubility of several metals, as mentioned in chapter 2.1.1. As metal solubility is dependent on pH, oxygen content, and availability of ligand atoms, dissolved metal concentrations can vary from lake to lake, ocean to ocean, as well as depth. [31, 53] Depth profiling graphs are therefore a helpful tool when wanting to observe patterns down the water column. Depth profiling is useful when deciding which compounds are nutrients, as well as comparing oceans and compounds to one another. [54, 55]

Figure 2.1 shows three examples of depth profile graphs. Zinc has a nutrient profile, where it is depleted in the surface water as it is used by primary producers. When these producers die and decompose the zinc is released in deeper water. Aluminum has a scavenger profile, where it is introduced into the surface water by air (often dust from deserts). The dissolved aluminum fraction quickly decrease when sinking due to aluminum's affinity for particles. Iron can be seen as a hybrid. It has a nutrient profile since it is used by primary producers in the surface water, but will act as a scavenger in the deep due to its affinity for particles. [56]

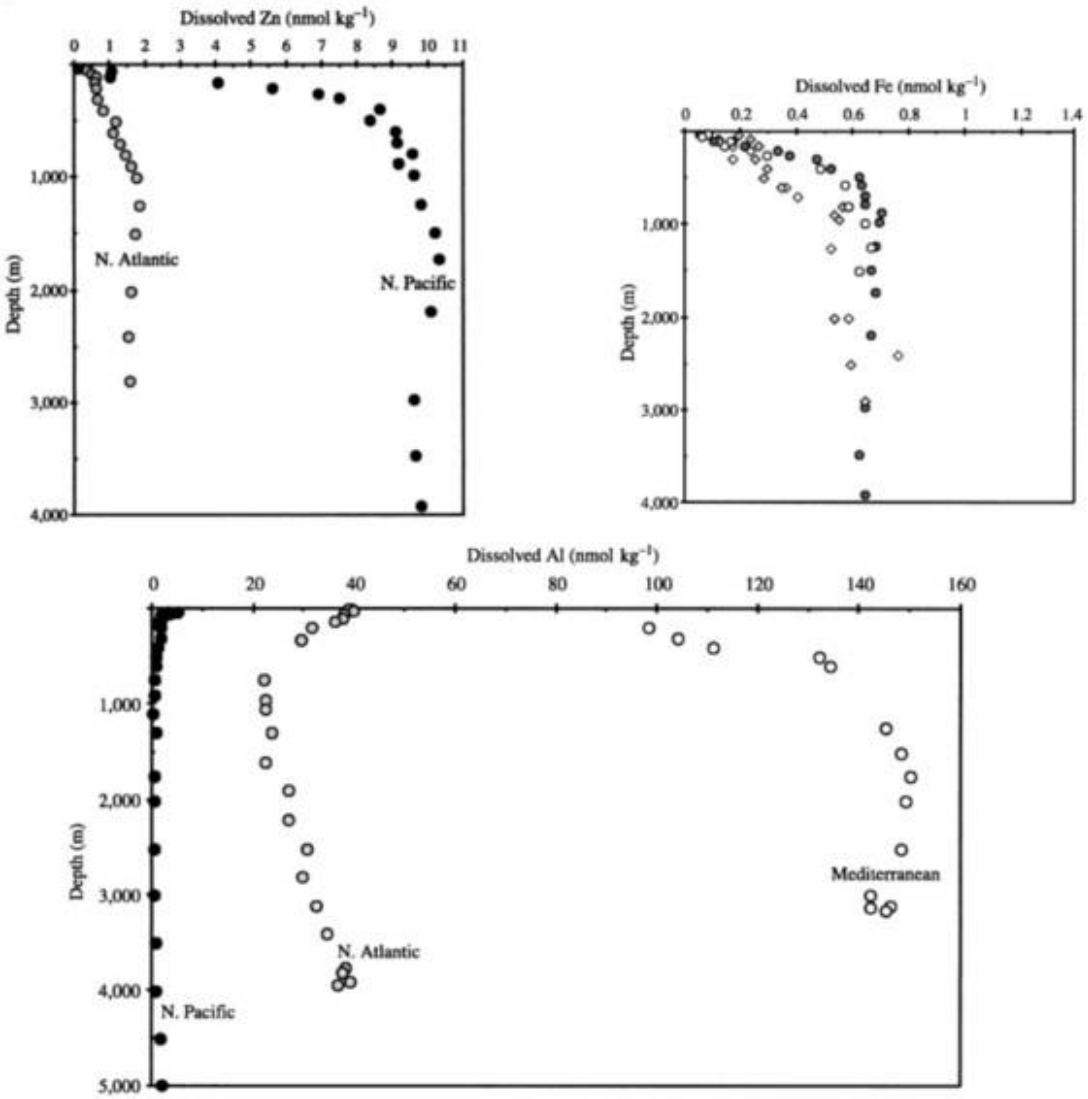

Figure 2.1. Depth profile graphs of zinc, iron, and aluminum. Zinc acts as a nutrient, aluminum as a scavenger, and iron as a hybrid. Adapted from Elderfield et. al. [56]

2.1.2.2 *Short on fjords*

Fjords are results of either massive ice movement carving valleys through land, or of seismological activity. Fjords can reach significant depths and lengths, and tend to receive a large freshwater input from rivers, which makes riverine input a major source of particles in fjords. The largest fjords in Norway are the Sognefjord, the Hardangerfjord, and the Trondheimsfjord. The Trondheimsfjord has a maximum depth of around 600 meters, whereas the Sognefjord has a maximum depth of 1300 meters, which is quite deep. [57, 58] Fjords receive only small amounts of seawater from its outlet. This is due to a sill located in the outlet allowing the relatively fresh water on top to pour out, but not the salty (and therefore heavier) bottom water to pour in. [59] This gives a limited circulation, which may lead to anoxic bottom water. [60] If mining activity or industry is found close by a river leading to the fjord, or the fjord itself, contaminants may end up there.

Fjords are seen as a very important tourist attraction in Norway, and is thought to be a sign of untarnished beauty that define the Norwegian sightseeing experience. In order to protect the Norwegian tourism and heritage it is therefore important to make sure the fjords are as uncontaminated as possible.

2.1.2.3 *Main composition of soil/sediment*

One may think of soil and sediment as the same thing, except for the fact that sediment exists in an aquatic medium. [61, 62] The main difference would therefore be the interface they meet. Where top soil will meet and somewhat equilibrate with the atmosphere, top sediment will equilibrate with the water column, be it salt or fresh. As both are made up of the weathered crust of the earth, their geological parent material should be somewhat the same if both soil and sediment samples are taken in the same area. Soil and sediment are therefore used somewhat interchangeably in this chapter.

The relative amounts of heavy metals found in soil will vary depending on two main factors. Firstly, the geological parent material the soil stems from is a major contributor to which metals are found in the soil. This is called the lithogenic source and the soil could have been developed from several possible rock formations weathered over millions of years. The other main factor is a wide array of anthropogenic sources, from sewage sludge to agricultural chemicals to nuclear waste. The lithogenic source is usually the dominant factor concerning heavy metals in soil, but the anthropogenic sources can be quite significant depending on the area.

The ten major elements found in the earth's crust are oxygen, sodium, magnesium, aluminum, silicon (Si), phosphorus, potassium, calcium, titanium (Ti), and iron, and constitute 99 % of the soil elements. The remaining 1 % are known as trace elements. This 1 % will consist of different elements depending on the lithogenic source and the anthropogenic sources found in the area. [33] Natural organic material (soil organic matter (SOM)) is also found in the soil, consisting of plants, animals, and microorganisms, both dead and alive. [63]

In sediment, some animals like polychaete (ragworms), may transfer metals from the sediment to other compartments or organisms. [64] Ragworms may be predated upon when reaching the top of the benthic layer, which means if the ragworm has ingested contaminants, they can be transferred to the predator. Also, some organisms that eat sediment will transport contaminants across the sediment layer. The contaminants are either moved physically with the sediment when the organism moves through it, or released as a part of the fecal matter after digestion. Contaminants are also released when the organism dies and is decomposed.

Organisms might also transfer dissolved nitrate (NO_3^-), sulfate (SO_4^{2-}), and oxygen across the anoxic sediment layer. [65, 66] This can change the properties of the anoxic layer leading to a change in redox potential, which in turn has an effect on metal solubility, as mentioned in chapter 2.1.1.

In oxic sediment several surface related reactions occur. Metals with an affinity for particle adsorption will bind to OH-sites found on the particle surface. Here $\equiv S$ is the surface of a particle.

$$\equiv S - OH + M^{z+} \rightleftharpoons S - OM^{(z-1)+} + H^+$$

$$\equiv S - OH + M^{z+} + H_2O \rightleftharpoons S - OMOH^{(z-2)+} + 2H^+$$

However, the OH-sites can be replaced by ligand competitors, depending on the pH and redox potential.

$$\equiv S - OH + L^- \rightleftharpoons S - L + OH^-$$

This may ultimately lead to surface complex formations.

$$\equiv S - OH + L^- + M^{z+} \rightleftharpoons S - L - M^{z+} + OH^-$$ [25]

In anoxic sediment primarily sulfur related reactions are observed. For example, a reaction for metal hydroxides reacting with sulfur species was proposed 35 years ago.

$$(MOH \cdot xH_2O)^+ + HS^- \rightarrow [MS \cdot (x+1)H_2O]$$ [67]

Other chemical reactions under anoxic conditions show iron and manganese reduction, and how iron can assist in reducing manganese.

$$2FeOOH + H_2S \rightarrow 2Fe^{2+} + S^0 + OH^-$$

$$MnO_2 + H_2S \rightarrow Mn^{2+} + S^0 + 2OH^-$$

$$MnO_2 + 2Fe^{2+} + 2H_2O \rightarrow Mn^{2+} + 2FeOOH + 2H^+$$

These reactions show that iron and manganese are dissolved under anoxic conditions, as stated in chapter 2.1.1. Additionally, H_2S is toxic to organisms, making reactions using H_2S important for the continued existence of organisms in the sediment. [68]

Apart from H_2S, other toxicants such as mercury will have an effect on organisms. Mercury will react fairly quickly into organometallic forms, which is easily taken up by organisms. Depending on the ligand available, methylmercury can be found as several different complexes. Some examples are:

$$Hg^{2+} + CH_4(aq) = CH_3Hg^+ + H^+$$

$$HgCl_2 + CH_4(aq) = CH_3HgCl + H^+ + Cl^-$$

$$CH_3Hg^+ + H_2O = CH_3HgOH + H^+$$

$$CH_3Hg^+ + SO_4^{2-} = CH_3HgSO_4^- \text{ [25]}$$

In seawater it is normal to find chlorinated mercury complexes due to the abundance of chloride and the pH range of the water. In freshwater the mercury complexation tends to vary between hydroxide and chloride based on the chloride concentration and the pH found. [69]

2.1.2.4 *Classification of sediments*

Sediment may be classified according to its degree of contamination by looking at contaminants in the sediment and pairing it with detrimental effects on aquatic life found there. A tried and tested method for doing this is the Apparent Effects Threshold (AET).

The AET is a helpful tool developed for determining sediment quality values. This is possible by using several biological indicators showing whether the sediment is contaminated, where both chemical and biological information have been gathered and matched. By checking the concentration of several contaminants in the sediment, one might be able to discover which contaminants caused the adverse effects. The AET is useful since it uses field data, meaning it is a quantitative tool that helps assess whether the sediment needs remedial action or not. As sediment cleanup is expensive and time consuming it is important to make sure it is needed. Ultimately, the AET concentration of a selected chemical tells us that a statistically significant biological effect will always happen above this concentration, which can be a helpful reference point. [70, 71]

Several other tools for classifying sediment exist, such as the Screening Level Concentration (SLC), and the Sediment Quality Triad (SQT), both effects based (biological effects are matched with chemical concentrations), like the AET. [70]

The background approach is also well-used, where an unpolluted sample is used as reference and compared with the samples of interest.

The background approach also tends to use values decided by a government entity as a basis for comparison. [71] However, it is important to remember that while the background approach is quick and easy to use, it can also be unreliable if used indiscriminately. Also, its lack of biological effects data makes it somewhat less feasible compared to effects-based tools. [72] The background approach is therefore viable when looking for contamination or enrichment of toxicants, but will not be able to properly assess whether the contamination found is hurting biological life located there. This is partly because some contaminant species found in sediment are unavailable for biological uptake, and when using the background approach a total concentration tends to be determined. [73]

The former Climate and Pollution Agency in Norway has created a guideline containing values for determining the contamination level in water and sediment. By comparing these guideline values to the sample data of interest one can get an indication as to whether a water/sediment sample is contaminated or not. It is important to mention that these guideline values have been created using total concentrations, which limits the knowledge gained on potential biological effects.

This classification divides the concentration of a contaminant into five potential states. The concentration might be at a *background* level, which is the desirable state. The next state is *good*, where no toxic effects are observed. At this state, the sample is thought to be partially contaminated by one or more sources, but not enough to cause adverse effects. At a *moderate* level chronic effects will be observed during long-term exposure, and remedial action should therefore be considered. At a *poor* level acute toxic effects is observed during short-term exposure. Finally, at the *very poor* level extensive acute toxic effects are observed. [74]

Table 2.1 and Table 2.2 show the classification of several metals (and the metalloid Arsenic) in seawater and sediment. The data has been retrieved from the former Climate and Pollution Agency guideline and translated into English.

Table 2.1. Classification of important contaminants in seawater, provided by the former Climate and Pollution Agency.

	I Background	**II Good**	**III Moderate**	**IV Poor**	**V Very poor**
Elements *in µg/L*					
Arsenic	<2	2-4.8	4.8-8.5	8.5-85	>85
Cadmium	<0.03	0.03-0.24	0.24-1.5	1.5-15	>15
Copper	<0.3	0.3-0.64	0.64-0.8	0.8-7.7	>7.7
Chromium	<0.2	0.2-3.4	3.4-36	36-360	>360
Lead	<0.05	0.05-2.2	2.2-2.9	2.9-28	>28
Mercury	<0.001	0.001-0.048	0.048-0.071	0.071-0.14	>0.14
Nickel	<0.5	0.5-2.2	2.2-12	12-120	>120
Zinc	<1.5	1.5-2.9	2.9-6	6-60	>60

Table 2.2. Classification of important contaminants in sediment, provided by the former Climate and Pollution Agency.

	I Background	**II Good**	**III Moderate**	**IV Poor**	**V Very poor**
Elements *in mg/kg*					
Arsenic	<20	20-52	52-76	76-580	>580
Cadmium	<0.25	0.25-2.6	2.6-15	15-140	>140
Copper	<35	35-51	51-55	55-220	>220
Chromium	<70	70-560	560-5900	5900-59000	>59000
Lead	<30	30-83	83-100	100-720	>720
Mercury	<0.15	0.15-0.63	0.63-0.86	0.86-1.6	>1.6
Nickel	<30	30-46	46-120	120-840	>840
Zinc	<150	150-360	360-590	590-4500	>4500

Another useful tool is calculating the enrichment factor of a contaminant. The enrichment factor serves the purpose of eliminating the grain size difference in the various sediment types, effectively assisting with verifying anthropogenic contamination. [75, 76]

The enrichment factor is found by choosing a normalization element not strongly affected by anthropogenic sources, and using it to normalize the element of interest. The formula for the enrichment factor is:

$$Enrichment\ Factor\ (EF) = \frac{\left[\frac{C_{element}}{C_{norm}}\right]_{sediment}}{\left[\frac{C_{element}}{C_{norm}}\right]_{reference}}$$

Where $C_{element}$ is the concentration of a chosen element in a sediment sample and a reference sediment sample, and C_{norm} is the concentration of the normalization element in the same sediment and reference samples.

The EF values obtained can range from < 1, meaning no enrichment is present, to > 50, meaning an extremely severe enrichment is present. Table 2.3 displays the enrichment levels possible to observe in sediment.

Table 2.3. The degree of enrichment, divided into seven levels, from no enrichment to extremely severe enrichment.

EF ≤ 1	No enrichment
1 < EF ≤ 3	Minor enrichment
3 < EF ≤ 5	Moderate enrichment
5 < EF ≤ 10	Moderately severe enrichment
10 < EF ≤ 25	Severe enrichment
25 < EF ≤ 50	Very severe enrichment
EF > 50	Extremely severe enrichment

Aluminum has seen usage as a normalization element, along with lithium, cesium (Cs), rubidium (Rb), scandium (Sc), manganese, titanium, calcium, zirconium (Zr), and more. [75, 76, 77, 78, 79] However, research have shown that aluminum can be an unstable normalization element, along with several others depending on factors such as sediment type and the anthropogenic inputs affecting the sediment. [80]

Additionally, as aluminum forms aluminosilicates in sediment it is often necessary to completely digest the sample before analysis to make sure the ratio does not become artificially high due to aluminum's weakened presence. [75] Iron is also a possible normalization element, but only when iron's anthropogenic input is lower than the natural one. [81]

2.2 Environmental toxins – inorganic and organic

There are 118 elements in the periodic table, divided into 91 metals, seven metalloids, and 19 non-metals. These elements may combine into an unimaginable number of compounds, where the majority of these will be part of the organic category. However, there are many inorganic elements and compounds exhibiting toxic behavior, and their effect and accumulation in the body vary greatly.

2.2.1 Inorganic

While POPs, or nonpolar organic compounds in general, will accumulate in fatty tissues of animals due to their lipophilic nature, metals will persist in organisms in other ways. [82, 83] Lead will compete with the essential metal calcium for enzyme seats, ending up in the bone structure of organisms, and may also affect the liver and kidneys. Mercury will connect itself to a methyl or ethyl molecule forming an organometal, and may then accumulate in organisms [84] This also makes mercury able to cross the blood-brain-barrier and cause neurological damage to organisms. [85, 86]

Both mercury and lead are known to be toxic toward both aquatic life and mammals. Mercury is known to bio magnify, meaning it will be accumulated and transferred up the food web as it is able to persist in organisms. [87, 88] Elemental mercury has a residence time of one year in the atmosphere, making it a particularly dangerous metal for animals living in the arctic region as it may travel there by wind systems. [89] This has led to cases of mercury poisoning in apex predators such as polar bears. In aquatic systems, mercury in tuna is a cause for concern. Tuna, being high up in its food chain, will accumulate a fair amount of mercury. The fact that it is a popular fish for human consumption, both as sushi and on can, has led to cases of elevated mercury concentrations in humans. [90, 91, 92]

There are well-known cases where humans have been poisoned by mercury containing food. The Minamata disease, which took place in Japan, was caused by methylmercury poisoning. The disease manifested itself by causing neurological damage, impairing vision, mobility, and speech, and was caused by eating contaminated fish and shellfish. [93] The bio accumulative property of mercury therefore makes it an important metal to monitor in the food web.

Like mercury, cadmium poisoning has also been observed in Japan. The itai-itai disease (it hurts-it hurts disease) was thought to be a consequence of cadmium intake and led to severe back and joint pains. This was due to cadmium accumulating in the kidneys and removing calcium from the bones, which caused pseudo-fractures. The intake of cadmium came from rice and soya that had been irrigated with contaminated water [94]

Cadmium, having similar chemical properties to the essential metal zinc, will also compete with zinc for transport through the body, mostly ending up in the liver and kidneys. [95] Studies have shown that a calcium, zinc, or iron deficiency will increase cadmium uptake to the body. [96, 97] Cadmium is known to cause adverse effects in humans, but recent studies show that cadmium is used by certain phytoplanktons as nutrient when experiencing zinc deficiency. [98, 99]

The metalloid arsenic will mainly accumulate in the liver, kidneys, heart, and lungs during chronic exposure, and can cause cancer by affecting DNA repair and DNA methylation. [100, 101]

A way of visualizing the effect essential and nonessential metals have on organisms is using a dose-response curve. The dose-response curve found in Figure 2.2 shows the trends observed with essential and nonessential elements. Essential elements will become toxic in large enough doses, but is important for the organism at the appropriate dose. [102] Nonessential elements however will simply have no toxic effect when the concentration is sufficiently small and, ultimately, give a toxic response when the dose is large enough.

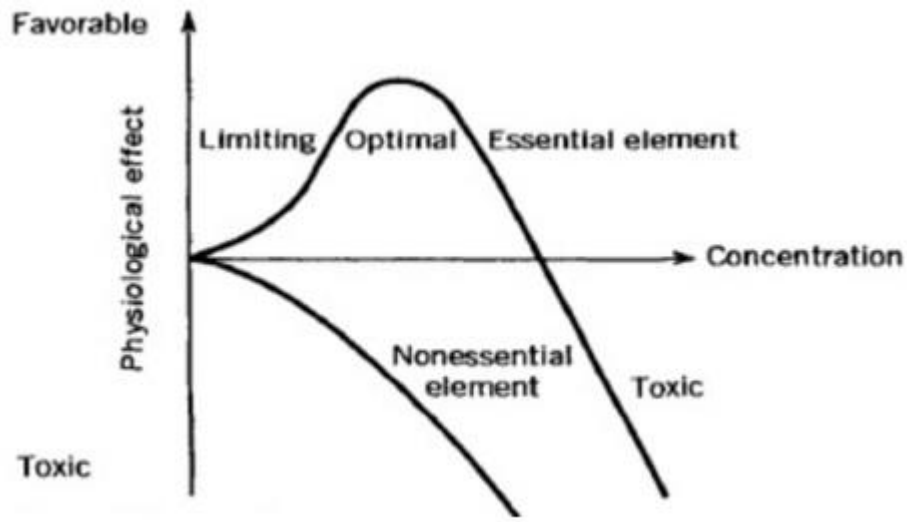

Figure 2.2. The dose-response relationship between essential and nonessential metals. Adapted from Stumm and Morgan. [25]

Elements may have an essential oxidation state, while another state is nonessential. Chromium is an example of this; Cr (III) is essential for organisms, and Cr (VI) is a carcinogen. [103] Both redox potential and pH will affect the chromium oxidation state, making them important to monitor in areas with chromium enrichment. [104]

Copper is essential for mammals, but toxic towards aquatic organisms. In fact, mammals have a 10 to 100 fold higher copper tolerance than fish, and up to a 1000 fold higher tolerance than algae. [105] In algae copper will inhibit several cellular processes and shows differing effects depending on the algae type. [106] Copper will also impact the olfactory system of fish which affects survival chances towards predators and migration success. [107] However, a chronic copper exposure will be damaging to mammals as well. In humans, copper toxicity will primarily affect the liver, and may lead to a coma and ultimately death. [108]

2.2.1.1 *Metals weaponized*

Several different metals have been used in weapon applications over the years. Metals such as lead are frequently used in bullets even today, while the bullet jacket (cartridge) usually is from brass, although iron, nickel, and lead can also be found in brass cartridges. Brass is an alloy of copper and zinc, where the field of use determines the copper-to-zinc ratio. In cartridges 70 % copper and 30 % zinc tends to be the basic composition ratio. [109] Other alloys than brass have also been used as cartridge material, such as steel, and cupronickel, a mixture of copper and nickel. [110, 111] Steel was used in a larger scale as cartridge material during the Second World War due to a copper shortage in both the US and Germany. [112, 113]

While firearm ammunition contains lead and brass, high explosive ordnances such as artillery grenades contain explosive organics rigged to explode upon contact with a surface. The grenade shells are either steel or brass, known to be strong and inexpensive alloys. [114] Artillery grenades also contain a fuse that starts the explosive reaction. [115] Apart from high explosive ordnances, the use of depleted uranium in tank shells have increased in the later years, as well as other radioactive elements used in nuclear bombs. [116]

2.2.1.2 *Gases*

Gases such as sulfur dioxide (SO_2) and nitrogen oxides (NO_x) are also of concern when discussing inorganic pollutants and their harmful effects. NO_x gases have been known to promote acidification in low-buffer freshwater systems when the concentration is high enough, as well as indirectly cause respiratory symptoms in humans. [117, 118, 119] NO_x gases are recognized as a short-lived greenhouse pollutant having an indirect effect on the climate as well by affecting ozone, methane, and particle concentrations.

They are not inherently harmful, but their effect on ozone and particle concentrations make them a concern. [120] NO_x gases are a somewhat urban problem in the modern day and age because of diesel fueled cars. [121] The burning of fossil fuels such as diesel and gasoline also causes emissions of CO_2, as well as organic pollutants if incompletely combusted. [122]

2.2.2 Organic

Dangerous organic compounds originate both naturally and from anthropogenic processes. Depending on the content of an old dumping site, several organic toxicants might be found there. Organic toxicants considered especially dangerous and widespread are those found in the dirty dozen list from the Stockholm convention. Pesticides such as Hexachlorobenzene (HCB) and Dichlorodiphenyltrichloroethane (DDT) as well as by-products such as polychlorinated biphenyls (PCB) have been found in old dumping sites. [123] In general POPs are regarded as a hazard to the environment and the organisms living there. They tend to be lipophilic, meaning they will accumulate in animal fat instead of being excreted in the urine, and have a slow degradation time. They are also able to travel long distances due to their ability to exist in the air without decomposing. [124] POP's ability to persist for many years without degrading makes aquatic sediment containing them a potential hazard. This is because a sediment sink switch might release them into the surrounding environment in the future. [125]

2.2.2.1 *Organic compounds weaponized*

Aquatic dumping sites used as a final resting place for unexploded ordnances can over time play host to chemicals of an explosive nature. Dumping ordnances into the ocean was not an uncommon occurrence after the Second World War as too much was made to store safely on land. Today, there are several confirmed aquatic ordnance dumping sites all over the world. These sites are relics of a past where the oceans were believed to have unlimited absorptive capacities. [126, 127, 128] Today, discarding unexploded ordnances in the aquatic environment is prohibited to protect human health. [129]

Research into explosives has been extensive. Ever since gunpowder was discovered by accident in China over 2000 years ago, mankind has tried to create explosives suitable for mining, construction work, and ultimately military applications. Nitroglycerin, pentaerythritol tetranitrate (PETN), TNT, RDX, and cyclotetramethylenetetranitramine (octogen, HMX) are examples of well researched explosives. PETN was more or less phased out of military applications by RDX during the Second World War due to RDX's higher stability, while HMX was not available until the end of the Second World War. [129]

It is therefore reasonable to think dumped ordnances from the Second World War would contain TNT or RDX as the main explosive compound.

TNT and RDX were two well-used explosives during the Second World War. [130] Both TNT and RDX are hazardous to the environment, where TNT has been branded a chemical that should be removed from the environment as soon as possible after discovery. [131] TNT is more soluble in water than RDX, but also adsorbs more easily to particles in the sediment. [132] This makes it difficult to conclude on which of the explosives might reach the water column from the sediment first if found there.

Figure 2.3 shows the chemical structure of TNT and RDX. As is common for explosives, both contain nitro groups (NO_2), an important factor for ignition. This is due to the nitro group's production of OH through reactions with hydrogen radicals, causing an uncontrollable chain reaction giving a large release of energy. [133]

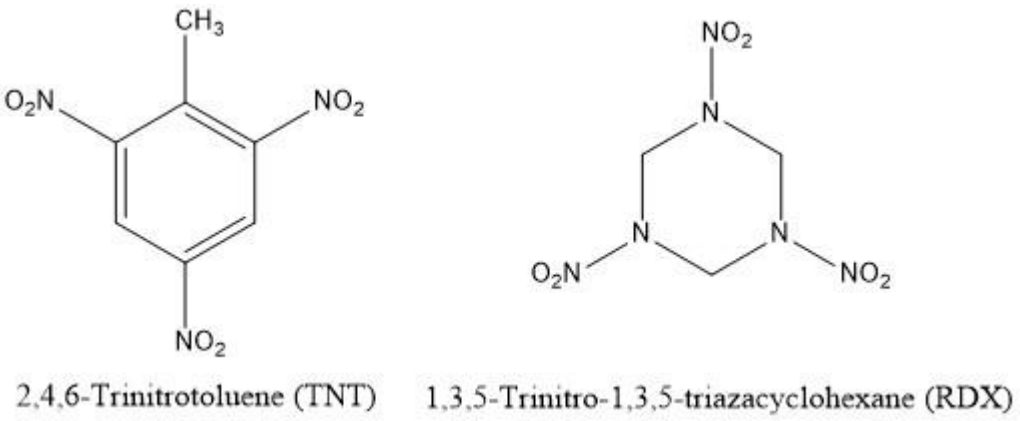

Figure 2.3. The chemical formulas of TNT and RDX, two explosives used during the Second World War.

In addition to explosive ordnances, weaponized chemical agents such as mustard gas ($C_4H_8Cl_2S$) were also used during warfare. Mustard gas was generally not used for killing, but rather incapacitation and fear, something it did very efficiently by causing painful blisters on bare skin, even in low concentrations. [134] Today chemical warfare agents (CWA) are banned globally, and stockpiles are gradually destroyed. [135] This however, has not stopped CWA's being dumped in aquatic systems in the past. Incidentally, mustard gas has been found inside scuttled ships on the seafloor of Skagerrak, the sea separating Norway and Denmark. [136] In general, ordnances can be found in aquatic dumping sites all over the world, where fishermen more than once have caught live explosives and CWA's in their nets. [137, 138 139]

Even though explosives and CWA's can be found in a dumping site, other equipment found there may be important contamination sources as well. Contaminants like mercury may be found in old dumping sites from equipment such as computers, batteries, and old TV's. [140, 141] It is therefore important not to ignore dumping sites filled with "normal" waste, as these sites also can be hostile to the environment.

2.3 Sampling techniques

2.3.1 Water sampling

Water samples can be collected using multiple techniques and equipment. One piece of equipment, which gives several samples in one operation is canisters programmed to close at specific depths. This device, which can be seen in Figure 2.4, works quite efficiently, although the canisters might malfunction and not close properly. The main advantage with this setup is the ability to get several water samples at once, as well as at different depths.

Figure 2.4. Water sampler used onboard RV Gunnerus.

However, a water sampling device does not need to be complex at all. Using a bottle to scoop up water from the surface is also an option, but will limit the possibility of getting deep water samples. Buckets with lead in the bottom to make it sink are also used to collect water samples, but is limited to one sample at a time. No matter which technique or piece of equipment used, of high importance is not contaminating the samples after retrieving them.

Keeping the sample in a closed atmosphere is a way of avoiding contamination after retrieval, as well as not opening the sample and working directly above it. Using gloves when handling the sample is also an important measure towards avoiding contamination. [142]

Another important factor is sample contamination during retrieval. Avoiding equipment material that might disturb the results, either by providing an adsorptive surface to contaminants or containing elements of interest, is important. This is especially important for water samples as seawater is approximately 96.5 % water and only 3.5 % elements. [143] Fjord systems usually have an even lower elemental content in the water due to the high river water input (estuarine system), making equipment contamination a larger factor there. [144]

Today's water sampling equipment should ideally consist of Teflon bottles/tubes to minimize sample contamination. Additionally, small components made from rubber and metal should not be a part of the sampling equipment if possible. [145]

2.3.2 Sediment sampling

When collecting sediment samples, a sampling device is often used. A common sampler is a cylindrical tube with a closing mechanism that is lowered from the boat using a crane and a wire, and dropped into the sediment. Such samplers are often called gravity corers since gravity forces them into the sediment. [146] A sediment column is extracted from the corer afterwards giving the possibility of analyzing several sediment samples from the same core. If the column layers are intact it may be possible to see changes in contaminant concentration over time, as explained in chapter 2.1.1.

Different sediment sampling equipment exist and are used regularly. They are generally divided between grab samplers and core samplers, but can be categorized further. Examples of grab samplers are the Birge-Ekman sampler, Ponar grab sampler, Petersen grab sampler, and the Smith-McIntyre grab sampler. Examples of core sampler categories are gravity corers, multiple corers, box corers, push corers, and piston corers, and can be categorized further.

If the water is shallow enough it is possible to use divers to retrieve samples, making it easier to get the sample from the exact area of interest. No samplers are optimized for all sediment properties, meaning a grab sampler may be appropriate for certain extractions, while corers are appropriate for others. For instance, a corer allows for an intact sediment column, but can enter the sediment at an angle if the boat moves or the descent is too fast. Hard/rocky sediment will also prove difficult for corers to extract successfully.

Grab samplers can prove difficult to use in areas affected by strong currents, and in poor weather conditions, but this can be somewhat eliminated if the sampler is heavy enough. Even though grab samplers fail to preserve the column integrity, a large amount can be sampled at once depending on the sampler size. This is important for biological sampling. [147]

Figure 2.5 shows a small gravity core sampler for sediment with a closing mechanism suspended from a wire with a steel closing mechanism.

Figure 2.5. A core sampler with a steel body and closing mechanism. A sampler of this size is able to extract a 50 cm sediment core.

Figure 2.6 shows a large gravity core sampler. The design looks quite rudimentary, where a large steel pipe is connected to a main body for weight balance. The pipe is fed with a removable plastic tube which receives the sediment column, is removed and then sawed into appropriate sections after sampling. This allows for a 2 m sediment core, giving many samples and also an extensive depth profile.

Figure 2.6. A large core sampler, able to retrieve a 2 m sediment core.

The sediment sampling equipment should ideally be made from inert materials that do not readily adsorb contaminants and are not found in the sampling area, like glass and Teflon. [148] However, this is not as important as for the water sampling equipment. This is because the amount of metals found in the water column is much lower than for the sediment. [149] Also, the inner part of the sediment core will be virtually undisturbed by the sampling procedure, decreasing the equipment contamination contribution if the inner part is analyzed.

2.4 Remedial methods

If sediment samples show obvious signs of contamination after analysis, remedial action should be considered. While remediation of a contaminated area is very important, of equal importance is removing the source of contamination. If an area is contaminated, removing the contaminated sediment is merely a temporary solution and will not stop new sediment from becoming contaminated. Therefore, if a point source nearby is constantly supplying contaminants to the area, it should be handled before remediation is performed.

When an area is shown to be contaminated, a decision based on the remedial alternatives available, budget, and manpower should be made. One alternative is *doing nothing*. The area might be inaccessible or other areas might be more contaminated and therefore have precedence. Also, if the area has a high sedimentation rate and it is believed that the contaminated sediments will be buried in a short amount of time, the *doing nothing* approach may be applicable.

Another approach needing limited manpower is *monitoring the site*. Unlike the *doing nothing* approach, *monitoring the site* will pay close attention to the area so that further evaluations can be made. If no contaminant reduction is observed over time, a more active approach might be taken, like capping or dredging. [150] Capping means a layer of clean material is placed on top of the sediment to lessen the contaminant load spread into the water column, and is explained in more detail in chapter 2.4.1.

Dredging is when the sediment is removed from its original location and moved someplace else. Several dredging equipment exist specialized for different operation parameters. A *hopper dredge* is a boat equipped with either a *cutterhead dredge* or a *suction dredge* for removing sediment. The hopper dredge is made in such a way that contaminated sediment is pumped directly onto the boat's main deck. A *clamshell bucket dredge* can also be used with a hopper dredge or with an excavator. [151] Both the suction dredge and clamshell bucket dredge are suited for removing soft sediment. After dredging, the sediment can be moved to a land-based area for storage, or to a water facility, such as a Confined Aquatic Disposal (CAD) or a Confined Disposal Facility (CDF). These two terms are explained in chapters 2.4.2 and 2.4.3 respectively. When dredging it is important to make sure as little contaminated sediment as possible is released to the water column during the operation. This may cause resuspension of sediment particles which can cause contaminants to dissolve. [150]

2.4.1 Capping

Contaminated sediment may be covered with a layer of clean material to stop the sediment from becoming a source of contamination. This layer is called a cap and, depending on its thickness, can function as a pure isolation remedy, or as a way of reducing the contaminant load by supplying more sediment. When using capping in-situ, a thin capping layer is often applied to reduce the environmental risk. This environmental risk reduction is achieved by reducing the contaminant concentration in the surface sediment as well as partly isolating the contaminated sediment from the surrounding environment.

When contaminated sediment has been dredged and placed in an ex situ location, an engineered isolation cap can be placed on top of the sediment to isolate the contaminants. This layer should be thick enough to avoid bioturbation, diffusion from, and erosion of the contaminated sediment. When capping it is important to take factors such as water depth, currents, dredged material and capped material characteristics, as well as site capacity into consideration. Incidentally, if the contaminated sediment is situated at a harbor, it is very important to make sure the water is deep enough when using in-situ capping. This is to avoid ships running aground as a consequence of decreasing the water depth. In such situations, dredging must be performed first where the sediment is moved to a disposal site.

The capping material used can vary greatly. Use of active materials that are able to sorb organic material has been suggested in the later years. An example of such a material is activated carbon, which is thought to reduce the amount of organic contaminants available for interaction with organisms found in the water and on the seafloor. Active materials will also have an effect even if the cap gets mixed with the sediment and no longer functions as a barrier between the contaminants and the water. [150, 152]

Capping has been used in several projects. The most recent example is the “cleaner harbor” project in Trondheim where several contaminated harbors have been chosen for remediation. Limestone ($CaCO_3$) was used as capping material and one of the harbors was dredged beforehand. [153]

2.4.2 CAD

After dredging contaminated sediment, it has to be placed somewhere. One possible location is a CAD, which is found in open water. The sediment is dumped either on the level seafloor, in a natural depression, or an artificially made depression and covered with an engineered cap for isolation. A CAD tends to be used when there is a large amount of dredged contaminated sediment to be removed.

It is important that the dredged material is placed in the CAD in a way that minimizes the contaminant release. It is also important to monitor the site in the future to ensure the CAD does not release contaminants to its surroundings. [150]

2.4.3 CDF

Smaller amounts of dredged material can be placed in a CDF, which is quite similar to a CAD. The main differences are the fact that a CDF is found close to the shore, and that the dredged material might extend above sea level. If the dredged material does indeed extend above sea level this new area can be used in the future. This may add economic value to the area, increasing the attractiveness of the project. A CDF should also be monitored, but this tends to be easier than for a CAD as the material is close to shore and in shallow waters. Addition of stabilizers, such as cement, can minimize the contaminant release from a CDF, as well as making sure the surface cover is stable which helps promote future use of the site. [150]

2.5 Analysis

2.5.1 Decomposition – UltraCLAVE

Acid aided decomposition using UltraCLAVE is a standard treatment step before Inductively Coupled Plasma – Mass Spectrometry (ICP-MS) analysis. By using different types of acid the method will remove organic matter, break down silica compounds, aluminosilicates, and more depending on the acid's strength. Nitric acid (HNO_3) is well used when wanting to remove organic matter, but not bothering to break the strong bonds found in the soil itself. Using HNO_3 with microwave digestion is thought to be the standard method of decomposition before trace metal analysis. [154] The UltraCLAVE also has a basin with hydrogen peroxide (H_2O_2) that helps oxidize the organic matter and free more elements. [155] Nevertheless, the combination of HNO_3 and H_2O_2 is not strong enough to completely decompose the soil matrix. Therefore, when geologists want to observe the core composition of the soil, they use aqua regia (King's water, a mixture containing one part HNO_3 and three parts hydrochloric acid (HCl)) with hydrofluoric acid (HF) to make sure the whole sample is ionized. [156, 157, 158]

Apart from the acid aiding step, the microwave itself has evolved over the years. Simple microwave heating was used before when wanting to break down organic matter. Now however, a greater measure is taken to prevent sample loss through volatilization. This measure has culminated into a pressurized microwave, called an UltraCLAVE. UltraCLAVE is in principle a microwave adding N_2 gas to increase pressure which prevents boiling and sample loss, as microwaves heat up the sample. The UltraCLAVE is a single reaction chamber (SRC), meaning all samples are placed in the same chamber and are subjected to equal conditions.

This eliminates a major source of error. The UltraCLAVE can operate at temperatures up to 300 ^{o}C and a pressure of 199 bar. [159] This, in combination with acid, makes for an effective method for decomposing samples before trace metal analysis.

2.5.2 Inorganic/Metal analysis – ICP-MS

ICP-MS is a powerful technique for metal analysis in today's scientific world. The ICP will ionize an aqueous sample using an argon plasma reaching temperatures of 6 000+ K. The argon plasma will easily ionize atoms into cations, but ionize certain atoms into anions as well. However, the transport mechanism and the MS are not optimized for all anions, making detection of for instance halogens difficult. [160] Sulfur, on the other hand, can be detected. In addition, the ICP-MS will not be able to analyze elements found in abundance in air, such as nitrogen and oxygen. [161]

The MS often consists of a quadrupole, four rods forming a square making the cations oscillate between the rods by applying alternate current (AC) and direct current (DC) in alternation. The separation is based on the difference in mass-to-charge ratio (m/z) of each ion. This allows only ions of a certain mass to enter the detector at a given time. [162] Other mass analyzers in use are magnetic sector and time-of-flight (TOF). [163, 164]

The ICP-MS is able to detect isotopes which makes spectral interferences a problem. This is caused by mass overlap, both polyatomic and monoatomic. An example where polyatomic interference is observed is between ^{56}Fe and ^{40}Ar^{16}O. [165] Monoatomic mass overlap may be observed between for instance ^{87}Sr and ^{87}Rb. As argon is the main constituent of the plasma it may overlap with analytes such as ^{40}Ca. However, mass overlap is reduced by using High Resolution (HR) or magnetic sector mass spectrometers. Although by increasing resolving power, the analysis time is increased and the signal intensity is weakened. The technique also becomes more complicated as the resolving power increases. [162]

Matrix effects can also cause problems. The matrix is the component that carries the sample, in other words the solvent. It may interfere with the plasma's ionizing environment or simply cause a spectral interference. An important method for minimizing both spectral interferences and matrix effects is using blanks and standards, as well as optimizing the operating conditions and diluting the sample adequately. [166]

The most effective, and possibly only way of running an ICP-MS is having a designated operator responsible for the instrument.

This, coupled with the big price tag makes ICP-MS a somewhat unattractive choice for companies lacking the resources and/or expertise to buy and operate the instrument. [160]

2.5.3 Organic analysis – Chromatography

When analyzing samples for organic compounds there are several instrumental techniques available. One of them is chromatography, a well-known concept used both for qualitative and quantitative sample analyses. The field of chromatography contains several analytical techniques. They range from simple thin layer chromatography (TLC), taking place on a silica plate placed in a beaker with solvent, to gas chromatography (GC), using an inert gas to transport the sample through a column. The chromatographic principle itself involves the separation of compounds in a sample. A detector at the end makes it possible to find out what the sample contains. GC and liquid chromatography (LC) are examples of versatile chromatographic techniques used frequently in many industries. A GC can be found in the research lab of oil companies and in a law enforcement forensics lab, while a high-performance liquid chromatograph (HPLC) is often found at pharmaceutical companies. [167, 168, 169]

A chromatographic instrument can be coupled with a mass detector, increasing its field of use. [170] GC-MS and LC-MS are coupled techniques that are widely distributed and well-used. LC-MS couples a liquid chromatograph with a mass spectrometer, where the LC will separate the sample components based on polarity, and the MS detects them based on their mass-to-charge ratio afterwards. A LC can potentially analyze any organics-containing sample that is soluble, making it quite versatile when coupled to a MS. On the other hand, GC-MS will, depending on the column used, separate the sample components based on either boiling point or polarity, and is dependent on volatile analytes. [171, 172, 173] A tandem system can also be used, where two mass spectrometers are coupled making it possible to look for specific ions. LC-MS/MS where one of the mass spectrometers is a quadrupole and the second is a time-of-flight can be used for specific ion monitoring (Selective Reaction Monitoring (SRM)). This is quite helpful when looking for a specific set of compounds within a sample. [174]

2.5.4 Statistical tools

2.5.4.1 *T-test*

When comparing sediment core samples from different locations a t-test can help determine whether the contaminant concentration averages found at each site is significantly different from each other. This is helpful when wanting to know how statistically significant the contamination is at the area of interest.

The t-test formula takes into account the difference between the mean values from each area, as well as the variance of the samples and the sample sizes. The following formula shows a t-test assuming unequal variances:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

Here $\bar{x}_x$ is the mean of sample x, n_x is the sample size,

and s_x^2 is the variance of sample x $\frac{\sum(x_x - \bar{x}_x)^2}{n_x}$ [175]

In excel performing a t-test is possible by installing the "Analysis ToolPak" found in the add-on tab in "options" under "file". Afterwards, one can use the tool by heading to the "Data" tab and clicking on the "Data Analysis" button. Here one may choose the appropriate t-test and simply select the column range containing the sample concentrations from the area of interest and afterwards the column containing the concentrations from comparative areas.

2.5.4.2 *Standard deviation*

When analyzing for trace metals using ICP-MS each sample will be run multiple times and the relative standard deviation (RSD) calculated. The RSD will provide a percentage showing the overall precision of the data, in other words how spread the parallels are. The RSD should ideally be below 5 % for major elements and below 10 % for trace elements. [176] Standard deviation (SD) and RSD are helpful since the mean of a set of numbers can be misleading. It is therefore important to calculate the overall precision of the method which the SD (and RSD) displays in simple terms.

The formula for the SD of a sample is $s = \sqrt{\frac{\sum(x - \bar{x})^2}{n-1}}$

Here x is the value of each parallel run, $\bar{x}$ is the mean value of the parallels, and $n - 1$ is the number of parallels minus 1. [177]

The formula for the RSD of several sample parallels is $RSD = \frac{s}{\bar{x}} \times 100$

Here s is the standard deviation of a sample and $\bar{x}$ is the mean value of the parallels. By multiplying by 100 the number becomes a percentage which is easy to interpret [178]

3 Experimental details

3.1 Sampling

Field expeditions were conducted using RV Gunnerus, a state of the art research vessel co-owned by NTNU. The vessel was used to access the dumping site, as well as take water and sediment samples.

11 water samples were taken at different depths in the middle of the dumping site, using the sampler seen in Figure 2.4. Three droplets of concentrated nitric acid (HNO_3) were added to each water sample equaling approximately 0.1 M solutions. This was to lower the pH minimizing metal adsorption onto the container wall. [179]

In addition to 11 water samples, the first expedition yielded 81 sediment samples outside the dumping site. Location one and two provided two sediment samples each, while location three gave 11 samples. Location four gave 43 samples, and location five gave 23 samples giving a total of 81 samples. Location one, two, three, and five used a small sediment core sampler (Figure 2.5) while location four used a large core sampler (Figure 2.6).

During the second expedition, a remotely operated vehicle (ROV) was used which made it possible to retrieve sediment samples inside the dumping site, close to an anthropogenic object. The ROV sediment column gave 12 samples.

All sediment columns retrieved were cut in sample portions onboard the vessel using a plastic dough cutter and placed inside plastic sample vials.

Figure 3.1 shows the sampling location in the Trondheimsfjord. Six sampling locations can be observed.

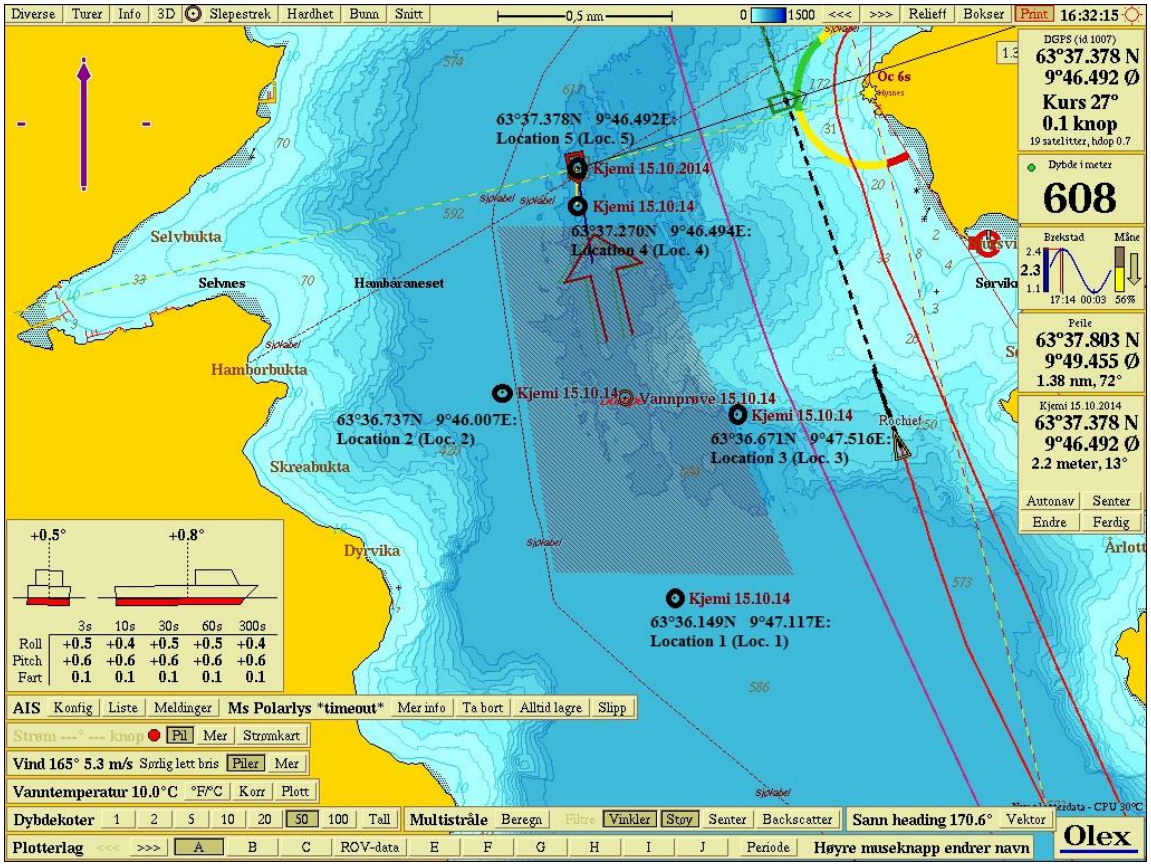

Figure 3.1. The five sediment sampling locations outside the dumping site. Location one to four could be found directly outside the site, while location five was closer to the fjord outlet. The water sampling location could be found in the middle of the site.

3.2 Metal analysis

After the expedition the sediment samples were stored in a freezer and freeze dried to remove the water. The samples were decomposed using acid digestion and UltraCLAVE and analyzed using an ICP-MS. The ICP-MS analysis was performed by Syverin Lierhagen, the NTNU senior engineer responsible for the instrument.

The following steps were done before using the UltraCLAVE:

The UltraCLAVE tubes were emptied and rinsed twice with distilled water (the tubes originally contained a mixture of distilled water and HNO_3).

The now dry tubes were placed, one by one, on a scale. 200-300 mg of the freeze dried sediment samples were transferred to the tubes and the exact weight was written down for each sample. 9 mL 50 % HNO_3 was added to each tube to aid the decomposition.

Using the UltraCLAVE:

The UltraCLAVE was turned on, as well as the compressor, cryo, and gas. The hydrogen peroxide (H_2O_2) basin in the UltraCLAVE was checked. The minimum amount of H_2O_2 in the basin was always supposed to be 300 mL. The UltraCLAVE was started using the computer, and used approximately 2.5 hours to finish.

The following steps were preformed after the UltraCLAVE had finished:

The run was saved using the computer, and the samples were retrieved from the instrument. The content of each tube, one at a time, was added to a bottle placed on a scale. The sample was diluted until required weight was reached (109.3 – 110.3 g). The bottle was capped, turned over once, and the content of the bottle was transferred into an ICP-MS test tube. The test tube content was then analyzed on a magnetic sector ICP-MS where the sample content was ionized by the ICP and analyzed for metals by the MS.

3.3 TNT and RDX analysis

3.3.1 LC-MS/MS

The freeze dried samples no. 5 and 16 were also analyzed for traces of the two explosives TNT and RDX using LC-MS/MS. One gram of each sample was transferred to a 50 mL volumetric flask and 25 mL methanol was added to each flask. The flasks were shaken and placed in an ultrasound bath for 60 minutes in four intervals. After four hours the flasks were left to their own volition so the sediment could settle. After roughly 30 minutes 10 mL of the supernatant was pipetted from each flask and centrifuged for five minutes on 3 000 rpm. 1.5 mL of each sample was filtered through a 0.2 µm filter coupled to a B-D plastic syringe. Both the centrifuge and filter were to make sure no particles were introduced into the LC-MS system. A method for quantifying TNT and RDX from sediment samples had been adapted from literature, and standard solutions of both explosives were acquired from Great Britain. This was to optimize a method as well as make an external standard curve assisting with quantification if needed.

After initial analysis the two samples were concentrated 100 fold to verify the presence of TNT and RDX. Six mL of the centrifuged supernatant was filtered through a 0.2 µm filter coupled to a B-D plastic syringe and concentrated on a SpeedVac. The speedvac was operated at 45 ºC and the samples run for two hours and ten minutes. 60 µL methanol was added to each sample using a micro pipette. The concentrated samples were then analyzed using LC-MS/MS.

Sample 5 and 16 were analyzed both in positive and negative ion mode using an Electrospray Ionization method (ESI), a soft ionization option causing reduced fragmentation.

Analytical parameters:

LC:

Run time: 19 minutes

Solvent A: Water

Solvent B: Methanol

Pressure limit range: 0 – 15000 psi

Gradient table:

Table 3.1. This gradient was used when analyzing sample no. 5 and 16.

Time (min)	**Flow rate**	**% A**	**% B**	**Curve**
Initial	0.300	40.0	60.0	Initial
1.00	0.300	40.0	60.0	6
15.00	0.300	8.0	92.0	6
16.00	0.300	0.0	100.0	6
18.00	0.300	0.0	100.0	6
19.00	0.300	60.0	40.0	6

Column type: Acquity UPLC BEH C18 1.7 µm

Injector: Waters Acquity FTN Autosampler

Injection volume: 2 µL

MS:

Capillary: 2.5 kV

Source temperature: 120 ^{o}C

Gas used: Helium

Mass scan range: 50 – 1500 Da

3.3.2 GC-MS

Due to the long preparative step before using LC-MS/MS, samples number 6, 7, 8, 9, 10, 17, 18, 19, and 20 were analyzed using GC-MS with a Thermal Desorption Probe (TDP) injection method. A few grains of freeze dried sediment were transferred to a small glass tube, inserted directly into the TDP and analyzed for TNT and RDX, as well as TNT derivatives.

Analytical parameters:

GC:

Run time: 9.375 min

Carrier gas: Helium

Column type: HP-5MS 5 % phenyl methyl siloxane

Actual length: 30 meters

Internal diameter: 250 µm

Film thickness: 0.25 µm

Temperature gradient: Holding 35 ^{o}C for 1 min, increasing temperature by 40 ^{o}C/min until 250 ^{o}C, holding 250 ^{o}C for 2 min, ending with a total run time of 9.375 min.

Injector: Thermal Desorption Probe (TDP)

MS:

Setpoint Quad temperature: 150 ^{o}C

Setpoint source temperature: 230 ^{o}C

Mass scan range: 50 – 400 Da

4 Results and discussion

4.1 Water samples

The following graphs show the concentration of six metals and arsenic in water. These elements have been recognized by the former Climate and Pollution Agency as contaminants at elevated concentrations. Mercury was not detected in the water samples. Several of the graphs have dashed lines showing the value where the guideline specifies a level change. The sample depth ranges from 1 to 588 m, where the bottom is found at 608 m.

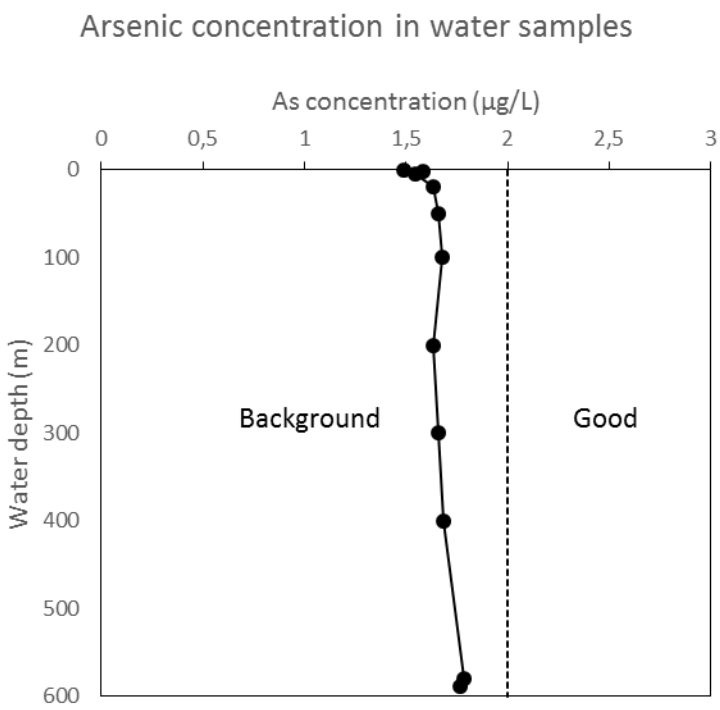

Figure 4.1. The concentration pattern of arsenic observed down the water column.

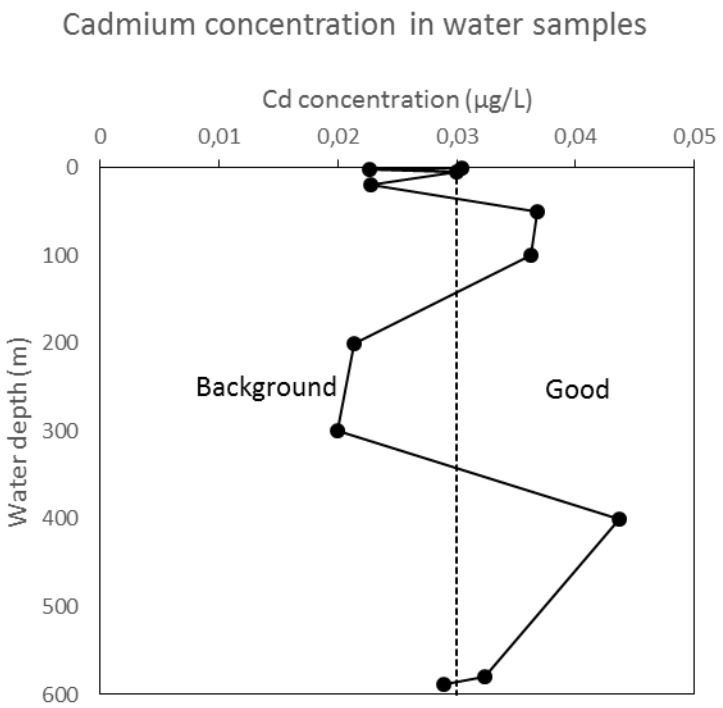

Figure 4.2. The concentration pattern of cadmium observed down the water column.

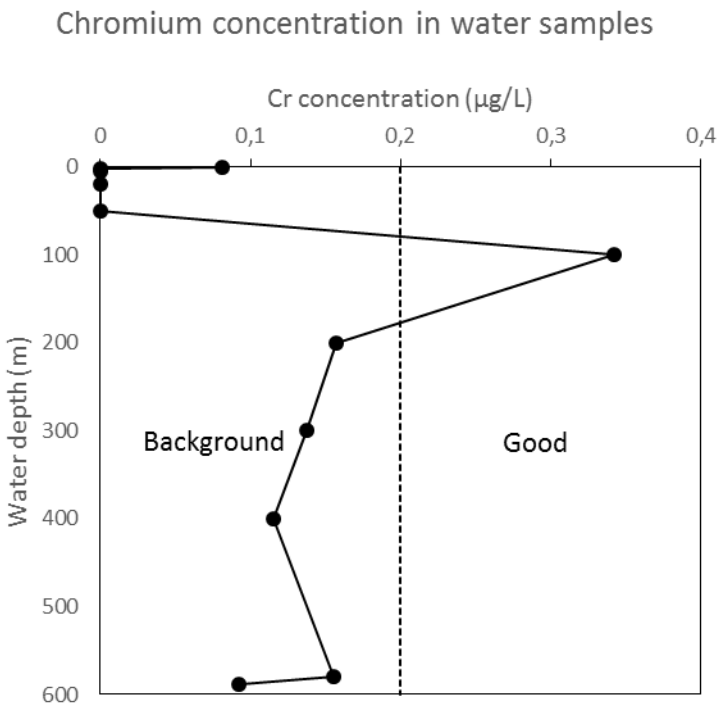

Figure 4.3. The concentration pattern of chromium observed down the water column. The values at two, five, 20, and 50 m were found to be below zero according to the ICP-MS, but were readjusted to 0 to make sense.

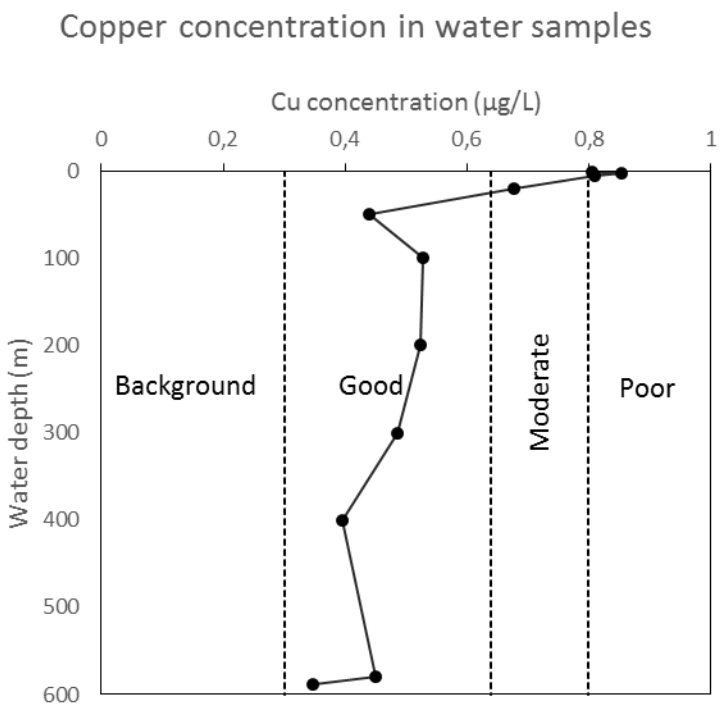

Figure 4.4. The concentration pattern of copper observed down the water column.

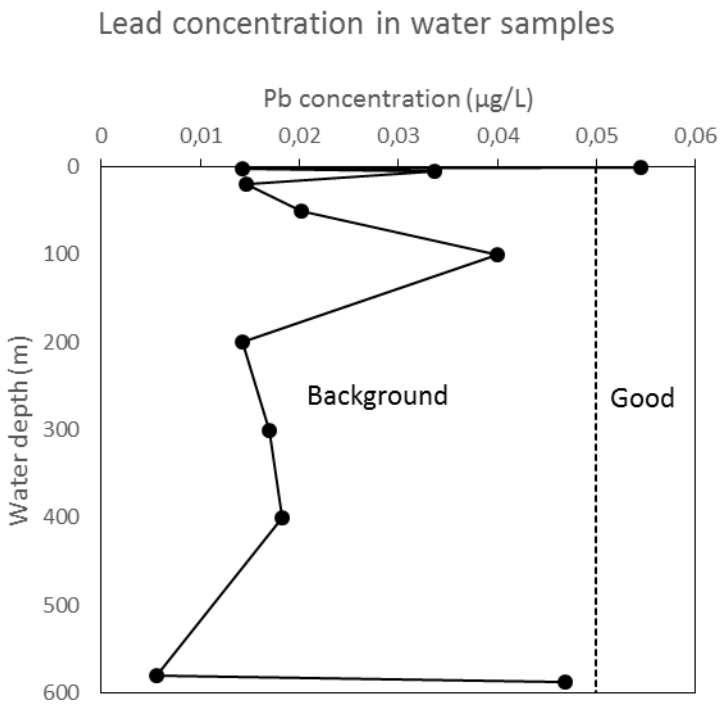

Figure 4.5. The concentration pattern of lead observed down the water column.

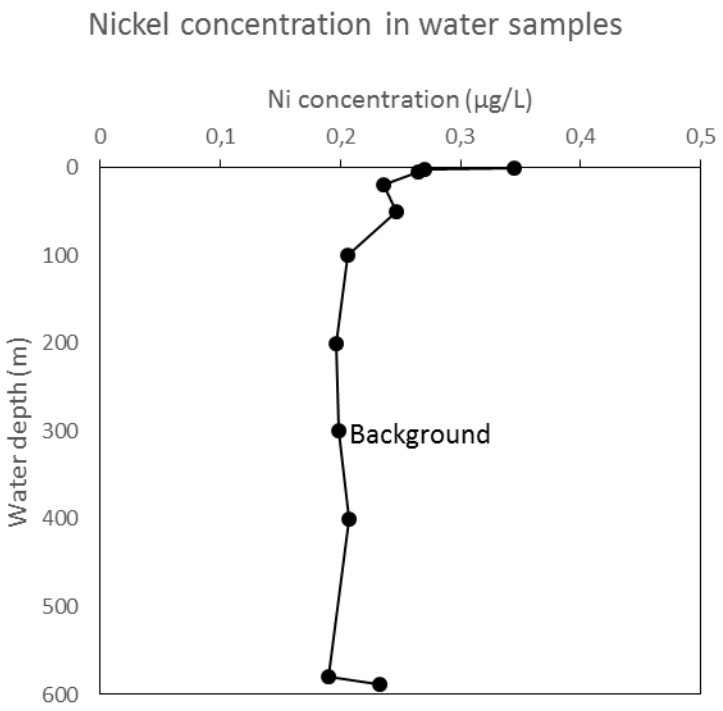

Figure 4.6. The concentration pattern of nickel observed down the water column.

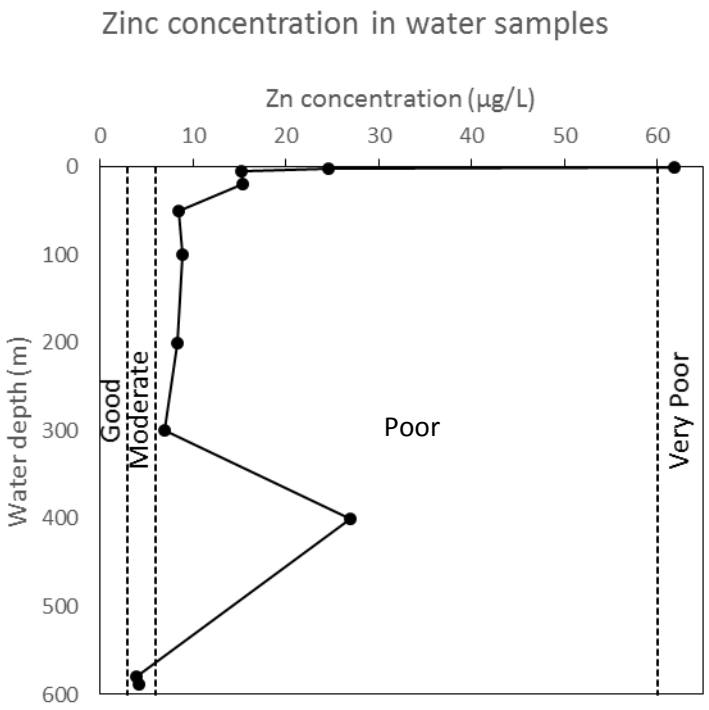

Figure 4.7. The concentration pattern of zinc observed down the water column.

These graphs show the concentration of known contaminants in 11 water samples taken in the Trondheimsfjord. Since only 11 water samples have been taken in a 608 m deep water column, the sample spread is fairly large. This makes for poor interpolation between sampling depths, increasing the chance of observing sudden concentration fluctuations down the water column.

However, the patterns are helpful as they give an indication of the contamination state found in the water column.

4.1.1 Guideline elements

Copper and zinc are the only metals showing concentrations in the poor level area (> 0.8 µg/L for copper and > 6 µg/L for zinc) of the guideline. This is observed in the surface water for copper, and also down the water column for zinc. Worth mentioning is the fact that the zinc concentration found at 400 m depth (26.9 µg/L) has a high RSD (128 %) and may therefore not be accurate. Regardless, the zinc concentration stays within the poor level range for the majority of the water samples.

Because of the water depth, the probability that these heightened concentrations of copper and zinc are a consequence of the dumping site is fairly low. A more plausible explanation is the river Selva supplying the excess copper and zinc, or the existence of an unidentified source. These irregular surface concentrations should be looked into, as copper is dangerous to aquatic organisms. The highest copper concentration found (0.855 µg/L) and the poor threshold level observed for copper in the guideline (0.8 µg/L) are found to be considerably lower than for zinc (61.9 µg/L and 6 µg/L respectively). This shows the low essentiality for copper in the aquatic environment. In seawater copper will bind to organic matter and inorganic particles, meaning the bioavailable concentration has not been determined. [180] If the majority of the copper is bound to inorganic particles and therefore not bioavailable, the copper concentration is not found at a dangerously high level. However, this is only a theory and should be researched more extensively. Taking new samples and biologically testing them may give more answers.

Inorganic copper is mostly found as carbonates in seawater ($CuCO_3$), which is not bioavailable. Copper hydroxides and free copper ions are the most bioavailable forms of copper, as well as low molecular weight, lipophilic organic copper complexes. The concentration of copper in seawater varies based on riverine input, meaning estuarine systems generally demonstrate higher copper concentrations than open water. In fact, several estuaries may show concentrations close to 1 µg/L (> 0.8 µg/L is found inside the poor level area of the guideline). Zinc will mainly adsorb to organic matter in seawater and very little free zinc ions are found. Like copper, estuarine zinc concentrations can be found inside the poor area threshold of the guideline (> 6 µg/L) [181] However, a surface water zinc concentration of 61.1 µg/L points towards contamination.

The cadmium and lead concentrations are below the moderate level threshold (< 0.24 µg/L for cadmium and < 2.2 µg/L for lead), which is encouraging. Cadmium, lead, and mercury are seen as nonessential heavy metals that can cause harm to humans, as explained in chapter 2.2.1. The metalloid arsenic is also found below its moderate level threshold (< 4.8 µg/L).

4.1.2 Iron

In addition to the former Climate and Pollution Agency mentioned contaminants, a graph of iron's depth pattern is made to look for signs of iron enrichment in the water column. This is to get an indication of the state of the ordnances found in the dumping site. The iron concentration is usually low in seawater, and much higher in river water. In estuaries the iron rich river water will mix with the seawater causing the iron to be removed by precipitation, coagulation, and sedimentation processes due to the salinity increase. [182]

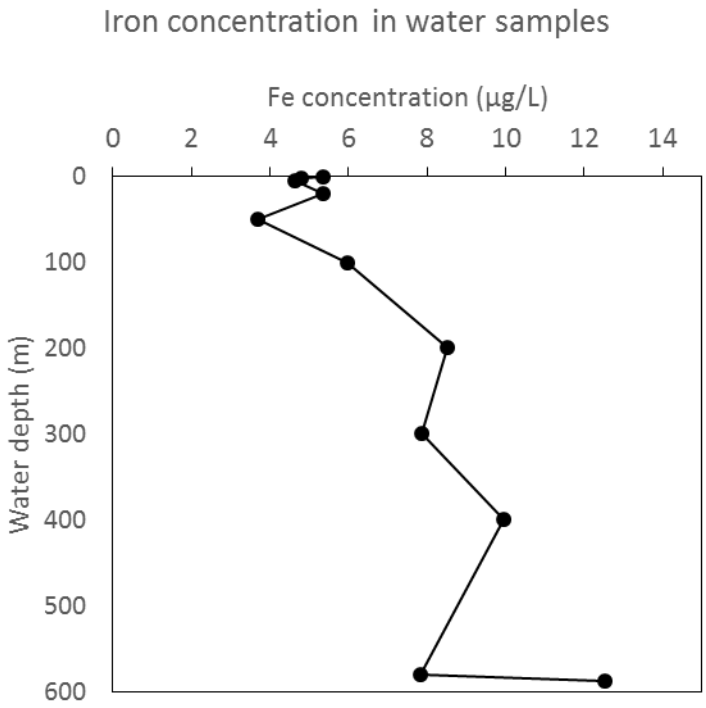

Figure 4.8. The concentration pattern of iron observed down the water column.

The iron concentration range (3.5 – 13 µg/L) observed in Figure 4.8 is higher than expected for seawater (0.2 – 0.8 nM = 0.01 – 0.05 µg/L in the northern North Pacific Ocean). [183] However, river water may contain iron concentrations above 1400 µg/L depending on the salinity, where an increase in salinity will cause iron to be removed rapidly. [184] This makes predicting the iron concentration in an area close to a river delta (estuary) quite difficult, as the salinity changes based on the input received from both the river and the sea. The iron concentration increases down the water column, but never to a value that would be considered unexpected.

The maxima found in the last sample can possibly be a consequence of the ordnances found on the seafloor, but may just as well have come from the river. In addition, iron is quickly immobilized and sinks, but will be released when digesting the samples before ICP-MS analysis. Therefore, this increasing trend observed for iron down the water column is reasonable.

When monitoring a water body, several samples over a time interval should be taken. This makes it possible to determine whether an area is contaminated by a source constantly supplying contaminants, or if the elevated concentrations observed was a one-time incidence. This also makes it possible to evaluate seasonal changes to the element concentrations.

4.2 Sediment samples

4.2.1 Arsenic

Figure 4.9 shows the concentration of arsenic and its pattern down six different sediment columns. The sediment sample patterns for arsenic can be found inside the background level area found in the guideline (< 20 µg/g).

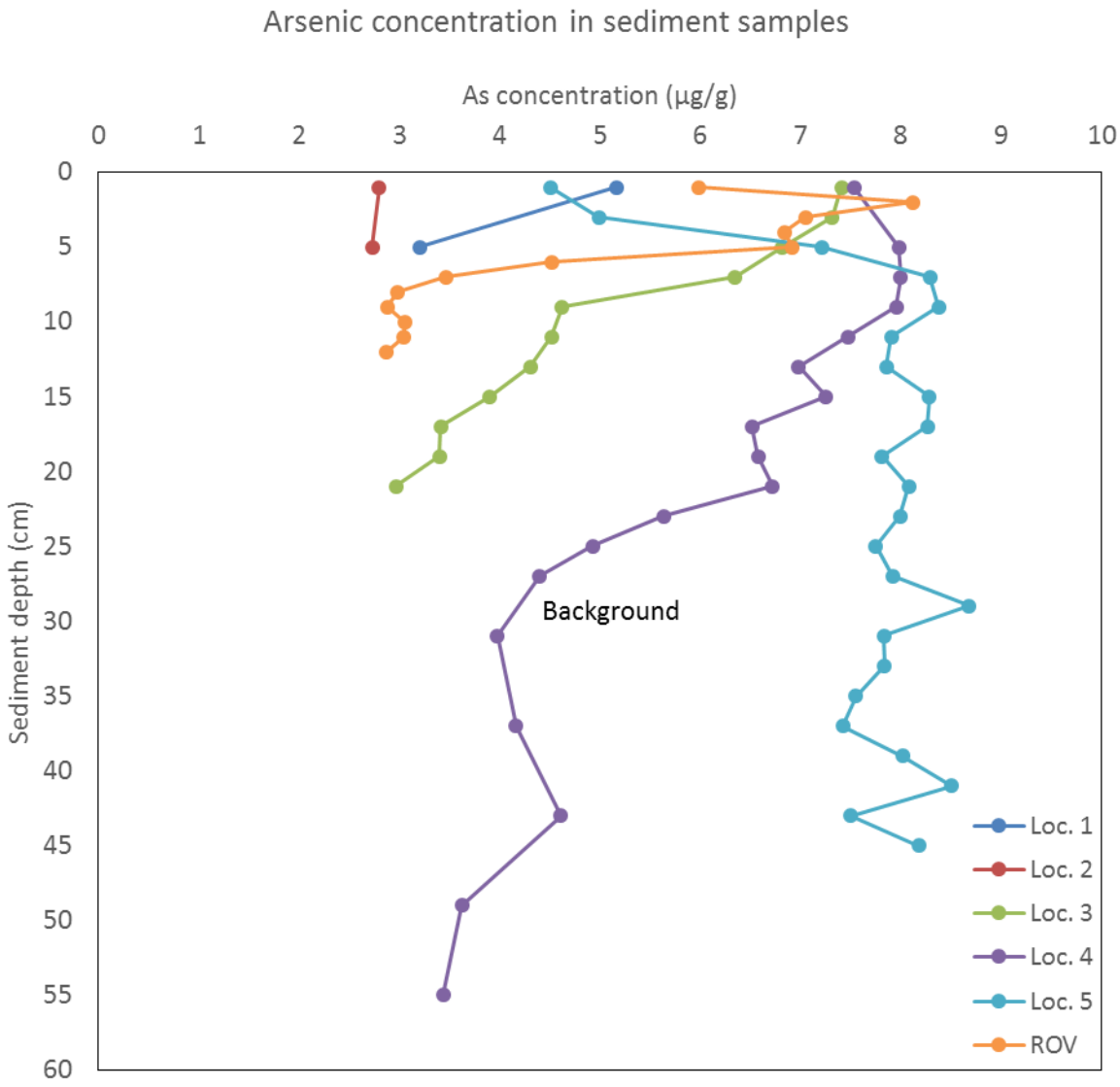

Figure 4.9. The concentration pattern of arsenic found down six different sediment columns.

When observing the concentration patterns in Figure 4.9, the highest concentration of arsenic from each sampling location looks to be in the first five cm of the sediment column. The patterns can be seen decreasing down the sediment column. A notable exception is location no. 5, where the concentration in the top sample is 4.51 µg/g (the lowest found at location no. 5) and increases rapidly to 8.29 µg/g after seven cm. Regardless the concentrations never increase past the background level area threshold (< 20 µg/g).

Enrichment Factors are also calculated to see if a possible contamination is due to anthropogenic enrichment. As location no. 4 gives an almost two meter long sediment column, the sample after 169.5 cm is used as the normalization sample, assuming it to be uncontaminated by anthropogenic sources.

The average EF value for arsenic is found to be 1.60 using aluminum, 1.48 using lithium, and 1.98 using rubidium. The average EF value for arsenic using only top sediment is found to be 1.89, 1.79, and 2.25, respectively. Seeing as the arsenic concentration is found inside the background level area according to the guideline, this very slight enrichment found using EF values is believed to be of no real concern.

In addition to EF values, a t-test is performed where the surface sediment samples at Loc. 1-5 and the ROV location are compared with seven samples from the Trondheimsfjord taken by previous students. One of the samples is from the Korsfjord, while the remaining six are from 5000 m outside the river delta of Byelva, Verdalselva, Orkla, Gaula, Nidelva, and Stjørdalselva. The null hypothesis states that the top sediment element concentrations around the dumping site are not significantly different from the ones found in the other Trondheimsfjord samples. One t-test value is determined per metal(loid). To discard the null hypothesis the "P(T<=t) two-tail" value has to be below 0.05 (5 %). The t-test for arsenic shows a P(T<=t) two-tail of 0.0545, which is above 0.05. Therefore, the null hypothesis is not rejected. The guideline, EF, and t-test all arrive at the same conclusion; the area is not contaminated with arsenic.

4.2.2 Cadmium

Figure 4.10 shows the concentration of cadmium and its pattern down six different sediment columns.

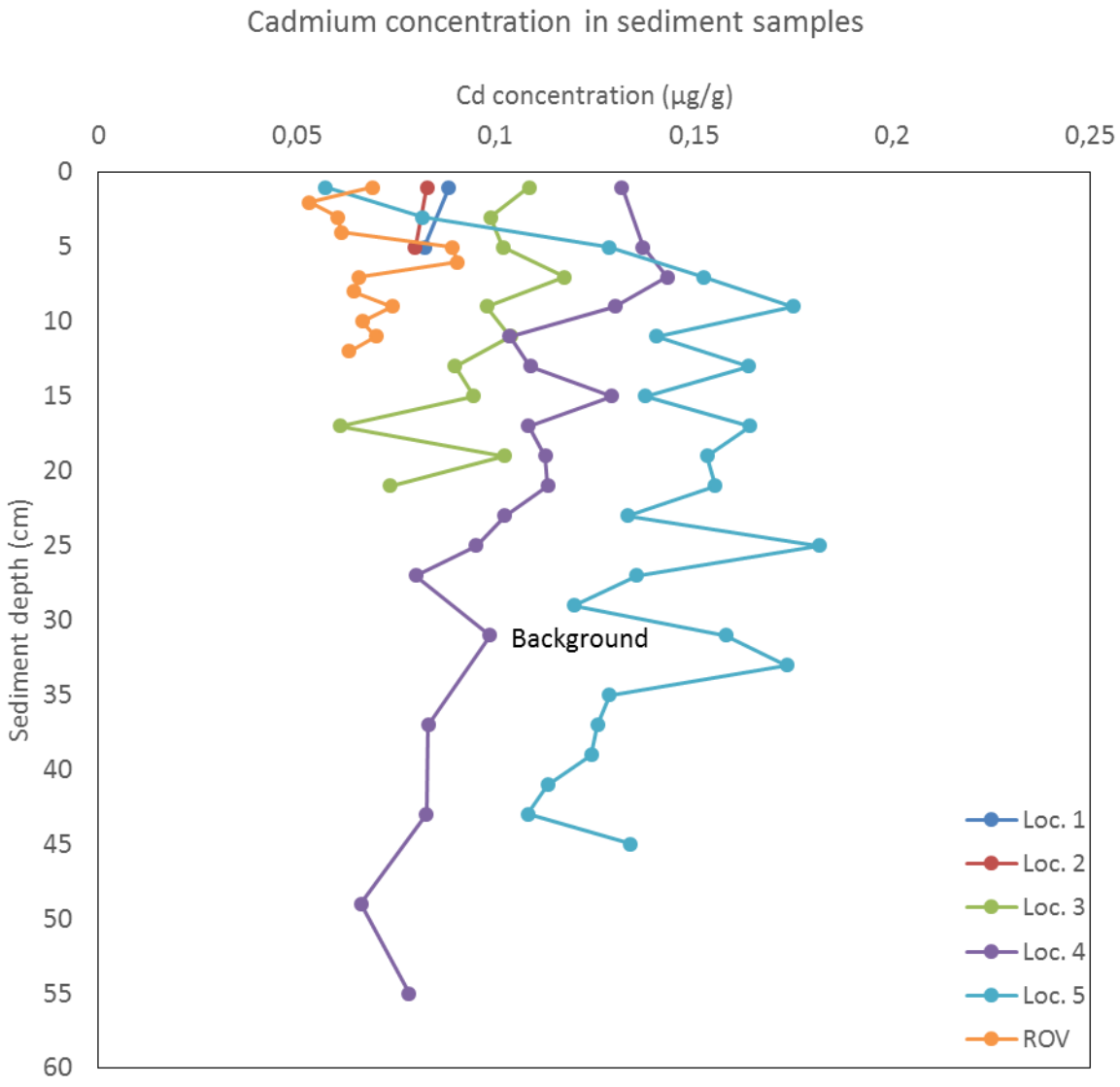

Figure 4.10. The concentration pattern of cadmium observed down six different sediment columns.

The cadmium patterns at location no. 1, 2, 3, and 4 in Figure 4.10 show a slight decrease down the sediment column. The pattern at location no. 5 increases the first seven cm (from 0.057 µg/g to 0.15 µg/g) then stabilizes, while the ROV samples ultimately show a constant pattern (0.069 µg/g after one cm to 0.063 µg/g after 12 cm). The cadmium concentrations show overall high RSD (see appendix A.2), which may be due to the low concentrations found in the samples, making it an analytical limitation. The cadmium concentration patterns stay inside the background level area (< 0.25 µg/g) at all locations and depths.

The average EF value for cadmium is found to be 1.23 using aluminum, 1.14 using lithium, and 1.55 using rubidium. The average EF value for cadmium using only top sediment is found to be 1.31, 1.23, and 1.54, respectively. This slight cadmium enrichment found using EF values is thought to be of no major concern because of the low concentrations.

The t-test for cadmium gives a P(T<=t) of 0.239, meaning the null hypothesis cannot be rejected. As with arsenic, the guideline, EF and t-test all point towards no cadmium contamination in and around the dumping site.

4.2.3 Chromium

Figure 4.11 shows the concentration of chromium and its pattern down six different sediment columns. The dashed line indicates the concentration where the guideline suggests a contamination level change (70 µg/g separates the background and good level for chromium).

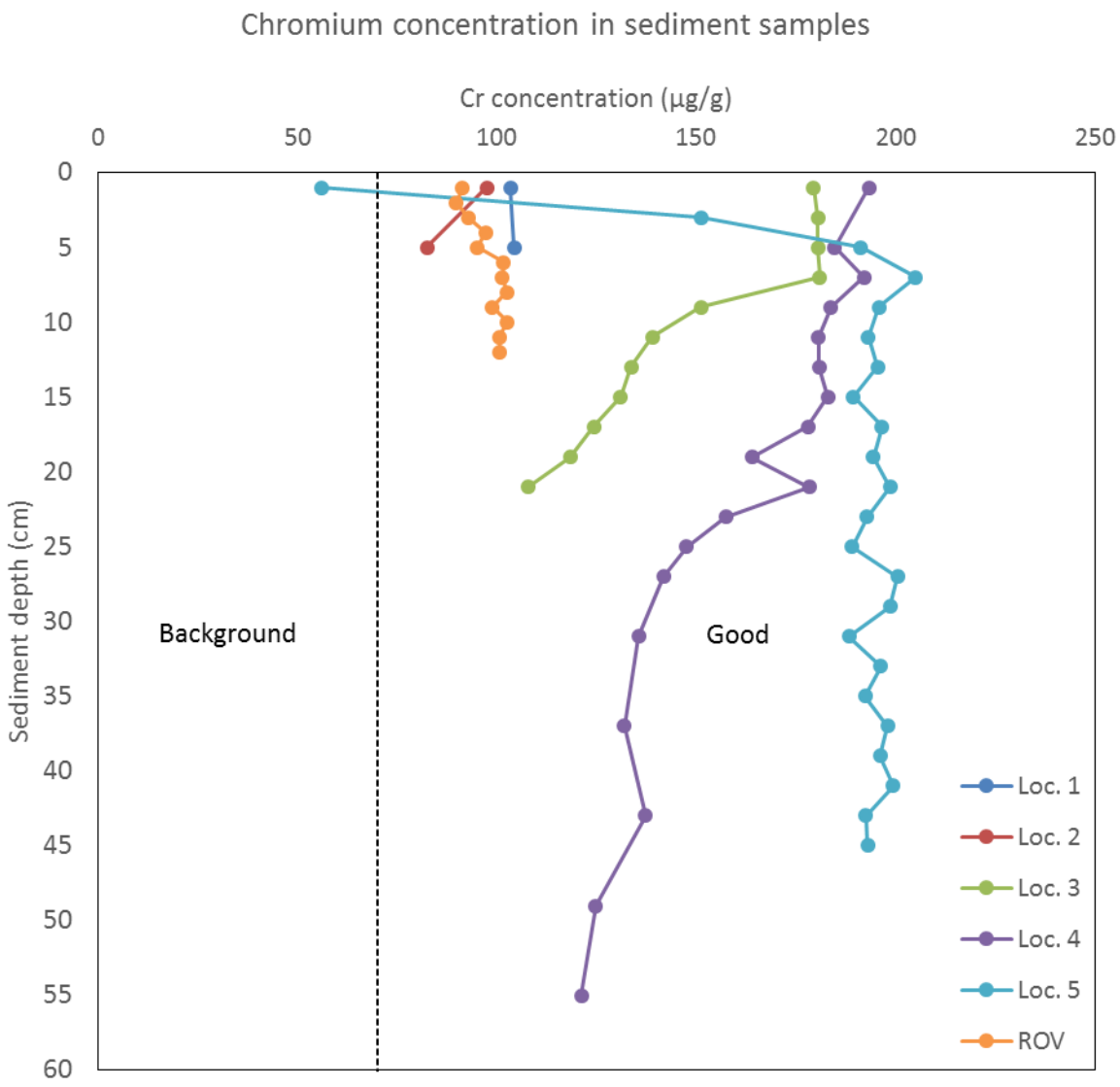

Figure 4.11. The concentration pattern of chromium observed down six different sediment columns.

For chromium the concentration patterns are primarily found in the good threshold area (> 70 µg/g). At location no. 3 and 4 the concentration is highest in the top sediment, and decreases down the sediment column. Location no. 5 displays the same concentration leap as before, increasing from 55.9 µg/g in the top sample to 200 µg/g after seven cm.

The average EF value for chromium is found to be 1.19 using aluminum, 1.11 using lithium, and 1.50 using rubidium. The average EF value for chromium using only top sediment is found to be 1.12, 1.05, and 1.32, respectively. These EF values are quite similar to cadmium's EF values, although the guideline places the chromium concentration inside the good level area.

The t-test for chromium gives a P(T<=t) of 0.928, meaning the null hypothesis cannot be rejected. Both the guideline and the EF show a minor chromium enrichment in the area, while the t-test points towards no difference between the samples tested. A natural chromium enrichment may be the explanation for the somewhat heightened chromium concentrations observed. [185]

4.2.4 Copper

Figure 4.12 shows the concentration of copper and its pattern down six different sediment columns.

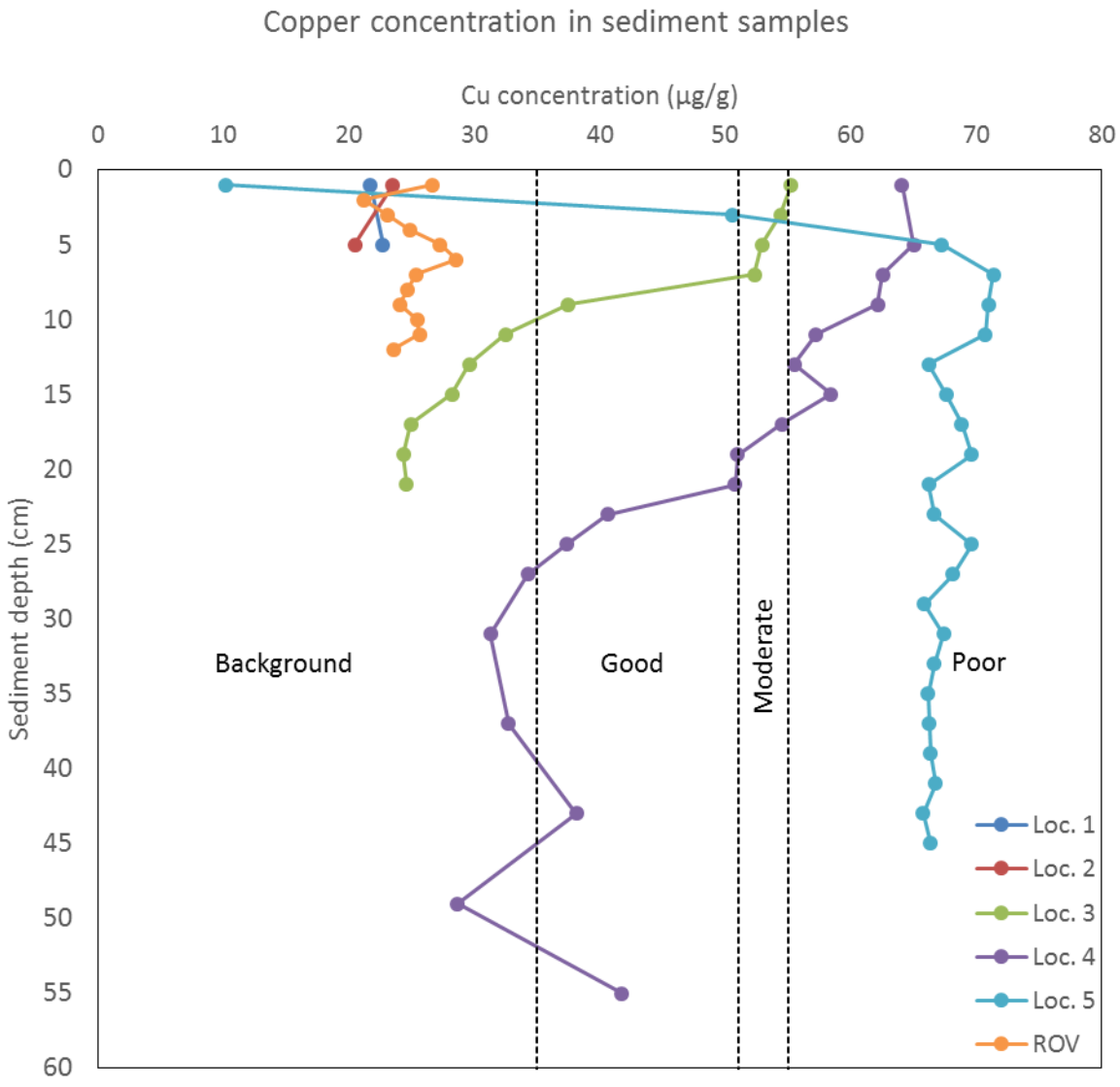

Figure 4.12. The concentration pattern of copper observed down six different sediment columns.

The copper concentrations show a somewhat similar pattern to chromium, as seen in Figure 4.11. However, the copper tolerance in sediment is notably smaller than for chromium (moderate level threshold range is 51 – 55 µg/g for copper and 560 – 5900 µg/g for chromium). Both location no. 3 and 4 are inside the poor level area (55 – 220 µg/g) in the top sediment, but ends up in the background level area (< 35 µg/g) down the sediment column. The opposite is observed for location no. 5, where the pattern starts off in the background level area, and ends up in the poor level area after five cm. After seven cm the concentration at location no. 5 has made a sevenfold leap from 10.1 µg/g to 71.4 µg/g.

The EF values found at location no. 5 after seven cm are 2.24 (aluminum), 1.94 (lithium), and 2.45 (rubidium). The average EF value for copper is found to be 1.88 using aluminum, 1.73 using lithium, and 2.32 using rubidium. The average EF value for copper using only top sediment is found to be 1.59, 1.49, and 1.87, respectively. The EF values do not suggest a major copper enrichment in the area. The copper may be particulate bound and therefore not bioavailable to organisms in the sediment, explaining the lack of evidence pointing towards anthropogenic contamination.

The t-test for copper gives a P(T<=t) of 0.347, which means the null hypothesis cannot be rejected. Copper is the first element that shows deviation between the methods. The guideline suggests the area is contaminated by copper, and that organisms living there may experience adverse effects. The EF however, does not fully agree with the guideline, and suggests the area is only slightly enriched. In addition, the t-test does not conclude on any difference between the samples. When compared to the normalization element patterns, observed in Figure 4.17, the copper concentrations follow the same trends. The samples do not seem to be contaminated by copper. It appears the guideline is rather stringent when it comes to copper, but considering copper's low essentiality in aquatic systems, this is not surprising. Both location no. 4 and 5 are closest to Selva's outlet, which means the copper may come from the river.

4.2.5 Lead

Figure 4.13 shows the concentration of lead and its pattern down six different sediment columns.

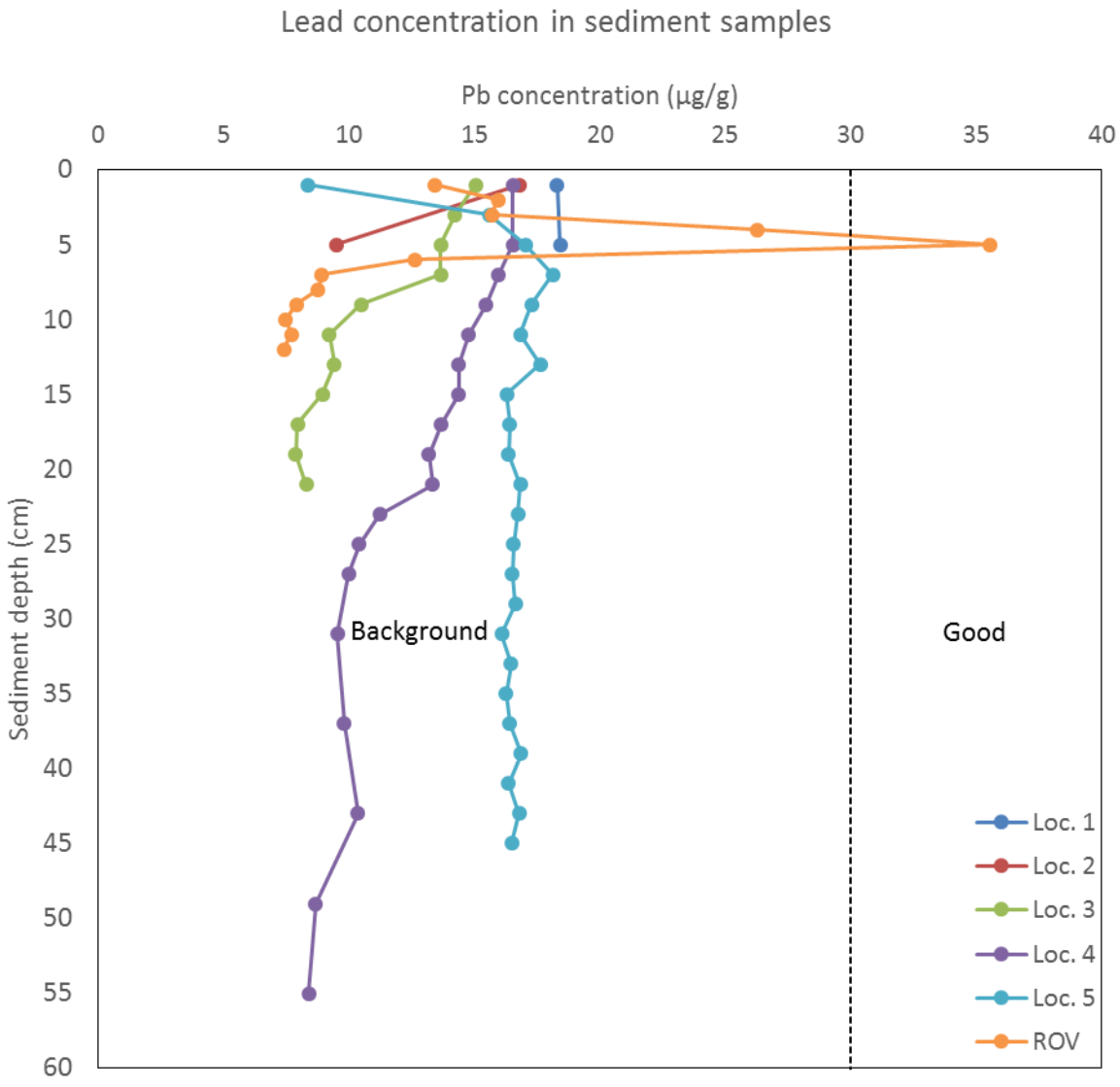

Figure 4.13. The concentration pattern of lead observed down six different sediment columns.

The surface concentration is highest at location no. 1 and 2 (18.3 µg/g and 16.8 µg/g respectively), which has not been seen for any of the other elements. The concentration pattern looks to be fairly conservative at location no. 4 and 5 down the sediment column, and stays inside the background level area (< 30 µg/g). Interestingly, it is the ROV samples at four and five cm that differ from the others. At five cm the concentration (35.6 µg/g) enters the good level area (30 – 83 µg/g), but quickly ends up in the background level area again after six cm (12.6 µg/g). The surface concentration at all sampling locations show lead inside the background level area.

The largest calculated EF for lead is 6.34 at the ROV location after five cm, using rubidium as normalization element. For comparison, the EFs calculated using aluminum and lithium are 5.00 and 5.01, respectively. The average EF value for lead is found to be 1.50 using aluminum, 1.40 using lithium, and 1.88 using rubidium. The average EF value for lead using only top sediment is found to be 1.99, 1.88, and 2.37, respectively.

The t-test for lead gives a P(T<=t) of 0.101, which means the null hypothesis cannot be rejected. Both the guideline and the EF values point towards no major lead contamination present in the area, apart from the ROV sample after five cm, which suggests a moderately severe enrichment.

4.2.6 Mercury

Figure 4.14 shows the concentration of mercury and its pattern down six different sediment columns.

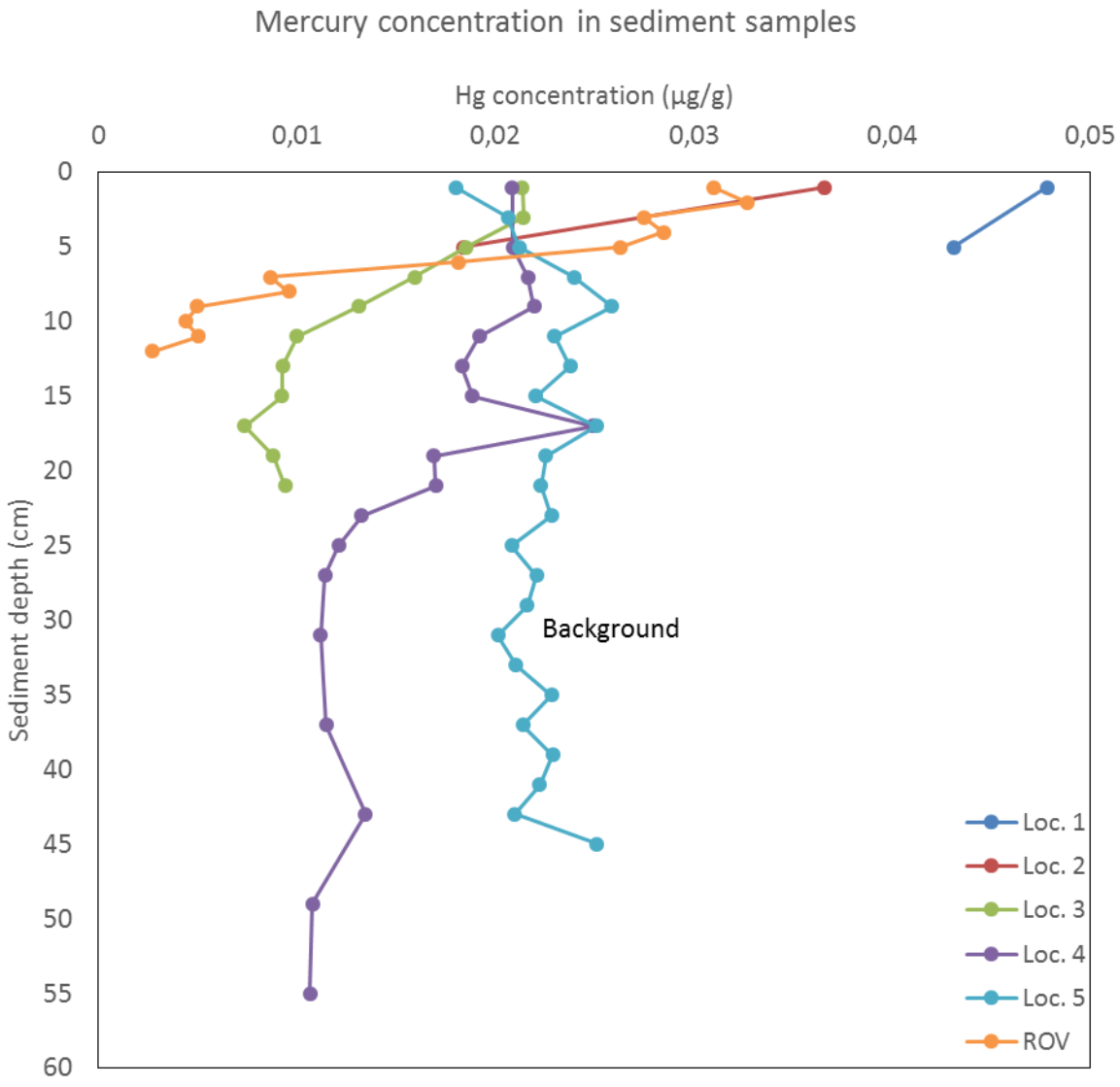

Figure 4.14. The concentration pattern of mercury observed down six different sediment columns.

For almost all locations, the mercury concentration decreases down the sediment column. The only exception is location no. 5. However, the mercury concentration increase down the sediment column at location no. 5 is more modest than for previous elements. The most surprising pattern is observed for location no. 1, which has the highest mercury concentration of all locations (0.048 µg/g). Location no. 1 has been quite anonymous, staying fairly low for all the previous elements. Regardless, the concentration stays inside the background level area (< 0.15 µg/g) at all locations.

The largest calculated EF for mercury is 9.17 at location no. 1 after one cm, using rubidium as normalization element. For comparison, the EFs calculated using aluminum and lithium are 7.73 and 7.33, respectively. The average EF value for mercury is found to be 2.50 using aluminum, 2.34 using lithium, and 3.09 using rubidium. The average EF value for mercury using only top sediment is found to be 5.02, 4.77, and 6.05, respectively.

The t-test for mercury gives a P(T<=t) of 0.062, which means the null hypothesis cannot be rejected. Despite the guideline stating that the mercury concentration is within background level, the EF suggests a minor to moderately severe enrichment, where mercury has the largest average top sediment EF found so far. However, if the area is contaminated with mercury, it is very slightly, as the guideline suggests no mercury contamination in the area. A possible reason for the higher mercury concentration at location no. 1 and 2 can be that they contain a larger organic matter content (humus, humic acid, fulvic acid) than the other sampling locations. Since mercury adsorbs readily on organic matter compared to other particles (like manganese and iron oxides) this will cause a higher mercury concentration in the organic matter samples. [186] This is only speculation, however.

4.2.7 Nickel

Figure 4.15 shows the concentration of nickel and its pattern down six different sediment columns.

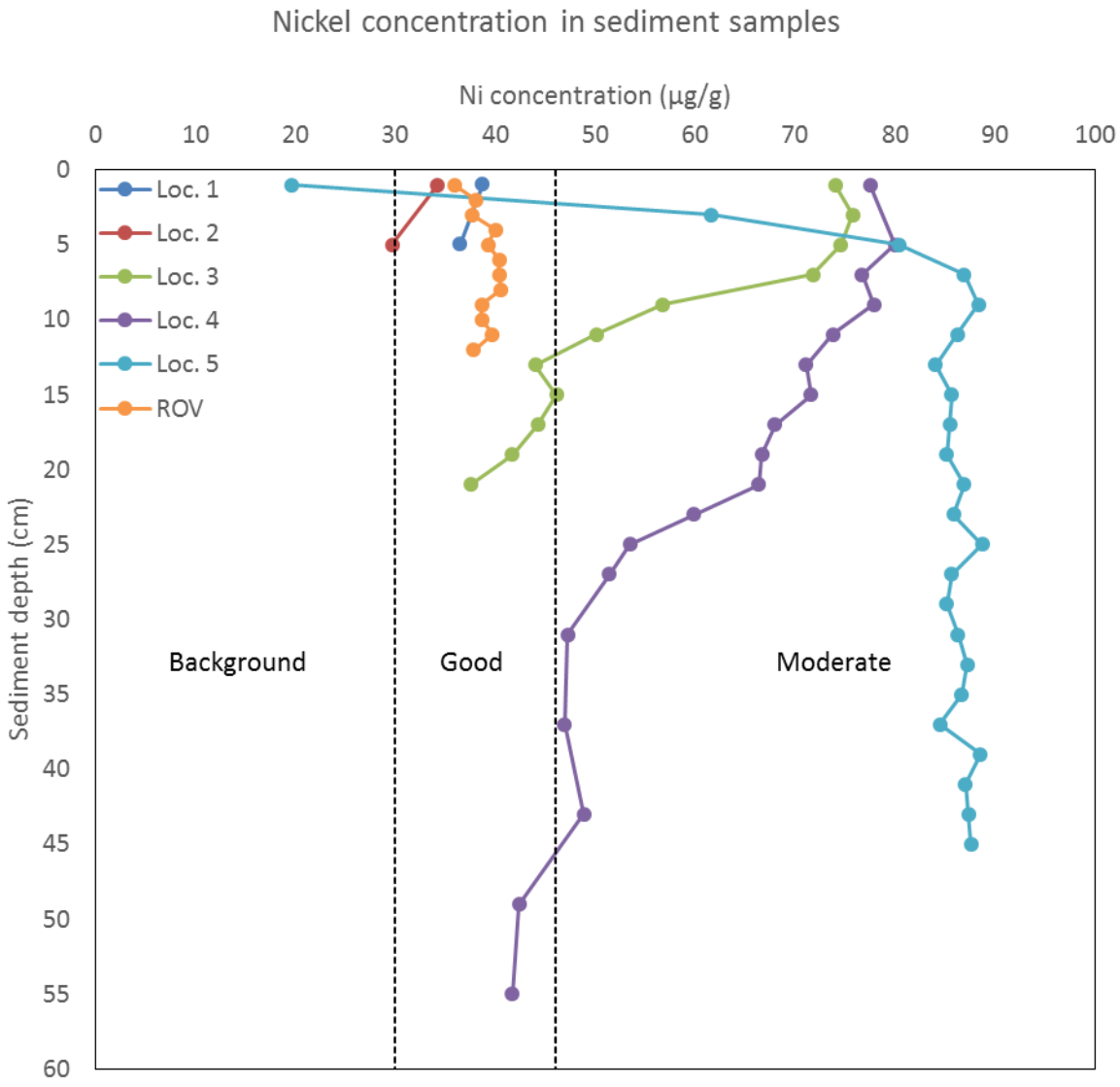

Figure 4.15. The concentration pattern of nickel observed down six different sediment columns.

The nickel concentration patterns for both location no. 3 and 4 begins in the moderate level area (46 – 120 µg/g) in the top sediment, and decreases to the good level area (30 – 46 µg/g). Location no. 5 experiences its characteristic leap yet again, going from a nickel concentration of 19.6 µg/g to 86.9 µg/g after seven cm. The heightened nickel concentration observed is possibly explained by the natural nickel enrichment found in the bedrock in Trøndelag. [185]

The average EF value for nickel is found to be 1.16 using aluminum, 1.07 using lithium, and 1.44 using rubidium. The average EF value for nickel using only top sediment is found to be 1.04, 0.97, and 1.22, respectively. As the bedrock is believed to be naturally enriched with nickel in the Trondheimsfjord, the area is most likely not contaminated by nickel.

The t-test for nickel gives a P(T<=t) of 0.28, which means the null hypothesis cannot be rejected. As with copper, the guideline and EF values for nickel are not in complete agreement.

4.2.8 Zinc

Figure 4.16 shows the concentration of zinc and its pattern down six different sediment columns.

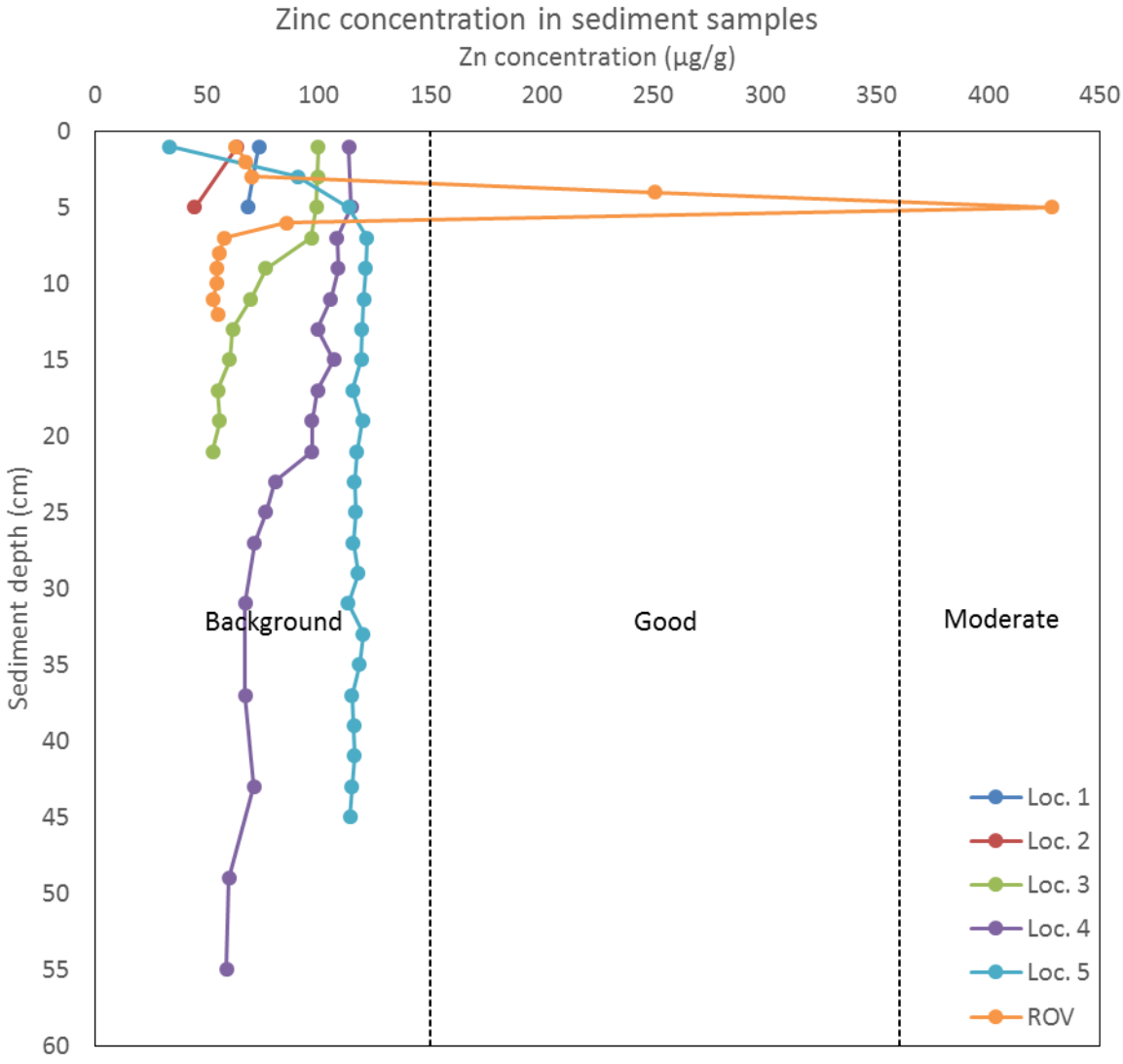

Figure 4.16. The concentration pattern of zinc observed down six different sediment columns.

The zinc threshold in sediment is quite high (moderate level area begins at 360 µg/g), which leads to almost every sample being inside the background level area (< 150 µg/g). The two notable exceptions can be found in the ROV samples. After four cm the concentration is 251 µg/g and has entered the good level area (150 – 360 µg/g). After five cm it is 428 µg/g and has entered the moderate level area (360 – 590 µg/g). A highly similar leap can be seen for lead in the exact same samples. Lead and zinc coexist in ore formations such as ZnS (Sphalerite) and PbS (Galena), which may help explain the pattern similarities they show. [187] Location no. 5 shows the same initially low top sediment concentration (33.3 µg/g), before it increases down the sediment column, experiencing an almost fourfold leap after seven cm (122 µg/g). However, the concentration never exceeds the background level area for location no. 5, and stays quite stable between 114 and 120 µg/g down the sediment column.

The largest EF calculated for zinc is 10.67 at the ROV location after five cm, using rubidium as normalization element. For comparison, the EFs calculated using aluminum and lithium are 8.41 and 8.43, respectively. The average EF value for zinc is found to be 1.43 using aluminum, 1.33 using lithium, and 1.79 using rubidium. The average EF value for zinc using only top sediment is found to be 1.30, 1.23, and 1.55, respectively.

The t-test for zinc gives a P(T<=t) of 0.028, which means the null hypothesis is rejected and the dumping site values are thought to be different from the other samples. However, as the mean of the dumping site samples is smaller than the mean of the other samples (see appendix B.1.8), this difference does not necessarily equal a zinc contamination. Apart from the single large EF value obtained in the ROV location at five cm, the average EF does not suggest a notable zinc enrichment, which is supported by the guideline. The t-test however was able to reject the null hypothesis for the first time, but the sample means for each data set suggests a smaller zinc concentration in the dumping site samples. As none of the three methods point towards contamination, the area is thought not to be contaminated by zinc.

Table 4.1 summarizes the concentrations found in the top sediment at each location, as well as the average EF values calculated for the top sediment and the P-values obtained. Each element discussed in chapter 4.2 so far is represented, and the values are color coded to make them easier to interpret. The concentration values are colored according to Table 2.2, and the EF values according to Table 2.3. The P-values are colored green, meaning the null hypothesis is not discarded, or red, meaning the null hypothesis is discarded.

Table 4.1. The concentration found in the top sediment sample for each element discussed in this chapter. The average EF values in the top sediment are also given, as well as the P-values found for each element.

Element	**Concentration top sediment sample (µg/g)**						**Avg. EF top sediment**			**T-test**
	Loc. 1	Loc. 2	Loc. 3	Loc. 4	Loc. 5	ROV	Al	Li	Rb	P-value
Arsenic	5.16	2.80	7.32	7.54	4.51	5.99	1.89	1.79	2.25	0.0545
Cadmium	0.088	0.083	0.11	0.13	0.057	0.069	1.31	1.23	1.54	0.239
Chromium	103	97.4	179	193	55.9	91.3	1.12	1.05	1.32	0.928
Copper	21.7	23.4	55.2	64.1	10.1	26.7	1.59	1.49	1.87	0.347
Lead	18.3	16.8	15.0	16.5	8.36	13.4	1.99	1.88	2.37	0.101
Mercury	0.048	0.037	0.021	0.021	0.018	0.031	5.02	4.77	6.05	0.062
Nickel	38.7	34.2	74.0	77.5	19.6	35.9	1.04	0.97	1.22	0.28
Zinc	73.2	63.3	99.6	114	33.3	62.8	1.30	1.23	1.55	0.028

4.2.9 Normalization elements

Figure 4.17 shows the concentration of the four potential normalization elements lithium, aluminum, rubidium, and iron, and their patterns down six different sediment columns.

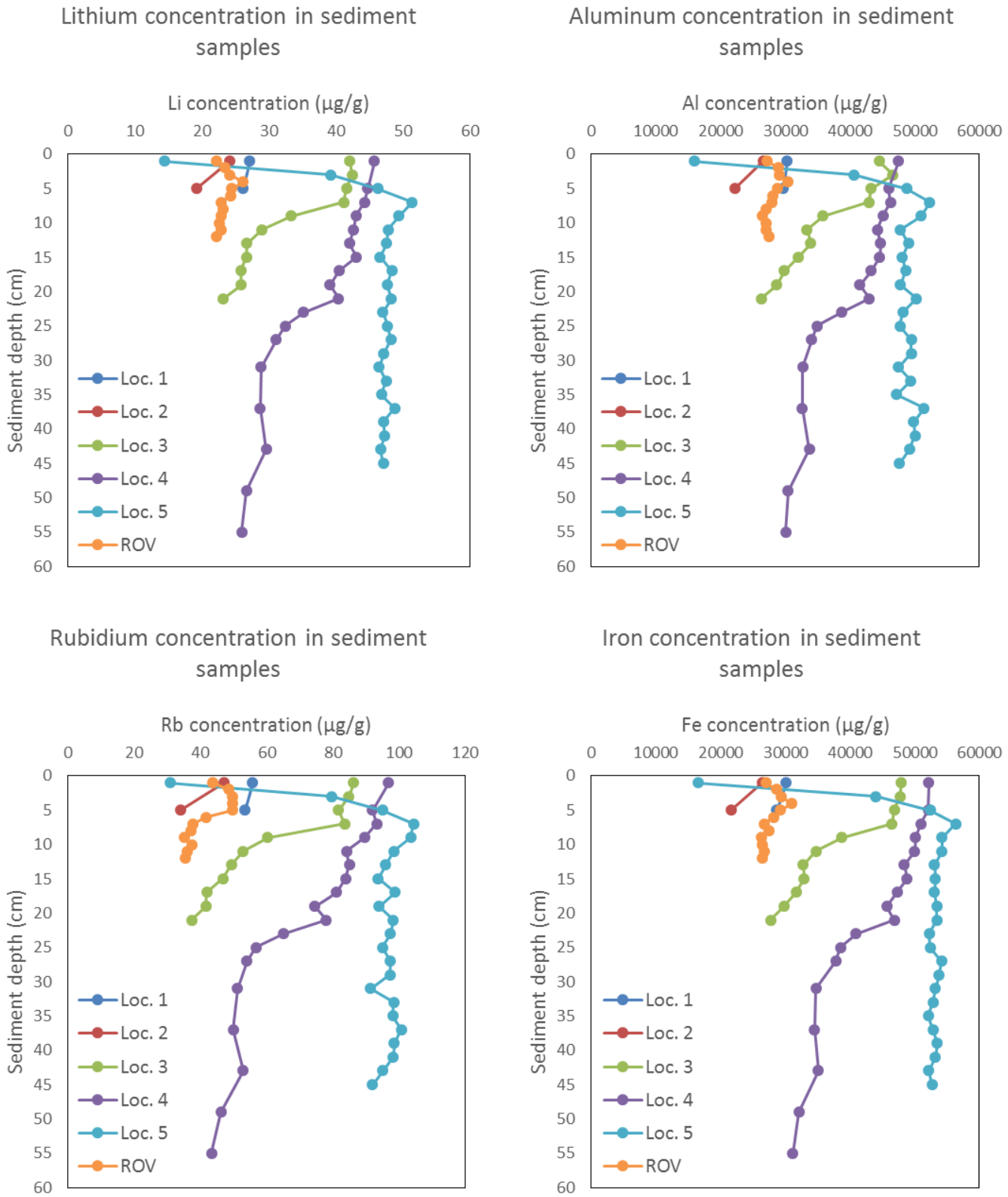

Figure 4.17. Concentrations of lithium, aluminum, rubidium, and iron found in the sediment samples.

When comparing the graphs similar trends are observed for the four elements. The change observed down the different sediment columns is thought to be because of their lithogenic source, not potential anthropogenic sources. This makes all four possible normalization elements. However, iron was not chosen as a normalization element due to the fact that the dumping site contained ship wrecks and Second World War ordnances, both believed to contain iron (steel). It was therefore surprising to see similar patterns to the three other elements, making iron a possible normalization element in this situation. An additional discovery is made when comparing the copper graph with the normalization element graphs. They show very similar patterns, increasing the possibility of copper being naturally embedded in the sediment adsorbed on particles.

4.2.10 Enrichment factor

The largest EF values are obtained when using rubidium as normalization element, where lithium generally gives the smallest EF values. Lithium and rubidium are both alkali metals whereas aluminum is known as a post-transition metal. Aluminum can be found in abundance in the earth's crust (7.96 %), while lithium and rubidium are found sparingly (18 and 78 ppm). [188] However, all three have been recognized as possible normalization elements in literature. [38, 76, 77, 189]

An important factor when using EF is the digestion step before the element analysis. While HNO_3 is widely used to assist digestion, it is not able to dissolve the whole soil matrix. Since aluminosilicates are important constituents in soil, the aluminum concentration obtained may not be entirely accurate, as mentioned in chapter 2.1.2.4. Perhaps using aqua regia with HF during digestion would have given different concentrations for several elements, effectively changing the EF values. As the EF values obtained using aluminum as normalization element are found to be in between the values obtained using lithium and rubidium, the digestion step does not seem to have affected the aluminum concentration notably.

One paper raises questions about indiscriminant usage of EFs, and suggests other methods of verifying anthropogenic contamination they believe to be less flawed. [190] Although it is perfectly true that elements are affected by crustal composition which may distort the obtained EF values, EF values can be thought of as an aid to making an informed conclusion. EF values should not be the sole basis for a decision on whether an area is contaminated or not, but can be helpful when used sensibly.

For most of the elements a substantial leap is observed in the sediment samples at location no. 5 five cm down the sediment column. As five cm can equal a large amount of time depending on the sedimentation rate it is difficult to assess the reason behind this concentration decrease in the surface sediment. It may simply be due to a sediment type change, giving a reduction in grain size, or it could have been the removal of a point source. Considering the EF values calculated for location no. 5 are found to be lower than expected, the most probable reason behind the leap is a sediment type change after five cm. This change most likely consists of somewhat coarse particles being exchanged for finer sediment particles with larger surface areas, as described in chapter 2.1.1.

4.3 Sources of error and limitations

4.3.1 Sampling equipment

A potential source of error is the sampling equipment. The canisters used for the water samples are fastened to a metal grid as seen in Figure 2.4. The white paint used on the grid has also started to flake off showing the metal underneath. The grid seems to be made of steel, but since a major concentration increase of iron has not been observed in the samples, it looks like the grid has not contaminated the samples. The canisters appear to be made of either plastic or Teflon, which are inert materials ideal for water sampling.

The smallest sediment sampler (Figure 2.5) has a metal flap which closes when the sample is retrieved. This may potentially contaminate the bottom part of the sediment column. The sampler has a glass tube inside the metal container, eliminating sample contact with the metal. Therefore, by not analyzing the bottom part of the sediment column, the sediment sampler should not affect the results notably.

The largest sediment sampler (Figure 2.6) is made of steel, but contains a removable plastic pipe that receives the sediment column. Research conducted in recent years show how plastic will adsorb contaminants, especially hydrophobic organic compounds, like POP's. However, this research is mainly focused on microplastics and plastic debris found in aquatic systems that has a large surface area. [191] In fact, plastic looks to be a common and perhaps even favorable material for sediment sampling. [147b] After interpreting the results of the samples and comparing them to the guideline, there is nothing that indicates the results have been affected by the sampling procedure.

4.3.2 Relative standard deviation

Cadmium and nickel show mostly high relative standard deviation (RSD) values in the water samples (see appendix A.1), while the other elements are mainly observed within the 10 % threshold. Cadmium is found in low concentrations in the water samples (0.02 – 0.04 µg/L), which means the reason for the high RSD values observed may be due to analytical limitations. Nickel is subjected to polyatomic interferences, which may help explain the high RSD values observed in the water samples. [165] The nickel concentration was also quite low in the water samples (0.20 – 0.35 µg/L), though nearly ten times as high as for cadmium.

In several of the sediment samples both the arsenic and cadmium concentrations show quite high RSD. Mercury also has some samples with a fairly high RSD. This can be due to a high detection limit coupled with low concentrations, or interferences. Both arsenic and cadmium are subjected to polyatomic interferences. For instance, $^{40}Ar^{35}Cl^{+}$ will interfere with ^{75}As. Since an argon plasma is used and the samples are from a fjord this interference is highly plausible. As arsenic was analyzed using high resolution ICP-MS, which greatly increases resolving power, this polyatomic interference seems to be difficult to bypass.

For ^{111}Cd examples of possible polyatomic interferences are $^{95}Mo^{16}O^{+}$ and $^{39}K_2{}^{16}O_2{}^{1}H^{+}$. [165] It is plausible that the high cadmium RSD values found are caused by analytical limitations (high LOD, LOQ, etc.) coupled with low concentrations found.

Mercury was run in low resolution mode. As mentioned in chapter 2.5.2, sensitivity goes up when the resolution decreases, and vice versa. This means running the ICP-MS in low resolution mode when analyzing for mercury is appropriate because of the low mercury concentration generally found in sediment.

4.3.3 Interpreting the results

The most significant limitation when using guideline values coupled with calculated EFs and t-tests is the lack of biological significance. The total element concentration is found using ICP-MS with acid digestion, which does not take biological availability into account. This makes it difficult to assess the potential danger heightened element concentrations pose to organisms found in the area. If for instance the majority of the copper is particulate bound and therefore unavailable to organisms, the toxicity risk is not as pronounced as the guideline suggests. Instead of determining the total element concentration, an effects based tool, such as the AET, could have been used (see chapter 2.1.2.4). However, such a method is rather laborious. The fact that the t-test sample size for each variable is relatively small (six versus seven) may also be seen as a limitation.

4.3.4 Contamination source

There are no known point sources, other than the content of the dumping site, in this part of the Trondheimsfjord, including mining activity and industry. Nonpoint sources, such as runoff, are more likely to be the cause of these elevated copper and zinc concentrations (0.805 µg/L and 61.9 µg/L) in the surface water.

Figure 4.18 shows a map obtained from the Norwegian Geological Survey's database, and indicates that metal deposits close to the river Selva and the dumping site are nonexistent. The map however shows occurrences of the industrial mineral limestone not far from the dumping site. Limestone is often used to combat acidification in lakes and is typically low on dangerous metal contaminants.

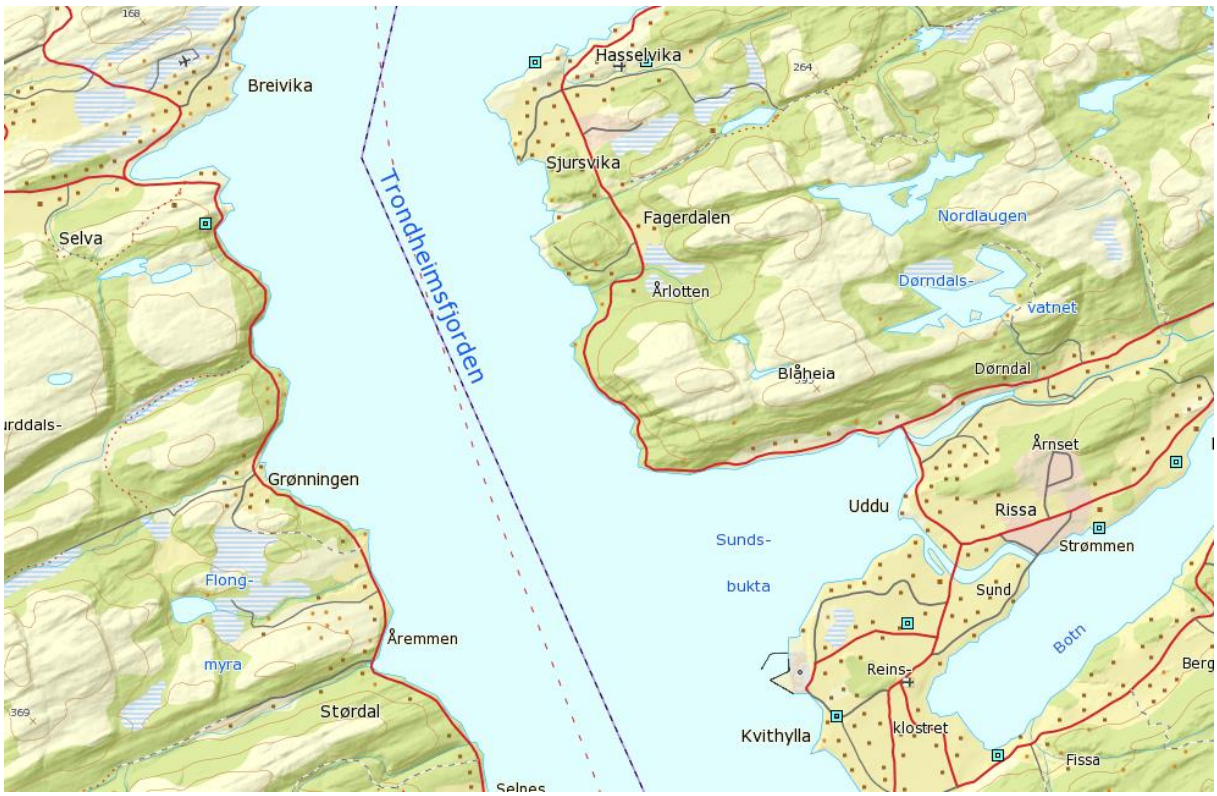

Figure 4.18. A map of the Trondheimsfjord showing potential metal, industrial mineral, and natural rock formations in the area. The turquoise squares are industrial mineral occurrences, more specifically limestone. [192]

Figure 4.19 was created using ArcMap and shows the top sediment concentrations of copper at the sampling locations outside the dumping site. The concentrations are given in µg/g.

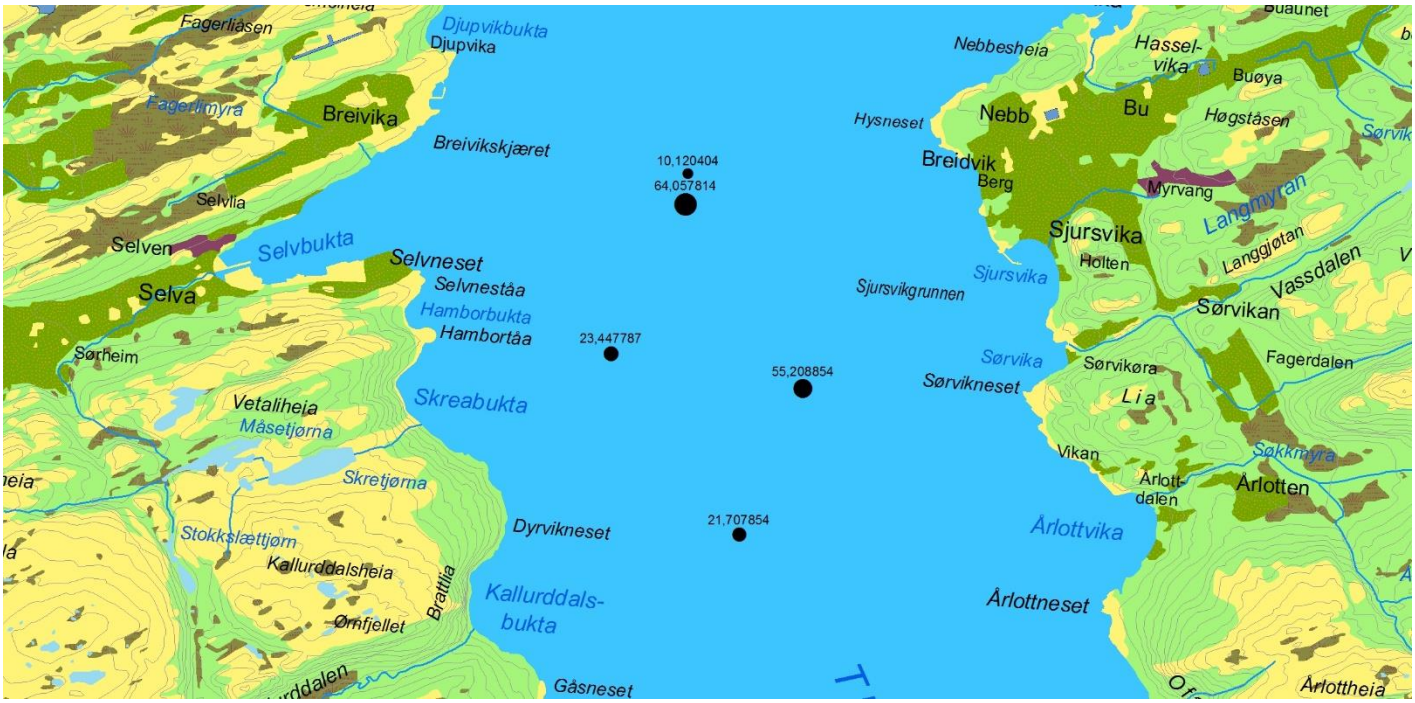

Figure 4.19. The concentrations of copper found in the top sediment at each sampling location outside the dumping site. The raw map data was retrieved from kartverket. [193]

Location no. 4 has the highest surface sediment concentration of copper (64.1 µg/g), a trend that can be observed for all elements apart from lead and mercury.

4.4 Organic explosives

Figure 4.20 shows the results of the organic analyses using LC-MS/MS. Sample no. 5 and 16 did not contain TNT, RDX, or TNT derivatives. This was determined by using the LC-MS/MS system's ability to look for specific ions, as mentioned in chapter 2.5.3. Some unknown organic material was found, but is not believed to be of explosive origin.

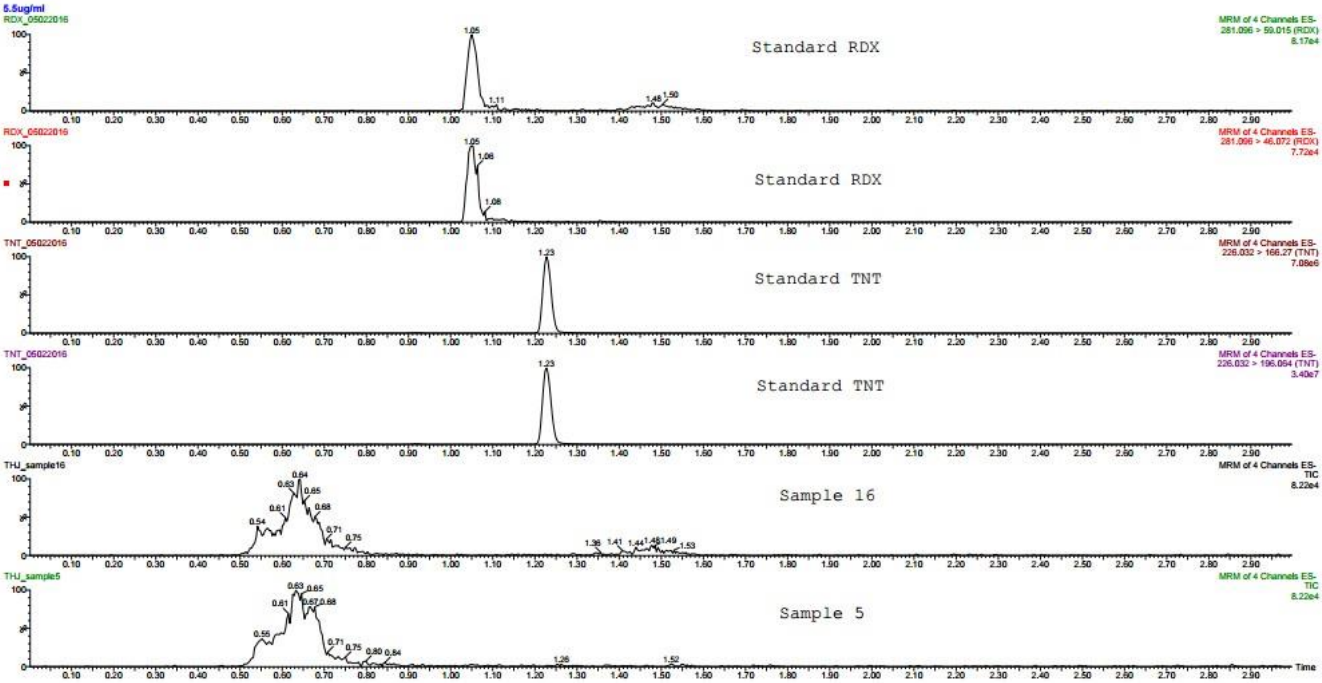

Figure 4.20. The LC-MS/MS results obtained using TNT and RDX standards, and comparing them with sample no. 5 and 16.

Explosive ordnances can be found in many shapes and sizes depending on its intended use. The chemical composition will also vary somewhat depending on manufacturing country and time of production. Neither is known for the ordnances in the dumping site, making it difficult to predict the explosives used. In other words, an explosive not tested for might be present in the samples. However, as mentioned in chapter 2.2.2.1, TNT and RDX were well used explosives during the Second World War, increasing the possibility of one of them being the main explosive in the grenades. As sample no. 5 and 16 are found outside the area, one can conclude that neither TNT nor RDX have not leaked out of the area. However, the state of the unexploded ordnances remains unknown, making a localized TNT and RDX contamination inside the dumping site possible.

The GC-MS analyses did not detect any TNT or RDX, and the chromatogram for each sample can be found in appendix D.1.

The ROV samples, which were taken inside the dumping site, could have helped determine if a localized TNT and/or RDX contamination were present. Unfortunately, the samples were misplaced after elemental analysis and not found again.

4.5 Remediation

As the dumping site does not seem to be a major source of contamination at this point in time, the question of remediation remains open. One might argue that the site can become a source of contamination in the future and that proactive remediation may be suitable. However, the depth of the site makes remediation difficult, and the content of the site makes certain remedial methods highly dangerous. For instance, dredging is inadvisable because of the unknown state of the explosive grenades. Capping may ultimately be the best active remedial method as the natural sedimentation has not been able to bury the military material, but more information is needed first.

As the military material has been dumped into the deepest part of the Trondheimsfjord, it may be considered a natural CAD (see chapter 2.4.2). However, objects found in the area are believed to be subjected to erosion-corrosion (see chapter 2.1.1.1) because of the riverine input nearby. This input will also cause turbulence in the area, which may re-suspend sediment causing increased contaminant remobilization in the water column (see chapter 2.1). Monitoring the site by taking water and sediment samples several times a year may be the best course of action at this point in time. This method increases knowledge of the site and helps create a better strategy for future handling of the dumping site and its content. If contamination from the site is confirmed in the future, a capping layer may be placed over the site preventing the contaminants from remobilizing into the water column and spreading (see chapter 2.4.1).

5 Conclusion

Due to this area's use as a dumping site for military material after the Second World War, as well as its use as a ship cemetery, some kind of contamination was expected. The surface water samples taken inside the dumping site revealed elevated concentrations of copper and zinc (0.805 µg/L and 61.9 µg/L), according to the guideline by the former Climate and Pollution Agency. Both metals are primarily found as non-bioavailable species in seawater, meaning the actual concentration affecting the aquatic organisms in the area is unknown. New water samples should be taken at the same location which will answer whether the surface water is constantly supplied with copper and zinc, or if the elevated concentrations were a one-time occurrence. Regardless, this surface water contamination is thought not to originate from the dumping site, but the river Selva, or an unidentified source.

Elevated copper concentrations were also found in the sediment samples at location no. 3 (55.2 µg/g after one cm), 4 (55.2 µg/g after one cm), and 5 (67.3 µg/g after seven cm). However, only location no. 3 and 4 showed elevated copper concentrations in the surface sediment. As the lithogenic elements (lithium, aluminum, rubidium, and iron) found in Figure 4.17, showed the same pattern trends as copper, Figure 4.12, the sediment is not believed to be badly contaminated by copper. The majority of the copper is assumed to be particle bound, ergo non-bioavailable. Performing a more biologically directed study of the area would be advisable, considering the lack of biological effects data available, and would give an indication of possible adverse effects caused by copper or other contaminants.

Neither TNT nor RDX were found in the tested sediment samples, as observed in Figure 4.20 and appendix D.1. If explosives have leaked out of the grenades, they have not ended up outside the area. It would have been interesting to look for TNT and RDX in the ROV samples taken inside the dumping site, but they were misplaced after the elemental analysis and never located. It is therefore difficult to conclude on the integrity of the military material. However, the iron concentration range in the seawater (3.5 – 13 µg/L) and the patterns observed in the sediment samples (Figure 4.17) did not seem to support any major iron enrichment. As the grenade shells most likely are made of steel, iron is believed to give an indication of the state of the shells.

Monitoring dumping sites containing military material is highly important, as there have been several casualties involving military dumping sites in the past where fishermen have caught live grenades in their nets.

The unknown state of the explosive ordnances make them dangerous to remove. Dredging of the dumping site would therefore not only be difficult, but very unsafe. Capping is a possible option as natural sedimentation has not covered the ordnances, making them exposed to the water column. More research on the dumping site should be performed before active remediation is performed however. Gaining knowledge on the site by monitoring it is therefore thought to be an appropriate course of action.

In conclusion; the water samples taken above the dumping site seem to contain elevated copper and zinc concentrations, which do not seem to originate from the site itself or its content. No evidence has been found that suggests the integrity of the ordnances have been compromised. It is therefore recommended that the dumping site is monitored closely, and new water and sediment samples taken regularly.

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Appendix A

A.1 Water samples

A.1.1 ICP-MS values and RSD

Table A.1.1. Water sample concentrations of arsenic, cadmium, chromium, and copper and each concentration's relative standard deviation. LR, MR, and HR = Low, Medium, and High Resolution. The chromium concentration was below 0 at 2, 5, 20, and 50 m, but were adjusted to 0.

	Depth (m)	As (µg/L) HR	RSD %	Cd (µg/L) LR	RSD %	Cr (µg/L) MR	RSD %	Cu (µg/L) MR	RSD %
Water samples	1	1,49052888	9,8	0,03043571	12,5	0,08100381	4,6	0,80548123	4,7
	2	1,5853175	1,8	0,02268831	40,4	0	4	0,85470292	5,6
	5	1,54759552	8	0,03001946	12,5	0	6	0,80893303	2,7
	20	1,6333447	9,5	0,02276442	29,6	0	2,3	0,6780884	0,7
	50	1,66077036	8,9	0,03674503	10,3	0	4,9	0,4394988	2,8
	100	1,67852927	7,4	0,03618155	24,5	0,34278554	7,9	0,52848891	5,6
	200	1,63418783	5,3	0,0213077	17	0,15712979	6	0,52442183	4,5
	300	1,66247145	4,6	0,01999766	10,9	0,13792987	5,6	0,48652606	10,6
	400	1,68239915	5,9	0,04369306	22,2	0,11532469	4,6	0,39456082	6
	580	1,78546352	1,5	0,03237212	13,3	0,15510848	3,3	0,45002128	4
	588	1,76604175	10,5	0,02892363	20,7	0,09237359	3,5	0,34630144	5,9

Table A.1.2. Water sample concentrations of lead, nickel, zinc, and iron and each concentration's relative standard deviation.

	Depth (m)	Pb (µg/L) LR	RSD %	Ni (µg/L) MR	RSD %	Zn (µg/L) MR	RSD %	Fe (µg/L) MR	RSD %
Water samples	1	0,05446224	5,3	0,34469777	14,9	61,8842749	4,2	5,36	3,4
	2	0,01428197	10,5	0,27012933	13,8	24,6281714	3,6	4,79	1,3
	5	0,03367566	3,3	0,26452085	24,5	15,1525948	3,1	4,65	1,8
	20	0,01464192	9,7	0,23570759	4,5	15,3611	4	5,37	1,2
	50	0,02024545	5,9	0,2469081	8,7	8,47840376	5,4	3,70	3,2
	100	0,03998507	6,6	0,20624372	3,4	8,89824779	2,8	5,97	3,7
	200	0,01426415	7	0,19643254	20,7	8,26179669	0,8	8,50	4,2
	300	0,01695807	0,7	0,19839355	9,4	6,89768662	3,5	7,87	5,1
	400	0,01828198	8,1	0,20671492	14,3	26,9144384	128,1	9,95	1,7
	580	0,00551858	14,1	0,19054189	19,2	3,93114213	8	7,83	3,6
	588	0,04684571	4,5	0,23260514	15,4	4,16472043	2,2	12,53	2,8

A.2 Sediment samples

A.2.1 ICP-MS values and RSD

Table A.2.1. Sediment sample concentrations of arsenic, cadmium, chromium, and copper and each concentration's relative standard deviation.

	Depth (cm)	As (µg/g) HR	RSD %	Cd (µg/g) MR	RSD %	Cr (µg/g) MR	RSD %	Cu (µg/g) MR	RSD %
Loc. 1	1	5,16283336	12,5	0,08830855	52,7	103,326702	2,4	21,7078538	2,1
	5	3,20440217	9,3	0,08215942	22,3	104,298215	0,4	22,7002017	1,3
Loc. 2	1	2,80243463	11,4	0,08285334	44,6	97,4283013	3,8	23,4477869	3,8
	5	2,73298252	10,6	0,07987249	6,2	82,513494	4,9	20,4649208	2,9
Loc. 3	1	7,40837799	11,9	0,10859641	51,8	179,356204	3,1	55,2088538	0,4
	3	7,31528117	10,6	0,09882563	42,6	180,572599	1,3	54,376857	3,8
	5	6,81928709	19,9	0,10189548	12,7	180,442659	4,7	52,8868963	3,6
	7	6,35243534	11,7	0,11744344	17,2	181,053592	1,9	52,3075291	1,6
	9	4,62441724	8,5	0,09790894	7,9	151,086508	1	37,4910021	0,5
	11	4,51730143	8	0,1038641	16,8	138,985924	0,9	32,4526895	2,9
	13	4,30901092	14	0,08983359	24,9	133,609805	2,5	29,5978519	2
	15	3,90606721	12,3	0,09457221	9,6	131,050118	1,5	28,2038255	3,6
	17	3,41648742	17	0,06083484	24,1	124,318314	1,2	24,9197075	1,6
	19	3,40304104	11,1	0,10227767	22,1	118,427557	3,6	24,3261468	0,9
	21	2,96660323	12,2	0,07358208	6,9	107,760902	3,2	24,5844082	1,4
Loc. 4	1	7,53768283	9,5	0,13193555	10,4	193,354238	4,8	64,0578142	0,5
	5	7,98446379	11,8	0,13719454	23	184,703348	1,8	65,0287395	2,9
	7	7,99955679	15,6	0,14344844	18,6	192,099588	4,2	62,5341757	2,2
	9	7,95778269	7	0,13018722	12,1	183,800623	1,7	62,1357778	1,8
	11	7,47273285	7,1	0,10364075	13,9	180,738372	3,9	57,2240329	1,5
	13	6,98475282	5,2	0,10892501	24,8	180,88958	0,8	55,4828472	1,6
	15	7,25724017	10,6	0,12945987	39,6	183,06114	2,8	58,4173613	0,9
	17	6,5181333	14	0,1084699	43,3	177,947868	1,2	54,464839	2,4
	19	6,58083391	9,3	0,11261696	29,4	164,021094	1	50,9708715	1,1
	21	6,72303069	11,4	0,11321784	19	178,374334	1,3	50,7584965	3,6
	23	5,63837854	11,1	0,10235633	12,8	157,372736	2	40,603643	1,4
	25	4,92636843	14,2	0,09518931	16,9	147,540977	1	37,2949069	1,9
	27	4,39841019	9,7	0,0800708	35	141,715678	1,8	34,22479	0,8
	31	3,9794258	11,2	0,09864882	34,9	135,461181	1,7	31,2551153	1,9
	37	4,16765805	11	0,0831464	11,2	131,995467	2,6	32,7166329	0,1
	43	4,60995036	9	0,08271729	36,2	137,29706	3,2	38,0876625	1
	49	3,62234759	10,8	0,0661413	19,9	124,687836	2,3	28,6384108	1
	55	3,43741622	11	0,07832324	14,4	121,231677	2,4	41,74188	0,4
	61	2,95388808	9,9	0,09539133	29,9	107,41842	1,5	22,8066837	3,7
	67	2,82179911	6,8	0,08597314	27,7	106,266587	0,6	23,9407404	3,1
	73	3,09326751	4,4	0,07725664	14,4	98,3627209	1,1	21,4408544	1
	79	2,55782743	7,9	0,06463822	20,7	93,8556676	3,1	20,9621061	1,6
	84,5	2,67275558	11,4	0,07259336	34,2	93,2710695	1,3	22,1847053	3
	89,5	2,22807304	15,7	0,07932427	22,2	89,9058863	3,1	20,9328249	2,4

	94,5	2,14582906	7,4	0,06210285	9,1	89,2477661	1	18,9608628	1,5
	99,5	1,80629029	9,1	0,06927123	8,2	71,3483828	3,7	13,276744	3,7
	104,5	2,53766057	6,6	0,06722878	34	81,9012525	1	19,5463659	2,2
	109,5	4,43986653	12,9	0,09016923	30,3	82,7081922	3,2	21,7256561	4,1
	114,5	5,75051392	16,4	0,11169644	2,7	83,6987938	1,3	27,4858668	2,2
	119,5	0,99580775	16,2	0,06528531	35,4	54,6853274	3,1	8,34499192	1,9
	124,5	3,34341004	10,4	0,04291185	14,5	55,8687398	1,9	9,86142077	2,6
	129,5	3,59674535	18,9	0,06349539	7,9	94,5039651	3,6	15,7467447	2,7
	134,5	3,87442133	9	0,09031573	16,1	106,224379	2,4	19,0233266	1,5
	139,5	3,32508905	9	0,06380081	35,2	102,751187	4,2	18,7181523	2,3
	144,5	3,38120788	13,5	0,07936928	34,2	104,8407	1	19,2520451	1,9
	149,5	2,96858658	8,4	0,09837481	16	97,7906376	0,6	18,0717492	2,2
	154,5	2,89853272	9,9	0,09482997	12	94,8194048	1,6	17,1814626	3,1
	159,5	3,23195737	11,4	0,07921195	15,7	100,432439	5,3	18,8358974	2
	164,5	3,15638104	13,5	0,07718642	37,3	107,301107	1,6	18,3902059	0,4
	169,5	3,25024379	16,5	0,07436715	6,2	109,619807	2,3	20,3849418	1,7
	174,5	2,68935168	6,4	0,12484652	2,6	99,7441815	1,3	16,9962498	0,5
	179,5	2,71605433	13	0,09228808	17,2	88,9550662	2,3	17,1499045	3,4
	184,5	2,76750831	10,9	0,08386867	16	109,666553	2,5	19,0110102	3,9
Loc. 5	1	4,50772461	9,9	0,05721993	27,8	55,8995083	1,6	10,1204045	2,3
	3	4,9912366	16,4	0,08177738	14,4	151,196064	2,5	50,5411501	1,8
	5	7,21215828	11,5	0,12858384	9,8	191,254422	2	67,2583796	1,8
	7	8,29231318	12,9	0,15245967	13,4	205,050133	2	71,3648371	1,8
	9	8,37722803	10	0,1750146	15,3	195,832414	3	70,9522744	1,9
	11	7,90757451	10,3	0,14071309	13,9	193,224973	1,8	70,7382368	3,1
	13	7,86113534	9,6	0,16394766	6,4	195,463417	1	66,1956933	4,5
	15	8,28394726	9,6	0,13793505	5,5	189,444206	2,6	67,6039865	2,7
	17	8,26912552	11,1	0,16422589	9,9	196,52343	1,7	68,8222071	2,5
	19	7,8118476	10,2	0,15345942	28,6	194,457006	0,5	69,6100872	1,1
	21	8,08114371	9,1	0,15541685	10,7	198,693666	0,6	66,2068204	3,5
	23	7,99191604	11,6	0,1332704	4,6	192,800077	0,8	66,6707068	2,8
	25	7,75556453	8,7	0,18165804	20,4	189,109877	1,9	69,6426862	0,8
	27	7,92289698	9,3	0,1356352	6,7	200,50446	0,8	68,1533725	2,5
	29	8,68238318	10,8	0,11991487	23,5	198,637608	1,8	65,837721	2,3
	31	7,8360911	11,8	0,1581707	10,1	188,289586	1,8	67,377365	1,3
	33	7,84064368	13,7	0,17348604	12,3	196,20665	1,2	66,6262345	2
	35	7,5556531	10,3	0,12875677	26,8	192,383312	1,6	66,1702193	2
	37	7,42089719	14,6	0,1257352	23,3	197,928043	0,7	66,2419944	1,3
	39	8,0200314	11	0,12430964	19,3	196,11922	3	66,3397067	1,9
	41	8,51253715	13,4	0,11327375	26,9	199,465023	0,2	66,7416842	1,2
	43	7,50463442	12,1	0,10819275	15,1	192,517236	0,4	65,7409395	0,4
	45	8,18200095	14,8	0,13407868	12,8	192,948405	1,1	66,3688946	0,6
ROV	1	5,98784557	6,7	0,06906127	13,9	91,3287823	0,9	26,6581327	1,7
	2	8,12201181	2,4	0,05316289	22	89,7795765	0,9	21,1616272	1,9
	3	7,05236456	8,8	0,06042884	3,5	92,6903476	0,9	23,027361	3,6

	4	6,84081507	4,1	0,06111515	6,2	97,134019	2,1	24,8275571	2,6
	5	6,92343136	4,2	0,08914124	7,9	95,1032234	0,6	27,245816	0,1
	6	4,51664685	1,4	0,0905348	17,2	101,58971	2	28,5307149	0,9
	7	3,46661689	5,3	0,06567353	3,3	101,37981	3,2	25,287576	2,6
	8	2,98396071	2,3	0,0643226	14,9	102,44647	0,9	24,6696609	0,4
	9	2,87925653	4,3	0,0740522	9,3	98,8347711	0,8	24,0247408	1,5
	10	3,05656522	6,1	0,06649035	20,3	102,553076	0,5	25,397103	2,2
	11	3,04607745	5,7	0,06988252	7,8	100,508405	0,7	25,6001085	0,6
	12	2,87213702	3,9	0,0631691	26,1	100,733913	2,1	23,5427851	2,4

Table A.2.2. Sediment sample concentrations of lead, mercury, nickel, and zinc and each concentration's relative standard deviation.

	Depth (cm)	Pb (µg/g) MR	RSD %	Hg (µg/g) LR	RSD %	Ni (µg/g) MR	RSD %	Zn (µg/g) MR	RSD %
Loc. 1	1	18,283754	1,4	0,04781826	3,8	38,711052	1,3	73,1732887	3,3
	5	18,4196558	2,2	0,04309543	5,2	36,4927845	1	68,1787754	5,9
Loc. 2	1	16,7917913	0,8	0,03661018	2,2	34,1981634	4,3	63,2741841	2,8
	5	9,48260936	1	0,01837594	1,9	29,6483363	4,5	44,3247268	2,2
Loc. 3	1	15,038401	1,3	0,02137104	10,7	74,0221984	1,1	99,60415	4,1
	3	14,2199047	2,1	0,02142396	6,7	75,7706841	1,4	99,5002869	5,4
	5	13,6359946	2,3	0,01853323	14,9	74,5762617	2,9	99,0217094	2,2
	7	13,641127	0,9	0,01594881	1,3	71,7883696	3,2	96,7099665	3,2
	9	10,461952	2,2	0,01311077	2	56,740439	2,5	76,2237022	2,6
	11	9,2042053	1,7	0,0100152	10,5	50,1177847	2,7	69,6493734	2,2
	13	9,40328283	1,5	0,00929264	0,4	43,9938896	2,5	61,5082192	4,8
	15	8,939195	2,5	0,00924754	7,2	46,1180551	2,3	59,9961965	4,9
	17	7,94095312	3,4	0,00737898	9,5	44,2083236	0,7	54,5992564	3,5
	19	7,87402317	2,4	0,00881916	3,5	41,6949482	2,9	55,4818594	1,3
	21	8,28960631	2,2	0,00939831	9,4	37,5385061	2,9	52,4237393	5,8
Loc. 4	1	16,522856	3,7	0,02084973	1,7	77,504405	2,2	113,540243	4,2
	5	16,5281402	1	0,02088966	3,8	80,0103164	3,8	114,594159	2,4
	7	15,9657621	2,3	0,02165394	5,1	76,6784593	0,3	108,084481	1,9
	9	15,4573253	3	0,02196955	2,4	77,8883478	1,8	108,602167	1,9
	11	14,7728559	1,7	0,01918693	9,8	73,7572442	5,5	105,321616	3,2
	13	14,3706126	1	0,01832527	3,7	71,0827216	4,5	99,3487517	3
	15	14,354091	2,6	0,01886877	2,7	71,5915841	0,8	106,74108	1,8
	17	13,6816153	2,6	0,02492997	5,7	67,951661	1,4	99,5816729	5,3
	19	13,1750013	2	0,01691823	6,7	66,6564131	3,5	96,9461911	0,5
	21	13,3142451	4,2	0,01699037	9,8	66,3269533	3,8	97,0280537	2,9
	23	11,2190619	1,8	0,01328061	6,6	59,8564378	1,8	80,4979587	0,1
	25	10,4073233	5,7	0,01210081	2,2	53,4383659	0,8	76,1415476	2,9
	27	9,96853441	2,2	0,01142655	2	51,4301272	2,9	71,3538026	2,2
	31	9,51774241	3,6	0,01119651	7,5	47,2291615	8,5	67,1456604	3,4
	37	9,80029726	4,1	0,01149113	6,9	46,9294121	2	67,1329756	3,4

	43	10,3558007	2,4	0,01344339	9,8	48,8242287	1,2	70,8456014	2,1
	49	8,66267406	1,1	0,01079937	6	42,3615515	3,2	59,8464219	1,9
	55	8,38647045	2,3	0,01065877	10,2	41,685261	5,8	58,5501427	4,2
	61	7,54192418	3,5	0,00788021	10,8	34,5859302	0,4	49,0775378	6,8
	67	7,57954575	1,6	0,00781533	1,3	33,6279533	2,7	49,7123096	2,5
	73	7,18106731	4	0,00711368	7,3	32,8917068	2,6	43,7183811	2,7
	79	6,57648826	2,6	0,00583155	4,1	28,7737635	1,6	43,180419	3,8
	84,5	7,04930731	4,1	0,00670061	10,7	30,3392277	6,4	42,4512599	0,7
	89,5	6,58787734	1,3	0,0070077	5,5	27,7997789	0,5	40,1528503	2,2
	94,5	6,49025113	4,1	0,00645476	14,2	27,2848296	5,9	41,416785	3,7
	99,5	5,1406569	1,7	0,00671954	4,4	16,8600658	3,9	23,8049678	3,2
	104,5	6,66217599	0,2	0,01452201	10,1	27,2594503	4,1	40,1522456	5,5
	109,5	7,88427453	0,4	0,01090549	6	28,3442366	3	41,9023379	1,7
	114,5	7,95182907	1,2	0,01274896	5,6	32,0653303	3,2	45,9876912	5,2
	119,5	4,00947676	1,8	0,00484963	11,4	15,5896517	0,3	24,1165682	3,1
	124,5	5,49047194	4,3	0,0088159	6,1	19,0191233	3,7	29,2492013	2,6
	129,5	9,38020332	1,4	0,01130363	9,7	36,4383326	2,6	53,5498168	3,2
	134,5	8,29400496	1,6	0,00734765	5,2	41,1674345	0,3	57,6841632	2,9
	139,5	8,21208262	2,7	0,00839091	8	40,9811169	3,5	58,6286552	4,9
	144,5	8,46583404	3,9	0,00703393	13,3	43,0048343	4,5	57,3139382	3,7
	149,5	7,87877398	1,2	0,00609361	12,5	41,2557038	1,6	53,3949286	2,1
	154,5	7,54729159	3	0,00675978	4,1	39,1361954	2,8	53,1389564	6,4
	159,5	7,9748823	2,9	0,00730619	6,5	41,004298	1,7	56,5672151	2
	164,5	8,0214631	1,7	0,00754718	4,5	45,9730599	2,8	58,3359337	4,7
	169,5	8,2595938	0,8	0,00683625	10,2	45,2210923	5,3	59,1743744	3,4
	174,5	7,74994267	3,7	0,00651083	14,3	40,604012	4,6	55,8925565	3,6
	179,5	6,97598529	2,6	0,00550183	6,3	37,4529073	4,1	47,5848027	1,7
	184,5	6,97954079	2,6	0,00569964	10,5	45,8664176	3,5	54,6577874	1,4
Loc. 5	1	8,35968671	1,8	0,01800098	1	19,5598108	2,2	33,3286234	6,3
	3	15,58972	2	0,02064311	2,3	61,627994	2,9	90,5383395	2,7
	5	17,022115	2,2	0,02122103	1,1	80,3645704	1,4	113,327437	5,1
	7	18,1107329	1,5	0,02396129	3,3	86,9250747	0,4	121,547146	2,7
	9	17,2809873	1,4	0,02587075	6,3	88,3334025	1,6	120,896364	4,3
	11	16,8242721	1,8	0,02300086	2,5	86,2534739	0,4	120,204443	0,7
	13	17,6108129	3	0,02378632	1,7	84,0227952	0,9	119,274337	3,2
	15	16,2800383	2	0,0220447	4,4	85,649408	2	119,136198	2,1
	17	16,410231	0,1	0,02509296	3,7	85,4862134	0,9	114,995973	2
	19	16,3389475	1,1	0,02257104	1,1	85,1823219	1,4	119,72395	2
	21	16,8151904	1,5	0,02229825	0,2	86,9458389	0,4	116,991917	3,8
	23	16,7117966	3,2	0,0228272	2,2	85,845268	2,9	115,964419	0,4
	25	16,5602398	2,2	0,02084061	7,9	88,7199149	3,6	116,448541	1,8
	27	16,4961586	3,7	0,02209682	2,2	85,6793706	1,2	115,452408	6,7
	29	16,6136745	1,2	0,02160174	12,9	85,1855594	2,4	117,726088	4
	31	16,0711046	3,8	0,02015259	7,1	86,3127737	2,6	113,128731	1,2
	33	16,4404514	1,2	0,02104947	5	87,2103203	4,3	119,727426	2,5

	35	16,2458433	2,5	0,022827	5,2	86,696516	1,6	118,225264	4,2
	37	16,3971671	3,9	0,0213823	6,2	84,4776472	2,4	114,868385	1,3
	39	16,8475628	1,7	0,02291549	3,1	88,5291522	3,8	115,722691	3,1
	41	16,3515706	3,1	0,02224363	10,6	87,0175968	3	115,86256	1,7
	43	16,7781945	3	0,02099823	8,6	87,3737517	3,4	114,851351	1,5
	45	16,4709556	1	0,02514351	5,7	87,6143318	1,3	114,04159	1,7
ROV	1	13,4305186	1,8	0,0309847	1,2	35,9109326	3,8	62,7872488	2,2
	2	15,9309783	1,1	0,03270499	2,7	38,0169055	1,2	67,4344124	2
	3	15,6829277	1,2	0,02747564	2,1	37,6451805	2,9	70,0461349	1,7
	4	26,2592377	0,6	0,02849487	3,7	40,0317859	2,7	250,564665	1
	5	35,5571811	2,1	0,02630766	3	39,2560703	1,8	428,415938	0,6
	6	12,6017884	1	0,01813907	2,4	40,3731545	1,9	85,5552422	0,8
	7	8,91763348	0,9	0,0086727	7,6	40,3833415	2,1	57,9073893	3,6
	8	8,75837735	1,4	0,00958971	4	40,5329734	1	55,3953132	1,1
	9	7,88178396	0,7	0,00497445	5,5	38,6341418	1,4	54,1287063	0,8
	10	7,45972659	1,3	0,00438068	4,3	38,6270301	4,5	54,5026594	6,1
	11	7,70052677	1,3	0,00506237	5	39,7037995	1,7	52,5005186	1,7
	12	7,38420976	1,2	0,00274061	5,9	37,8230573	3,6	54,6188188	5,4

Table A.2.3. Sediment sample concentrations of aluminum, iron, lithium, and rubidium and each concentration's relative standard deviation.

	Depth (cm)	Al (µg/g) MR	RSD %	Fe (µg/g) MR	RSD %	Li (µg/g) MR	RSD %	Rb (µg/g) MR	RSD %
Loc. 1	1	30312,208	0,9	30136,3002	4,4	27,1500595	3,5	55,8271401	1,3
	5	29720,7366	2,2	28733,1319	1,2	26,1768887	2,5	53,5273408	1,6
Loc. 2	1	26538,2041	1,8	26398,294	2,7	24,1084762	4,2	47,0997754	2,2
	5	22163,4057	2	21583,0894	1,3	19,1623223	2,6	34,0149677	2,3
Loc. 3	1	44500,7143	1,4	47985,4889	2,8	42,0985988	2,6	86,3517728	1,4
	3	46630,3342	2	47747,6177	1,6	42,483285	0,6	84,9393245	2,8
	5	43285,3803	2	46853,565	1,6	41,6302097	1,5	81,7491377	3,4
	7	42951,9695	2,8	46456,5839	2,3	41,173603	4,8	83,6024083	1
	9	35875,1173	1,1	38722,9701	3,8	33,3946195	3,1	60,3204505	1,8
	11	33337,9455	4,1	34731,5513	1,3	28,978649	1,8	52,9785805	2,9
	13	33923,6987	0,9	32798,4691	0,8	26,7501701	2,8	49,3597078	4,8
	15	32013,951	2,9	32924,7398	2	26,6768571	0,6	46,8295744	1
	17	29867,006	2,8	31668,7799	2,7	25,8181346	5,1	41,9951251	1,7
	19	28667,5967	1,3	29773,7316	2	25,9042332	2,1	41,6206164	5,2
	21	26305,4645	0,2	27707,3018	1,1	23,1959218	1,3	37,4421412	1,9
Loc. 4	1	47541,0591	1,9	52213,3047	2,8	45,7627911	2,8	96,8385332	1,6
	5	45976,0616	3,2	52100,2081	1,4	44,8150749	3,8	92,0553213	1,1
	7	46292,0445	1,9	50937,7543	2,4	44,3237243	3,6	93,2448834	1
	9	45114,4675	0,9	50170,9799	1,5	43,0187326	3,4	89,6454645	3,3
	11	44227,2767	1	49988,5028	0,4	42,6645155	2,4	84,2181547	3,6
	13	44763,7019	1,4	48389,0053	1,7	42,0121063	3	85,0365848	1,5

	15	44560,5715	1,4	48852,4109	0,6	43,0636086	5,1	83,9043141	3,2
	17	43301,0248	1,4	47321,0129	3,3	40,5036799	3,2	81,135612	1,5
	19	41512,8169	2,9	45717,9869	4,3	39,1430628	1,7	74,5788549	1,6
	21	43008,4789	1,9	46875,722	2,6	40,4439495	1	78,058846	1,7
	23	38667,911	2,7	40953,9452	3	35,1615338	1,1	65,0018781	3,3
	25	34910,7935	1,6	38529,7867	1	32,4573091	3,3	56,8611032	3,3
	27	34067,959	2,4	37805,7153	2	31,0696216	2	54,0302829	1,4
	31	32687,6063	0,2	34722,6493	1	28,8589829	1,3	51,2181844	1,9
	37	32604,8531	4,3	34548,4971	1,4	28,708384	0,3	49,9957348	0,9
	43	33700,4365	3,9	35087,3012	2,5	29,6156619	2	52,9636454	0,6
	49	30410,4764	0,7	32133,7214	2,1	26,6299021	1	46,1676519	0,8
	55	30107,5475	3,2	31173,5095	0,4	25,9568252	4,2	43,3834679	2,4
	61	26862,9217	2,5	26924,7112	2,5	22,3157743	6,3	35,8590461	0,7
	67	26533,8406	2,8	26761,5425	0,8	21,3706659	1	36,1603914	4,2
	73	23871,1797	2,1	24360,1995	2,2	20,2166755	2,7	33,0160665	2,4
	79	23224,2428	3,2	23580,1425	1,5	19,4913074	4,7	29,8535331	3
	84,5	23551,6651	0,8	23105,2222	1,2	19,1672953	1,6	30,7918594	1,1
	89,5	22890,6526	2,7	22197,0028	1,8	18,1688594	0,7	29,4087953	2,9
	94,5	22308,9285	1,8	22156,5842	1,6	19,0867379	2,3	30,9891391	1,5
	99,5	18406,5971	2	16777,0243	2,8	9,98111877	1,2	15,1335438	0,6
	104,5	21118,1984	2,9	21411,9084	2,1	17,8046659	4,3	28,6224732	3
	109,5	21011,0892	1,2	22477,2602	2,2	18,9637446	2	32,2378708	1,8
	114,5	21751,6548	0,3	24082,6319	2,6	18,980002	0,8	32,6581201	3,5
	119,5	15322,5369	1,9	14858,6918	0,9	11,0660265	3,5	17,0104399	0,6
	124,5	15499,8872	1,2	16343,2208	1,2	14,3262924	1,9	25,1951222	1,1
	129,5	30806,905	3,1	29657,8136	1,2	25,4476726	1,9	64,110856	1,5
	134,5	33178,1153	1,1	30968,4834	1,1	27,8300905	1,6	71,3514538	1,4
	139,5	32971,5445	3,3	32094,2479	2	27,6057048	4,3	70,8997053	4,1
	144,5	33086,1642	1,2	32485,5491	1,2	28,6031897	1,2	74,5331175	1
	149,5	30808,6934	2,3	30048,5966	2	26,1647899	2,2	67,1347371	0,9
	154,5	31136,5573	3,8	30055,3934	1,3	26,0465935	2,6	66,0991393	2
	159,5	31898,6801	2,6	30871,1853	3	27,4991295	2,3	71,6913815	3,8
	164,5	33125,0358	3,8	31993,2895	3	27,1681649	3,7	71,6890443	2,3
	169,5	33504,8413	1,9	32962,2203	2,1	28,4656621	3,1	73,1944502	1
	174,5	30762,1357	1,9	29569,7441	2,8	25,9788724	1,5	66,1316633	1,5
	179,5	27075,3936	1,2	27380,4933	0,9	23,0707215	3	57,7994507	1,7
	184,5	31000,5398	2,5	30148,6284	1,6	25,4016911	1,6	65,4358278	1,2
Loc. 5	1	15910,8192	3,4	16533,8724	0,1	14,4792068	0,2	30,7810462	1,9
	3	40577,7569	0,3	44043,7204	1,4	39,2366016	5,6	79,6465443	3
	5	48782,504	0,2	52389,755	3,4	46,2575567	1,4	94,9731089	1,4
	7	52309,2699	1,1	56365,4996	1,9	51,3830413	2,4	104,492436	1,4
	9	51041,0244	1,4	54192,7453	2,5	49,4017926	4,2	103,524021	1,7
	11	47828,4913	0,6	54241,3839	1,6	47,8196696	4,3	98,46971	1,4
	13	49033,933	1,4	53093,8901	3,7	47,6324863	2,2	96,0881606	1,9
	15	48118,4837	1,6	53176,0266	1,8	46,6472242	2,1	93,6758163	4,4

	17	48638,5847	0,8	53055,5211	2,4	48,3937292	2,8	98,8068308	6,1
	19	47788,9294	0,8	53393,7055	1,8	47,674934	4,4	94,0738194	1,7
	21	50279,0934	3,9	53428,0644	2,6	48,3005503	1,5	98,2403963	0,8
	23	48201,3041	0,4	52263,2011	1,2	47,0234039	1,8	97,4685359	0,9
	25	47743,7819	3,2	52410,276	2,1	47,7566172	1,3	95,0128417	1,7
	27	49494,9861	2,2	54123,9463	0,8	48,244285	2,4	97,4849339	1,8
	29	49513,876	0,7	53798,6236	1,9	47,1832296	1,6	97,2545208	2,2
	31	47528,2309	0,4	53237,3237	1	46,4502229	0,7	91,4997728	3,9
	33	49407,4138	1,1	52836,0328	0,7	47,5314102	4,5	98,4284547	0,9
	35	47215,0797	3,2	52093,6236	0,4	46,856929	5,7	98,2196134	3,1
	37	51431,9835	2,8	52825,3666	1,9	48,8315981	1,9	100,714493	0,3
	39	49861,178	1,8	53501,1017	1,2	47,1419273	2,3	98,6031738	2,4
	41	50070,7293	1,7	53169,9204	1,1	47,3556299	5,9	98,2396272	0,4
	43	49184,925	3,6	52178,9172	0,1	46,669428	3,2	95,2115925	0,4
	45	47649,0908	1	52727,3488	1,2	47,1118639	3,4	92,0724949	2,8
ROV	1	27208,4849	0,9	26981,3297	2,8	22,2309	2,1	43,7801707	1,7
	2	28964,1826	1,1	28629,7427	1,8	23,3999619	2,6	48,6171233	2
	3	29034,1727	3,2	29427,9088	1,8	24,1809554	0,7	49,6683617	1,7
	4	30343,0843	1,2	30915,1289	1	26,1964935	2,3	49,6139711	2,3
	5	28843,4165	2	29251,7151	1,8	24,456338	1,4	49,665871	0,9
	6	28085,4645	0,2	28209,0169	1,2	24,2981989	0,9	41,7889174	0,7
	7	27900,4372	2,6	26824,3651	1,3	22,8925824	6,4	37,848861	2,1
	8	27113,9328	1,1	27419,0444	1,9	23,1838723	3,4	37,2561619	1,1
	9	26476,2223	2,4	26249,6645	1,9	22,875175	3,2	35,1312264	1,9
	10	27016,9631	0,4	26456,2783	1,4	22,5895074	1,4	37,4156441	0,9
	11	27066,7265	3,1	26744,4087	2,6	22,8791865	1,7	36,0272036	2,1
	12	27432,8926	1,4	26435,2187	1,9	22,2463378	1,4	35,5122187	2,3

A.3 Enrichment Factor

Table A.3.1. The enrichment factors for arsenic and cadmium down the sediment column using aluminum, lithium, and rubidium as normalization elements.

		Arsenic			Cadmium		
		Enrichment Factor			Enrichment Factor		
	Depth (cm)	Aluminum	Lithium	Rubidium	Aluminum	Lithium	Rubidium
Loc. 1	1	1,75574792	1,66541578	2,08259559	1,31253715	1,24500793	1,55687729
	5	1,11142223	1,07209765	1,34813556	1,24544413	1,20137756	1,51070176
Loc. 2	1	1,08856807	1,01805463	1,33992	1,40658165	1,31546847	1,73136339
	5	1,27113591	1,24909097	1,80937676	1,62363046	1,59547231	2,31112913
Loc. 3	1	1,7161205	1,54120655	1,932031	1,09944858	0,98738833	1,23777365
	3	1,61716422	1,50805883	1,93947612	0,95483323	0,89041339	1,14513802
	5	1,62401249	1,4346162	1,87852946	1,06057194	0,93688546	1,22678591
	7	1,52457502	1,35122208	1,71113266	1,23189057	1,09181754	1,3826333
	9	1,32878682	1,21279072	1,72645257	1,22957629	1,12224075	1,59755132
	11	1,39679241	1,36523147	1,9201757	1,40363137	1,3719159	1,92957724
	13	1,30938097	1,4107706	1,96592629	1,19305921	1,28544166	1,79127886
	15	1,25774345	1,2823613	1,87837248	1,33091621	1,35696628	1,98765208
	17	1,17917908	1,15893831	1,83207464	0,91767129	0,90191934	1,42577351
	19	1,22367906	1,1505402	1,84128449	1,60737046	1,5112985	2,41862952
	21	1,16253254	1,12009068	1,78427177	1,2602379	1,214229	1,93423137
Loc. 4	1	1,63440859	1,44254944	1,75287873	1,25031495	1,1035436	1,34094407
	5	1,79021676	1,56036781	1,95325558	1,34440931	1,17179833	1,46684751
	7	1,78135794	1,58064752	1,93198225	1,39609799	1,23879585	1,51414631
	9	1,81830975	1,62009252	1,99906065	1,30010655	1,15837958	1,42934493
	11	1,74173022	1,53397398	1,99818618	1,05576388	0,92983075	1,21121674
	13	1,60848374	1,45606895	1,8497262	1,09629657	0,992415	1,26072053
	15	1,67885184	1,47593227	1,94782269	1,30891325	1,15070745	1,5186158
	17	1,55173191	1,40939949	1,80914734	1,12859341	1,02507331	1,31581477
	19	1,63414412	1,47241922	1,98713528	1,22221617	1,10125818	1,48622686
	21	1,61139733	1,45585086	1,93956877	1,18600693	1,07152294	1,42754488
	23	1,50312517	1,40440307	1,95339711	1,19258806	1,11426138	1,54983637
	25	1,45465096	1,32928998	1,95107437	1,22844271	1,12257622	1,64766885
	27	1,33088718	1,2398385	1,83324582	1,05889893	0,98645751	1,45859248
	31	1,25495722	1,20766017	1,74967928	1,35967536	1,30843168	1,8956788
	37	1,31765423	1,27141896	1,87724665	1,14891427	1,10859994	1,6368448
	43	1,41010792	1,3632646	1,96011068	1,105827	1,06909179	1,53714711
	49	1,22788735	1,19131306	1,7669105	0,97988684	0,95069958	1,41004168
	55	1,17692387	1,15980747	1,78430903	1,17203799	1,15499265	1,77690166
	61	1,13352843	1,15927756	1,85505811	1,59986051	1,63620279	2,61822654
	67	1,09627019	1,15641413	1,75733754	1,45978574	1,539873	2,34005842
	73	1,33578089	1,3400256	2,10986353	1,45810354	1,46273695	2,30307194
	79	1,13532789	1,14930587	1,92946862	1,25393289	1,26937111	2,13103561
	84,5	1,16984751	1,22124771	1,95472445	1,38867851	1,44969361	2,32037408

	89,5	1,00337408	1,07400701	1,70613898	1,56125685	1,67116215	2,65476378
	94,5	0,99153498	0,98462026	1,55936517	1,25417833	1,245432	1,97241856
	99,5	1,01159266	1,58494311	2,68787536	1,6955314	2,65652461	4,50515037
	104,5	1,23870615	1,24826001	1,99658861	1,43424983	1,44531187	2,31177255
	109,5	2,17827635	2,05045938	3,10145711	1,93346472	1,82001281	2,75289124
	114,5	2,72524773	2,65347963	3,965315	2,31352111	2,25259564	3,36624076
	119,5	0,66994084	0,78811419	1,31832404	1,91960224	2,25820799	3,77743469
	124,5	2,22357987	2,04390725	2,98837703	1,24731199	1,14652505	1,67632319
	129,5	1,20351983	1,23784702	1,26339843	0,92858269	0,95506803	0,97478237
	134,5	1,203779	1,21926353	1,22283043	1,22641684	1,24219256	1,24582654
	139,5	1,0395745	1,05489636	1,05613897	0,87179299	0,88464199	0,88568405
	144,5	1,05345765	1,03529177	1,02160922	1,08076799	1,06213117	1,0480939
	149,5	0,99327172	0,99366004	0,99578285	1,43859006	1,43915247	1,44222703
	154,5	0,95961989	0,97461396	0,98751709	1,37214954	1,39358938	1,41203941
	159,5	1,04444251	1,02932384	1,01522169	1,11877932	1,1025846	1,08747876
	164,5	0,98225602	1,01750014	0,991514	1,04981062	1,08747865	1,05970532
	169,5	1	1	1	1	1	1
	174,5	0,90120324	0,90663536	0,91579943	1,82846393	1,83948525	1,85807835
	179,5	1,03408277	1,03105689	1,05822242	1,53566785	1,53117426	1,57151651
	184,5	0,92026161	0,95418296	0,95243544	1,21886878	1,26379695	1,2614824
Loc. 5	1	2,92049499	2,72657821	3,29789037	1,62024708	1,51266494	1,82962041
	3	1,26797809	1,11409475	1,41124831	0,90797023	0,79777787	1,01056278
	5	1,52402745	1,36548808	1,71012088	1,18754136	1,06400549	1,33254771
	7	1,63413776	1,41338749	1,78711729	1,313115	1,13573063	1,43604204
	9	1,69189179	1,48512491	1,82230648	1,54483229	1,35603761	1,66391131
	11	1,70430862	1,44824513	1,80843478	1,32548333	1,12633636	1,40646484
	13	1,65264728	1,44539775	1,84237321	1,50638137	1,31747426	1,67931579
	15	1,7746676	1,55530967	1,99146214	1,29148431	1,13185029	1,44925287
	17	1,75254946	1,49649699	1,88466789	1,52120283	1,29895076	1,63588086
	19	1,68507055	1,43505655	1,87002409	1,44674732	1,23209335	1,60554247
	21	1,65682645	1,4652985	1,85244337	1,39263433	1,23164679	1,55705881
	23	1,70916406	1,48847725	1,84649734	1,24566525	1,08482529	1,34575587
	25	1,67451186	1,42228036	1,83820238	1,71421087	1,45599952	1,88178214
	27	1,65011583	1,43828015	1,83024287	1,23463236	1,07613489	1,36940512
	29	1,80760549	1,6115977	2,01044116	1,09112014	0,97280447	1,2135573
	31	1,69957156	1,47746441	1,92859784	1,49934239	1,30340203	1,70138673
	33	1,63587918	1,44469567	1,7938795	1,58197225	1,39708879	1,73476601
	35	1,64961619	1,41222385	1,73235146	1,22861489	1,05180785	1,29023515
	37	1,48735545	1,33094721	1,65930668	1,10141264	0,98558961	1,22874552
	39	1,65807879	1,48995821	1,83167067	1,12323003	1,00934034	1,24082614
	41	1,75253513	1,57431907	1,95134712	1,01922905	0,9155832	1,13485295
	43	1,5728567	1,40832347	1,77501459	0,99104323	0,88737228	1,11842115
	45	1,77009484	1,52101884	2,00120616	1,26774393	1,08935541	1,43326611
ROV	1	2,26859965	2,35895089	3,08003291	1,14355393	1,18909811	1,55258057
	2	2,89063973	3,03986165	3,76215405	0,82693954	0,86962819	1,07625793

	3	2,50389969	2,55426911	3,19754846	0,93769417	0,95655719	1,19746113
	4	2,32401943	2,28702041	3,10503197	0,90743514	0,89298853	1,2123888
	5	2,47437955	2,4793356	3,13924745	1,3923821	1,39517097	1,76651636
	6	1,65777717	1,62797378	2,43398126	1,45231348	1,42620391	2,13231541
	7	1,28081519	1,32622257	2,06260112	1,06048804	1,0980844	1,70779036
	8	1,1344679	1,12722984	1,80367051	1,06880259	1,06198348	1,69927038
	9	1,12102674	1,10235453	1,84564966	1,26010973	1,2391209	2,0746348
	10	1,16624223	1,18503795	1,83968157	1,10878808	1,12665784	1,74905087
	11	1,16009204	1,16601924	1,90402481	1,16320132	1,1691444	1,90912798
	12	1,07925353	1,13071194	1,82133387	1,0374276	1,08689176	1,75074897

Table A.3.2. The enrichment factors for chromium and copper down the sediment column using aluminum, lithium, and rubidium as normalization elements.

		Chromium			Copper		
		Enrichment Factor			Enrichment Factor		
	Depth (cm)	Aluminum	Lithium	Rubidium	Aluminum	Lithium	Rubidium
Loc. 1	1	1,04186999	0,98826643	1,2358231	1,17705676	1,11649792	1,39617606
	5	1,07259518	1,03464439	1,30103904	1,25535986	1,21094245	1,52272937
Loc. 2	1	1,12210148	1,04941587	1,38119632	1,45220664	1,35813804	1,78752325
	5	1,13790764	1,11817324	1,61973525	1,51765012	1,49132996	2,16027322
Loc. 3	1	1,23187872	1,10632065	1,38686525	2,03910617	1,83127221	2,29565251
	3	1,18359154	1,10373805	1,41948944	1,91665375	1,78734268	2,29865596
	5	1,27413813	1,12554504	1,47382242	2,00819062	1,77399053	2,32291639
	7	1,28837591	1,14188017	1,44603058	2,00160885	1,77401443	2,24653968
	9	1,28721439	1,17484735	1,67243877	1,71763867	1,56769786	2,23167603
	11	1,2742379	1,24544611	1,75169956	1,59996304	1,5638114	2,19947512
	13	1,20379813	1,29701214	1,80740246	1,43401959	1,54506039	2,15306078
	15	1,25117101	1,27566022	1,86855689	1,44799424	1,47633587	2,16250184
	17	1,27221923	1,25038141	1,97662987	1,37135325	1,34781379	2,13065306
	19	1,26264138	1,18717375	1,89991155	1,39469783	1,31133724	2,09861848
	21	1,25208489	1,20637364	1,92171802	1,53607306	1,47999394	2,35758717
Loc. 4	1	1,2430923	1,0971688	1,33319787	2,21463089	1,9546609	2,37515847
	5	1,22789586	1,07024424	1,33972293	2,32472539	2,02624998	2,53644304
	7	1,26834851	1,12544026	1,37559486	2,22028721	1,97012145	2,40802558
	9	1,24523029	1,10948548	1,36901364	2,2637267	2,01695376	2,48875471
	11	1,24904677	1,10005856	1,432959	2,12660266	1,87293825	2,43972804
	13	1,23511128	1,11807607	1,42035486	2,03718671	1,84414939	2,34272659
	15	1,25563653	1,10387018	1,45680355	2,15471221	1,89427632	2,49992121
	17	1,25606799	1,1408553	1,46443599	2,06736014	1,87773178	2,41031268
	19	1,20763595	1,08812091	1,46849717	2,01807799	1,81835665	2,45400264
	21	1,26764257	1,14527838	1,52580614	1,93978125	1,75253623	2,33483019
	23	1,24393394	1,16223498	1,61656328	1,72588709	1,61253446	2,24288896
	25	1,29172918	1,1804087	1,73255286	1,75585196	1,60453365	2,35506514
	27	1,27142373	1,18444307	1,75133722	1,65117371	1,53821358	2,27442818

	31	1,26663147	1,21889444	1,76595568	1,57157849	1,51234857	2,19111718
	37	1,2373578	1,19394006	1,76284927	1,64924222	1,59137184	2,34965621
	43	1,24521471	1,20384909	1,73090203	1,85757725	1,79586915	2,58211231
	49	1,25319715	1,21586897	1,80333089	1,54783186	1,50172759	2,22730558
	55	1,23072002	1,21282125	1,86586823	2,27873968	2,24559921	3,45474834
	61	1,22220497	1,24996847	2,00018031	1,39542655	1,42712493	2,28366336
	67	1,22409507	1,29125178	1,96224274	1,48298088	1,56434067	2,37724057
	73	1,25943334	1,26343543	1,9892727	1,4762717	1,48096284	2,33176851
	79	1,23520054	1,25040813	2,09920033	1,48351329	1,50177807	2,52120324
	84,5	1,21044169	1,2636255	2,02255417	1,54821096	1,61623551	2,58694042
	89,5	1,20046219	1,28496921	2,04126793	1,50303037	1,6088368	2,55575538
	94,5	1,2227486	1,21422145	1,92298972	1,3969391	1,38719719	2,19693527
	99,5	1,18475666	1,856253	3,14798472	1,18553987	1,85748011	3,15006576
	104,5	1,1853653	1,19450775	1,91061202	1,52127332	1,53300655	2,45203996
	109,5	1,20314645	1,13254818	1,71305496	1,69950491	1,59978131	2,41977634
	114,5	1,1761032	1,14513108	1,71126448	2,07689828	2,02220415	3,02194762
	119,5	1,09083402	1,28325028	2,14656672	0,89514489	1,05304281	1,76148542
	124,5	1,10168864	1,01266855	1,48061289	1,04570466	0,96120826	1,4053733
	129,5	0,93760625	0,96434896	0,98425488	0,840119	0,86408115	0,88191735
	134,5	0,97856802	0,9911556	0,99405518	0,94239471	0,95451698	0,95730938
	139,5	0,95250242	0,96654096	0,96767949	0,93308622	0,94683859	0,94795391
	144,5	0,96850535	0,95180439	0,93922522	0,95637571	0,93988392	0,92746229
	149,5	0,97015814	0,97053742	0,97261084	0,96410648	0,9644834	0,96654388
	154,5	0,93077597	0,94531935	0,95783464	0,90695894	0,92113018	0,93332522
	159,5	0,9623207	0,94839078	0,93539745	0,9705361	0,95648725	0,943383
	164,5	0,99007109	1,02559562	0,99940273	0,91249045	0,94523132	0,92109087
	169,5	1	1	1	1	1	1
	174,5	0,99103643	0,99701004	1,00708759	0,90810217	0,91357588	0,92281009
	179,5	1,00418664	1,00124825	1,0276284	1,04108219	1,03803583	1,06538523
	184,5	1,0812434	1,12109862	1,11904541	1,00793849	1,04509165	1,04317765
Loc. 5	1	1,07382616	1,00252561	1,2125893	1,04545037	0,97603393	1,1805467
	3	1,13886169	1,00064806	1,2675429	2,04717597	1,79872823	2,2784886
	5	1,19830102	1,07364585	1,34462118	2,26610694	2,03037158	2,542813
	7	1,19811893	1,036269	1,31028063	2,2423516	1,93943973	2,45226896
	9	1,17269137	1,02937621	1,26308496	2,28478337	2,00555893	2,46089943
	11	1,23479569	1,04927407	1,31023657	2,43089185	2,06566302	2,57940922
	13	1,2183927	1,06560069	1,35826568	2,2188661	1,94061015	2,47359465
	15	1,20333882	1,05460003	1,35033946	2,30918359	2,02375677	2,59127495
	17	1,23495729	1,05452651	1,3280563	2,3256575	1,98587231	2,50098049
	19	1,24369768	1,05917019	1,38020608	2,39410374	2,03889045	2,65688085
	21	1,20785588	1,0682286	1,35046408	2,16427968	1,9140905	2,4198102
	23	1,22255089	1,06469545	1,32078425	2,27339217	1,97985238	2,45606182
	25	1,21064253	1,02828361	1,32898789	2,3974899	2,03635632	2,63185455
	27	1,2381731	1,07922108	1,37333237	2,26320678	1,97266479	2,51025897
	29	1,22617677	1,09321623	1,36376895	2,18547556	1,9484934	2,43071291

	31	1,21085791	1,05261791	1,37402744	2,33002437	2,02552699	2,64400751
	33	1,21378044	1,07192717	1,33101263	2,2164158	1,95738558	2,43048687
	35	1,24538951	1,06616847	1,30785109	2,30345608	1,9719712	2,4189842
	37	1,17623092	1,0525401	1,31221344	2,11688964	1,89428045	2,36162049
	39	1,20219843	1,08030175	1,3280621	2,18680019	1,96507001	2,41574634
	41	1,21759083	1,09377349	1,35571739	2,1908434	1,96805558	2,43937817
	43	1,19634416	1,07119712	1,35010923	2,19685798	1,96704929	2,47921822
	45	1,23767069	1,06351388	1,39926638	2,28932819	1,96718911	2,58823288
ROV	1	1,02593971	1,06679968	1,39289807	1,61036178	1,67449746	2,18635637
	2	0,94740311	0,99631039	1,23304071	1,20084201	1,26283242	1,56289024
	3	0,9757613	0,99539009	1,24607389	1,30356534	1,32978836	1,66468862
	4	0,97843092	0,96285403	1,30724349	1,34484538	1,32343508	1,79679561
	5	1,00778309	1,00980163	1,27857527	1,55257006	1,55567978	1,96974697
	6	1,10557101	1,08569514	1,62322125	1,66966419	1,6396471	2,45143403
	7	1,1106034	1,14997644	1,7884952	1,48968444	1,54249665	2,39896031
	8	1,15484319	1,14747513	1,83606481	1,49543918	1,48589807	2,37757237
	9	1,14096488	1,12196057	1,87847565	1,49142281	1,46658116	2,45546686
	10	1,16019421	1,17889245	1,83014114	1,54506139	1,56996234	2,43724749
	11	1,13496062	1,14075941	1,86277734	1,55453238	1,56247488	2,55140809
	12	1,12233094	1,17584326	1,89403073	1,41053097	1,47778456	2,38039325

Table A.3.3. The enrichment factors for lead and mercury down the sediment column using aluminum, lithium, and rubidium as normalization elements.

		Lead			Mercury		
		Enrichment Factor			Enrichment Factor		
	Depth (cm)	Aluminum	Lithium	Rubidium	Aluminum	Lithium	Rubidium
Loc. 1	1	2,44678986	2,32090404	2,90228095	7,73154305	7,33375995	9,17083666
	5	2,5140321	2,42508009	3,04947661	7,10659586	6,85514879	8,62017547
Loc. 2	1	2,56669565	2,40043455	3,15934938	6,76114585	6,32318369	8,32230418
	5	1,73556243	1,70546308	2,47045678	4,06352582	3,99305328	5,78415663
Loc. 3	1	1,37082986	1,23110933	1,54329826	2,35368692	2,11378962	2,64981166
	3	1,23702089	1,15356268	1,48356763	2,2517548	2,09983543	2,70054494
	5	1,2778929	1,12886192	1,47816564	2,0984558	1,85372877	2,42732803
	7	1,28829715	1,14181036	1,44594218	1,8198482	1,612921	2,04253753
	9	1,18295513	1,07968937	1,53697786	1,79112119	1,63476574	2,32714965
	11	1,11994409	1,09463861	1,53959128	1,47234839	1,43908024	2,02404279
	13	1,12441124	1,21147806	1,68820967	1,34253528	1,44649215	2,01570472
	15	1,13268203	1,15485205	1,69159995	1,41571818	1,44342808	2,11429928
	17	1,07852401	1,060011	1,67568822	1,21086189	1,19007728	1,8812998
	19	1,11417723	1,04758326	1,67651578	1,50773804	1,41762108	2,26871143
	21	1,27831183	1,23164308	1,96197149	1,75102977	1,68710298	2,68750583
Loc. 4	1	1,40982479	1,24432898	1,51201597	2,14942073	1,8971056	2,30522155
	5	1,4582806	1,27104949	1,59108929	2,22684286	1,94093475	2,42964614
	7	1,39904656	1,2414122	1,51734419	2,29255937	2,03425051	2,48640878

	9	1,38984826	1,23833839	1,52800751	2,38668558	2,12650867	2,62393644
	11	1,35494959	1,19332913	1,55445517	2,12620586	1,87258878	2,43927282
	13	1,30226139	1,17886325	1,49757622	2,00638514	1,81626648	2,30730536
	15	1,30669377	1,14875622	1,51604073	2,07530917	1,82447057	2,40779692
	17	1,28170499	1,16414075	1,49432589	2,82171694	2,56289528	3,28980905
	19	1,28741136	1,16000126	1,56550485	1,99738924	1,79971539	2,42884492
	21	1,25577358	1,13455509	1,51151995	1,93614863	1,74925427	2,33045777
	23	1,17694105	1,09964204	1,52950219	1,68328311	1,57272862	2,18752265
	25	1,20928371	1,10506833	1,62197153	1,69880929	1,55240688	2,27855572
	27	1,1869545	1,10575255	1,6349841	1,64383822	1,53137993	2,26432382
	31	1,18113545	1,13662061	1,64675591	1,67876389	1,61549434	2,34055659
	37	1,21928682	1,17650317	1,73710375	1,7273102	1,66670049	2,46087876
	43	1,24651364	1,20510487	1,73270759	1,95507455	1,89012763	2,71763776
	49	1,15552042	1,12110168	1,66277563	1,74046381	1,68862174	2,50449992
	55	1,12993307	1,11350007	1,71306728	1,73508916	1,70985517	2,63053145
	61	1,13887954	1,16475022	1,86381539	1,43772073	1,47037986	2,35287923
	67	1,15875585	1,2223279	1,85750298	1,44356762	1,52276511	2,31406052
	73	1,22029264	1,22417036	1,92745004	1,46052937	1,46517049	2,30690353
	79	1,14868609	1,16282853	1,95217064	1,23064291	1,24579439	2,09145473
	84,5	1,2141538	1,26750071	2,02875682	1,39438547	1,45565132	2,32990996
	89,5	1,1674444	1,24962712	1,98512443	1,50040062	1,60602192	2,55128374
	94,5	1,18013493	1,17190496	1,85597215	1,41805014	1,40816101	2,23013614
	99,5	1,13290629	1,77501487	3,01021451	1,78918761	2,80326329	4,75400175
	104,5	1,27969983	1,28956986	2,06266361	3,37023286	3,39622669	5,43225569
	109,5	1,52216611	1,43284839	2,16727914	2,54382095	2,39455454	3,62192408
	114,5	1,4829401	1,44388759	2,15772114	2,87258194	2,79693387	4,17969059
	119,5	1,06146554	1,24870139	2,08877479	1,55120159	1,82482378	3,05248794
	124,5	1,43691148	1,32080427	1,93113516	2,78758324	2,56233728	3,74636855
	129,5	1,2351311	1,27035992	1,29658245	1,79829017	1,8495816	1,88776032
	134,5	1,01405487	1,02709892	1,03010365	1,08539157	1,09935325	1,10256935
	139,5	1,01032918	1,02522	1,02642765	1,24726789	1,26565086	1,26714173
	144,5	1,0379399	1,0200416	1,0065606	1,04193749	1,02397027	1,01043734
	149,5	1,03737132	1,03777688	1,03999395	0,96937428	0,96975326	0,97182501
	154,5	0,98326236	0,99862584	1,01184686	1,06402448	1,08064987	1,09495683
	159,5	1,01414591	0,9994658	0,98577272	1,12255719	1,10630778	1,09115093
	164,5	0,98230445	1,0175503	0,99156289	1,11665363	1,15672004	1,12717835
	169,5	1	1	1	1	1	1
	174,5	1,02195291	1,02811287	1,0385048	1,03731306	1,04356561	1,05411373
	179,5	1,04515248	1,0420942	1,06955053	0,99591526	0,99300107	1,01916393
	184,5	0,91328531	0,9469495	0,94521523	0,90109062	0,93430531	0,9325942
Loc. 5	1	2,13130861	1,9897927	2,40672289	5,54489696	5,17672356	6,26142568
	3	1,55847255	1,36933444	1,73456605	2,49331383	2,19072226	2,77503607
	5	1,4154623	1,26821659	1,58829924	2,1320251	1,91023781	2,39235891
	7	1,40444987	1,21472738	1,53592721	2,24502673	1,94175348	2,45519452
	9	1,37340317	1,20555893	1,47926806	2,48415973	2,18056941	2,67564415

	11	1,42691623	1,2125295	1,51409487	2,35693354	2,00281656	2,50093237
	13	1,45690606	1,27420338	1,62416066	2,37749938	2,07935009	2,65043922
	15	1,37243684	1,20279667	1,54009461	2,24534003	1,96780459	2,51963221
	17	1,36861924	1,16866007	1,47179454	2,52848794	2,15906865	2,71910159
	19	1,38690161	1,18112695	1,53912809	2,31480365	1,97135611	2,56887676
	21	1,35663566	1,19980954	1,51680988	2,17356797	1,92230506	2,43019512
	23	1,40641416	1,22481834	1,51942114	2,32104603	2,02135319	2,50754472
	25	1,40701484	1,19507639	1,54455642	2,1393589	1,81710755	2,34849016
	27	1,35198071	1,1784185	1,49956324	2,18805688	1,90716235	2,42690569
	29	1,36109253	1,21350239	1,51382392	2,13821671	1,90635907	2,37815104
	31	1,37164888	1,19239604	1,55648584	2,07811251	1,80653604	2,35814919
	33	1,34980332	1,1920532	1,48017319	2,0880411	1,84401389	2,28971318
	35	1,39575891	1,19489857	1,46576216	2,36950761	2,0285174	2,48834849
	37	1,29325577	1,15725878	1,44276739	2,03756296	1,82329566	2,27312296
	39	1,37064007	1,23166429	1,51413868	2,25245725	2,02406979	2,48827734
	41	1,32472104	1,19000958	1,47500072	2,17726655	1,95585936	2,42426113
	43	1,38376419	1,23901153	1,56161819	2,09237987	1,87350042	2,36131163
	45	1,40220998	1,20490029	1,58528864	2,58619506	2,22228284	2,92385998
ROV	1	2,00233758	2,08208444	2,71853417	5,58126793	5,8035524	7,57757718
	2	2,23115655	2,34633433	2,90383978	5,53404484	5,81972583	7,2025334
	3	2,191122	2,23519947	2,79812279	4,63797478	4,73127408	5,92282077
	4	3,51051851	3,4546301	4,69026724	4,6025327	4,52925912	6,14926492
	5	5,000685	5,01070111	6,34437334	4,47018457	4,47913811	5,67132699
	6	1,82011759	1,78739567	2,67233269	3,16536224	3,10845562	4,64744753
	7	1,29654468	1,3425097	2,0879316	1,52346857	1,57747849	2,45336565
	8	1,31032797	1,3019679	2,08326733	1,73341657	1,72235714	2,75592843
	9	1,2075841	1,18747015	1,98815701	0,9208295	0,90549184	1,51604649
	10	1,12004444	1,13809562	1,76680715	0,79468536	0,80749289	1,25357149
	11	1,15406213	1,15995852	1,89412809	0,91665035	0,92133375	1,50447116
	12	1,09189178	1,14395278	1,84266201	0,48962535	0,51297051	0,82628522

Table A.3.4. The enrichment factors for nickel and zinc down the sediment column using aluminum, lithium, and rubidium as normalization elements.

		Nickel			Zinc		
		Enrichment Factor			Enrichment Factor		
	Depth (cm)	Aluminum	Lithium	Rubidium	Aluminum	Lithium	Rubidium
Loc. 1	1	0,94620212	0,89752061	1,12234583	1,36681234	1,29649069	1,62125628
	5	0,909733	0,87754464	1,10349009	1,29886352	1,25290685	1,57549854
Loc. 2	1	0,95476781	0,89292147	1,17522508	1,34998491	1,26253786	1,66169838
	5	0,99112938	0,97394051	1,41080624	1,13235724	1,1127191	1,61183463
Loc. 3	1	1,23242788	1,10681384	1,3874835	1,26731432	1,13814451	1,42675911
	3	1,20392435	1,12269906	1,44387471	1,20817458	1,12666255	1,44897205
	5	1,2765149	1,12764462	1,47657168	1,29527825	1,14421974	1,49827563
	7	1,23833322	1,09752762	1,38986432	1,27485867	1,12989991	1,43085927

	9	1,17183342	1,06953853	1,52252776	1,20301377	1,097997	1,56303945
	11	1,11383164	1,08866428	1,53118848	1,18291155	1,1561833	1,62615288
	13	0,96085019	1,03525195	1,4426364	1,02660611	1,10609956	1,54136343
	15	1,06732879	1,08821965	1,59399839	1,06110493	1,08187397	1,58470339
	17	1,09667735	1,07785273	1,70389281	1,03506811	1,01730103	1,60817137
	19	1,0776027	1,01319477	1,62148164	1,09580584	1,03030992	1,64887213
	21	1,05729828	1,01869832	1,62275671	1,12838138	1,08718631	1,73185607
Loc. 4	1	1,20788073	1,06609062	1,29543399	1,35224336	1,19350689	1,45026075
	5	1,28937943	1,12383383	1,40680594	1,41125212	1,23005908	1,53977783
	7	1,22725139	1,08897366	1,33102273	1,32199822	1,17304511	1,43378096
	9	1,279155	1,139712	1,40631068	1,36300216	1,21441883	1,49849275
	11	1,23560882	1,08822351	1,41754242	1,34834555	1,18751283	1,54687874
	13	1,17653424	1,0650496	1,35299235	1,25663835	1,13756331	1,44511059
	15	1,19035839	1,04648208	1,38106712	1,35629679	1,19236382	1,5735907
	17	1,162702	1,0560533	1,3555816	1,30213236	1,18269443	1,51814194
	19	1,1896693	1,07193235	1,44664954	1,32227698	1,19141637	1,60790179
	21	1,14262174	1,03232568	1,37532402	1,27737122	1,15406794	1,5375161
	23	1,14690296	1,07157679	1,49046598	1,17871293	1,10129754	1,53180485
	25	1,1341225	1,03638448	1,52116034	1,2349116	1,12848763	1,65634536
	27	1,11850518	1,04198598	1,5406978	1,18589134	1,10476212	1,63351964
	31	1,07051716	1,03017132	1,49253032	1,16307768	1,11924341	1,62157951
	37	1,06642271	1,02900292	1,51932003	1,16580937	1,1249022	1,66091505
	43	1,07341184	1,03775346	1,49208865	1,19028581	1,15074491	1,65454849
	49	1,03208425	1,00134222	1,48515293	1,11426594	1,08107602	1,60341108
	55	1,02582591	1,01090698	1,55523265	1,10109925	1,0850856	1,66935296
	61	0,95392171	0,9755909	1,56112555	1,03443548	1,05793362	1,69288911
	67	0,93900269	0,99051857	1,50523538	1,06081027	1,11900879	1,70049475
	73	1,02089023	1,0241343	1,61249429	1,03696496	1,04026012	1,6378843
	79	0,91795549	0,92925721	1,56004828	1,05273528	1,0656964	1,78910403
	84,5	0,95444174	0,99637754	1,5947981	1,02057014	1,06541146	1,70529354
	89,5	0,89980766	0,96314998	1,53003446	0,99318945	1,06310542	1,68882101
	94,5	0,90616869	0,89984929	1,42511148	1,05116662	1,04383604	1,65314653
	99,5	0,67866004	1,06331095	1,80324913	0,7322645	1,14729735	1,9456801
	104,5	0,95637176	0,96374804	1,54151246	1,0765318	1,08483484	1,73519049
	109,5	0,99949981	0,94085113	1,42310033	1,12918104	1,06292292	1,60774209
	114,5	1,09221952	1,06345644	1,58921128	1,19708006	1,16555553	1,74178643
	119,5	0,75382798	0,88679849	1,48339897	0,89116623	1,04836235	1,75365614
	124,5	0,9091352	0,83567407	1,22183097	1,0684627	0,98212737	1,43595893
	129,5	0,87634869	0,9013442	0,91994958	0,98420102	1,01227273	1,03316787
	134,5	0,91932402	0,93114953	0,93387356	0,98441625	0,99707906	0,99999597
	139,5	0,92089691	0,93446963	0,93557038	1,00680307	1,02164193	1,02284536
	144,5	0,96302459	0,94641814	0,93391015	0,9808164	0,96390315	0,95116408
	149,5	0,99214977	0,99253765	0,99465808	0,98129734	0,98168097	0,9837782
	154,5	0,93126768	0,94581874	0,95834064	0,96630965	0,98140825	0,99440132
	159,5	0,95240833	0,93862189	0,9257624	1,00407459	0,98954026	0,97598316

	164,5	1,02828517	1,06518085	1,03797699	0,99713437	1,03291233	1,00653259
	169,5	1	1	1	1	1	1
	174,5	0,97795525	0,98385001	0,99379454	1,02875363	1,03495459	1,04541567
	179,5	1,02489004	1,02189106	1,0488151	0,99510151	0,99218969	1,01833118
	184,5	1,09620577	1,13661251	1,13453089	0,99828991	1,03508742	1,03319174
Loc. 5	1	0,91083273	0,85035471	1,02853335	1,18603834	1,10728705	1,33930187
	3	1,12526941	0,98870536	1,25241482	1,26333457	1,11001477	1,40608011
	5	1,22058226	1,09360926	1,36962312	1,31536072	1,17852824	1,47597462
	7	1,23121226	1,06489186	1,34647199	1,31564888	1,13792222	1,43881312
	9	1,28224819	1,12554404	1,38108666	1,34112034	1,1772214	1,4444968
	11	1,33615374	1,1354036	1,41778717	1,42300927	1,20920954	1,50994921
	13	1,2696	1,11038635	1,41535163	1,37728612	1,20456814	1,53540025
	15	1,31880003	1,15578965	1,4799055	1,40186339	1,22858595	1,57311593
	17	1,30221193	1,11195505	1,40038102	1,33867636	1,14309193	1,43959438
	19	1,3206529	1,12470756	1,46560791	1,4184944	1,20803231	1,57418851
	21	1,28123231	1,13312277	1,43250386	1,31747478	1,16517564	1,47302538
	23	1,31954465	1,14916539	1,42557156	1,36219681	1,18631032	1,47165087
	25	1,37679987	1,16941269	1,51138781	1,38099188	1,17297326	1,5159896
	27	1,28257148	1,11791977	1,42257729	1,32073498	1,15118398	1,46490673
	29	1,27469292	1,13647152	1,4177292	1,34623128	1,20025262	1,49729506
	31	1,34551933	1,16968121	1,5268352	1,34770598	1,1715821	1,52931651
	33	1,30780284	1,15496128	1,43411613	1,3720673	1,21171522	1,50458753
	35	1,36046519	1,16468388	1,42869831	1,4177624	1,21373559	1,48886921
	37	1,2169565	1,08898304	1,35764725	1,26456493	1,13158503	1,41075963
	39	1,31549829	1,1821136	1,45322385	1,31410443	1,18086107	1,45168405
	41	1,28762585	1,15668661	1,43369736	1,31018641	1,17695299	1,45881725
	43	1,31618061	1,17849772	1,48534815	1,32214164	1,18383519	1,49207535
	45	1,36234484	1,17064471	1,54021854	1,35513492	1,16444932	1,53206725
ROV	1	0,97788738	1,01683358	1,32765837	1,30659498	1,35863257	1,77393818
	2	0,97248297	1,02268493	1,26568202	1,3182391	1,38628984	1,71568201
	3	0,96065278	0,97997765	1,22677991	1,36599343	1,39347228	1,74441101
	4	0,97748873	0,96192684	1,30598467	4,67556385	4,6011276	6,246839
	5	1,00838561	1,01040535	1,27933968	8,40993826	8,42678292	10,6696959
	6	1,06506862	1,04592091	1,56375484	1,72480064	1,69379231	2,53238646
	7	1,07240236	1,1104211	1,72697695	1,17515964	1,21682133	1,89245538
	8	1,10759877	1,10053214	1,76095175	1,15678966	1,14940918	1,83915947
	9	1,08113958	1,06313175	1,77997976	1,15756535	1,13828454	1,90580655
	10	1,05930569	1,07637797	1,67099518	1,14223392	1,16064271	1,80180981
	11	1,0868221	1,09237495	1,78376903	1,09824026	1,10385145	1,80250931
	12	1,02152699	1,07023302	1,72391532	1,12730878	1,18105845	1,90243127

Appendix B

B.1 T-test – sediment

B.1.1 Arsenic

Table B.1.1. The arsenic concentrations at the locations constituting variable 1 and 2.

Dumping site	*Variable 1*	Locations for comparison	*Variable 2*
	µg/g		µg/g
Loc. 1	5,162833	The Korsfjord	5,623697
Loc. 2	2,802435	Byelva 5000 m	10,01242
Loc. 3	7,408378	Verdalselva 5000 m	9,243121
Loc. 4	7,537683	Orkla 5000 m	40,24223
Loc. 5	4,507725	Gaula 5000 m	18,78417
ROV	5,987846	Nidelva 5000 m	17,62039
		Stjørdalselva 5000 m	11,5877

Table B.1.2. The t-test of arsenic.

t-Test: Two-Sample Assuming Unequal Variances		
	Variable 1	*Variable 2*
Mean	5,567816	16,1591
Variance	3,275921	134,4214
Observations	6	7
Hypothesized Mean Difference	0	
df	6	
t-Stat	-2,38328	
P(T<=t) one-tail	0,027262	
T-critical, one-tail	1,94318	
P(T<=t) two-tail	0,054523	
T-critical, two-tail	2,446912	

B.1.2 Cadmium

Table B.1.3. The cadmium concentrations at the locations constituting variable 1 and 2.

Dumping site	*Variable 1*	Locations for comparison	*Variable 2*
	µg/g		µg/g
Loc. 1	0,08830855	The Korsfjord	0,2323707
Loc. 2	0,08285334	Byelva 5000 m	0,10292255
Loc. 3	0,10859641	Verdalselva 5000 m	0,06408213
Loc. 4	0,13193555	Orkla 5000 m	0,38847094
Loc. 5	0,05721993	Gaula 5000 m	0,0963552
ROV	0,06906127	Nidelva 5000 m	0,08418534
		Stjørdalselva 5000 m	0,07790046

Table B.1.4. The t-test of cadmium.

t-Test: Two-Sample Assuming Unequal Variances		
	Variable 1	*Variable 2*
Mean	0,08966251	0,14946962
Variance	0,00073413	0,0142762
Observations	6	7
Hypothesized Mean Difference	0	
df	7	
t-Stat	-1,28630478	
P(T<=t) one-tail	0,11962207	
T-critical, one-tail	1,89457861	
P(T<=t) two-tail	0,23924414	
T-critical, two-tail	2,36462425	

B.1.3 Chromium

Table B.1.5. The chromium concentrations at the locations constituting variable 1 and 2.

Dumping site	*Variable 1*	Locations for comparison	*Variable 2*
	µg/g		µg/g
Loc. 1	103,326702	The Korsfjord	116,130306
Loc. 2	97,4283013	Byelva 5000 m	81,6410867
Loc. 3	179,356204	Verdalselva 5000 m	107,902556
Loc. 4	193,354238	Orkla 5000 m	170,247824
Loc. 5	55,8995083	Gaula 5000 m	134,319522
ROV	91,3287823	Nidelva 5000 m	145,761542
		Stjørdalselva 5000 m	101,020685

Table B.1.6.The t-test of chromium.

t-Test: Two-Sample Assuming Unequal Variances		
	Variable 1	*Variable 2*
Mean	120,115623	122,431932
Variance	2924,46303	890,848799
Observations	6	7
Hypothesized Mean Difference	0	
df	8	
t-Stat	-0,09342731	
P(T<=t) one-tail	0,46393077	
T-critical, one-tail	1,85954804	
P(T<=t) two-tail	0,92786155	
T-critical, two-tail	2,30600414	

B.1.4 Copper

Table B.1.7. The copper concentrations at the locations constituting variable 1 and 2.

Dumping site	*Variable 1*	Locations for comparison	*Variable 2*
	µg/g		µg/g
Loc. 1	21,7078538	The Korsfjord	36,1381907
Loc. 2	23,4477869	Byelva 5000 m	24,6299042
Loc. 3	55,2088538	Verdalselva 5000 m	31,4294439
Loc. 4	64,0578142	Orkla 5000 m	335,497159
Loc. 5	10,1204045	Gaula 5000 m	49,3681882
ROV	26,6581327	Nidelva 5000 m	40,144975
		Stjørdalselva 5000 m	30,5086005

Table B.1.8. The t-test of copper.

t-Test: Two-Sample Assuming Unequal Variances		
	Variable 1	*Variable 2*
Mean	33,5334743	78,2452088
Variance	447,713191	12930,3629
Observations	6	7
Hypothesized Mean Difference	0	
df	6	
t-Stat	-1,01991949	
P(T<=t) one-tail	0,17355815	
T-critical, one-tail	1,94318028	
P(T<=t) two-tail	0,34711629	
T-critical, two-tail	2,44691185	

B.1.5 Lead

Table B.1.9. The lead concentrations at the locations constituting variable 1 and 2.

Dumping site	*Variable 1*	Locations for comparison	*Variable 2*
	µg/g		µg/g
Loc. 1	18,283754	The Korsfjord	23,318828
Loc. 2	16,7917913	Byelva 5000 m	15,2455401
Loc. 3	15,038401	Verdalselva 5000 m	16,3371265
Loc. 4	16,522856	Orkla 5000 m	52,329157
Loc. 5	8,35968671	Gaula 5000 m	18,6665413
ROV	13,4305186	Nidelva 5000 m	33,5065918
		Stjørdalselva 5000 m	15,0626637

Table B.1.10. The t-test of lead.

t-Test: Two-Sample Assuming Unequal Variances		
	Variable 1	*Variable 2*
Mean	14,7378346	24,9237783
Variance	12,4917539	188,514803
Observations	6	7
Hypothesized Mean Difference	0	
df	7	
t-Stat	-1,89107002	
P(T<=t) one-tail	0,05025857	
T-critical, one-tail	1,89457861	
P(T<=t) two-tail	0,10051714	
T-critical, two-tail	2,36462425	

B.1.6 Mercury

Table B.1.11. The mercury concentrations at the locations constituting variable 1 and 2.

Dumping site	*Variable 1*	Locations for comparison	*Variable 2*
	µg/g		µg/g
Loc. 1	0,04781826	The Korsfjord	0,05217712
Loc. 2	0,03661018	Byelva 5000 m	0,08709943
Loc. 3	0,02137104	Verdalselva 5000 m	0,0297522
Loc. 4	0,02084973	Orkla 5000 m	0,19260534
Loc. 5	0,01800098	Gaula 5000 m	0,04135765
ROV	0,0309847	Nidelva 5000 m	0,0904481
		Stjørdalselva 5000 m	0,04654293

Table B.1.12. The t-test of mercury.

t-Test: Two-Sample Assuming Unequal Variances		
	Variable 1	*Variable 2*
Mean	0,02927248	0,0771404
Variance	0,00013223	0,00311564
Observations	6	7
Hypothesized Mean Difference	0	
df	7	
t-Stat	-2,21475546	
P(T<=t) one-tail	0,03117902	
T-critical, one-tail	1,89457861	
P(T<=t) two-tail	0,06235804	
T-critical, two-tail	2,36462425	

B.1.7 Nickel

Table B.1.13. The nickel concentrations at the locations constituting variable 1 and 2.

Dumping site	*Variable 1*	Locations for comparison	*Variable 2*
	µg/g		µg/g
Loc. 1	38,711052	The Korsfjord	63,0814881
Loc. 2	34,1981634	Byelva 5000 m	33,8969856
Loc. 3	74,0221984	Verdalselva 5000 m	53,3019239
Loc. 4	77,504405	Orkla 5000 m	79,4311476
Loc. 5	19,5598108	Gaula 5000 m	69,3401321
ROV	35,9109326	Nidelva 5000 m	73,3521004
		Stjørdalselva 5000 m	45,5558248

Table B.1.14. The t-test of nickel.

t-Test: Two-Sample Assuming Unequal Variances		
	Variable 1	*Variable 2*
Mean	46,6510937	59,7085146
Variance	553,70252	264,475459
Observations	6	7
Hypothesized Mean Difference	0	
df	9	
t-Stat	-1,14492115	
P(T<=t) one-tail	0,14088757	
T-critical, one-tail	1,83311293	
P(T<=t) two-tail	0,28177513	
T-critical, two-tail	2,26215716	

B.1.8 Zinc

Table B.1.15. The zinc concentrations at the locations constituting variable 1 and 2.

Dumping site	*Variable 1*	Locations for comparison	*Variable 2*
	µg/g		µg/g
Loc. 1	73,1732887	The Korsfjord	129,433303
Loc. 2	63,2741841	Byelva 5000 m	99,3336735
Loc. 3	99,60415	Verdalselva 5000 m	117,237436
Loc. 4	113,540243	Orkla 5000 m	308,7378
Loc. 5	33,3286234	Gaula 5000 m	144,60784
ROV	62,7872488	Nidelva 5000 m	171,766895
		Stjørdalselva 5000 m	107,820813

Table B.1.16. The t-test of zinc.

t-Test: Two-Sample Assuming Unequal Variances		
	Variable 1	*Variable 2*
Mean	74,284623	154,133966
Variance	822,826096	5237,24494
Observations	6	7
Hypothesized Mean Difference	0	
df	8	
t-Stat	-2,68362794	
P(T<=t) one-tail	0,01388472	
T-critical, one-tail	1,85954804	
P(T<=t) two-tail	0,02776944	
T-critical, two-tail	2,30600414	

B.1.9 Iron

Table B.1.17. The iron concentrations at the locations constituting variable 1 and 2.

Dumping site	*Variable 1*	Locations for comparison	*Variable 2*
	µg/g		µg/g
Loc. 1	30136,3002	The Korsfjord	41251,4524
Loc. 2	26398,294	Byelva 5000 m	39246,0195
Loc. 3	47985,4889	Verdalselva 5000 m	52772,4131
Loc. 4	52213,3047	Orkla 5000 m	58194,0804
Loc. 5	16533,8724	Gaula 5000 m	46264,4565
ROV	26981,3297	Nidelva 5000 m	54196,9149
		Stjørdalselva 5000 m	41773,0294

Table B.1.18. The t-test of iron.

t-Test: Two-Sample Assuming Unequal Variances		
	Variable 1	*Variable 2*
Mean	33374,765	47671,1952
Variance	190402863	54717085,4
Observations	6	7
Hypothesized Mean Difference	0	
df	7	
t-Stat	-2,27327207	
P(T<=t) one-tail	0,02860043	
T-critical, one-tail	1,89457861	
P(T<=t) two-tail	0,05720085	
T-critical, two-tail	2,36462425	

Appendix C

C.1 ArcMaps

C.1.1 Arsenic

Figure C.1. The concentrations of arsenic (in µg/g) found in the top sediment at each sampling location outside the dumping site.

C.1.2 Cadmium

Figure C.2. The concentrations of cadmium (in µg/g) found in the top sediment at each sampling location outside the dumping site.

C.1.3 Chromium

Figure C.3. The concentrations of chromium (in µg/g) found in the top sediment at each sampling location outside the dumping site.

C.1.4 Lead

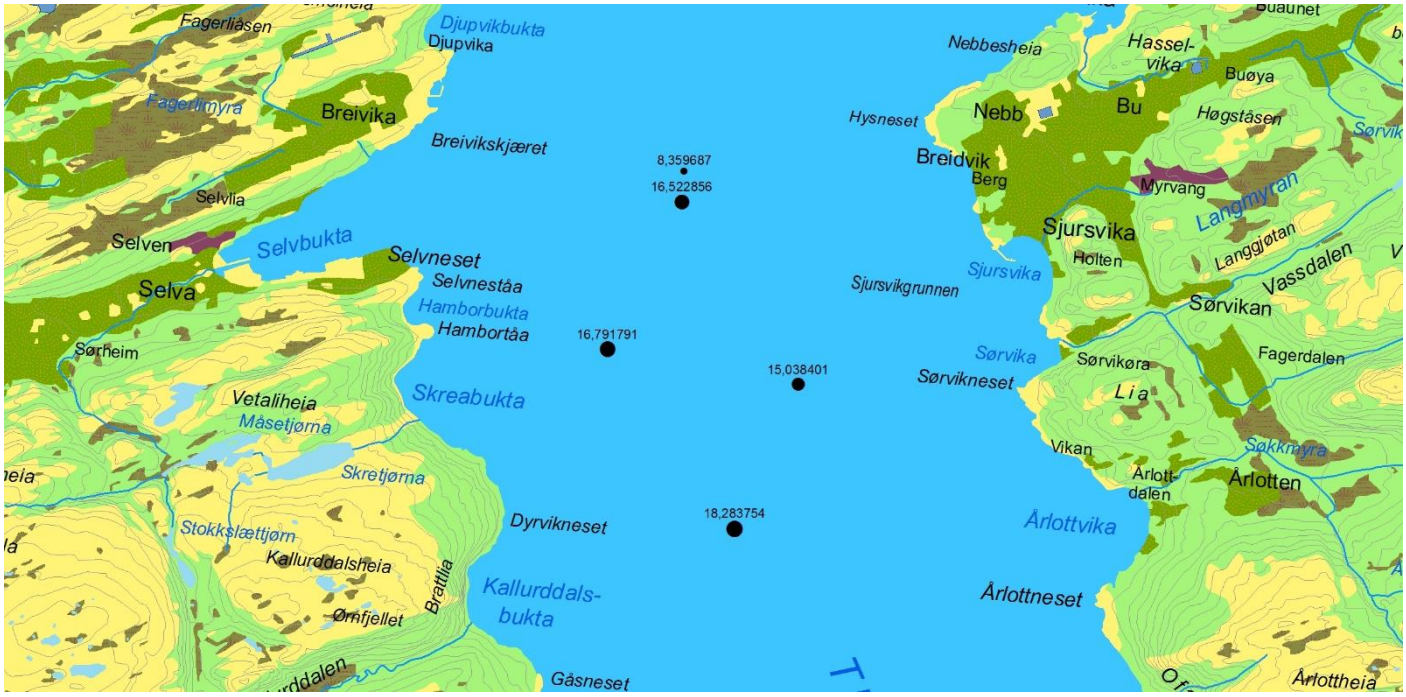

Figure C.4. The concentrations of lead (in µg/g) found in the top sediment at each sampling location outside the dumping site.

C.1.5 Mercury

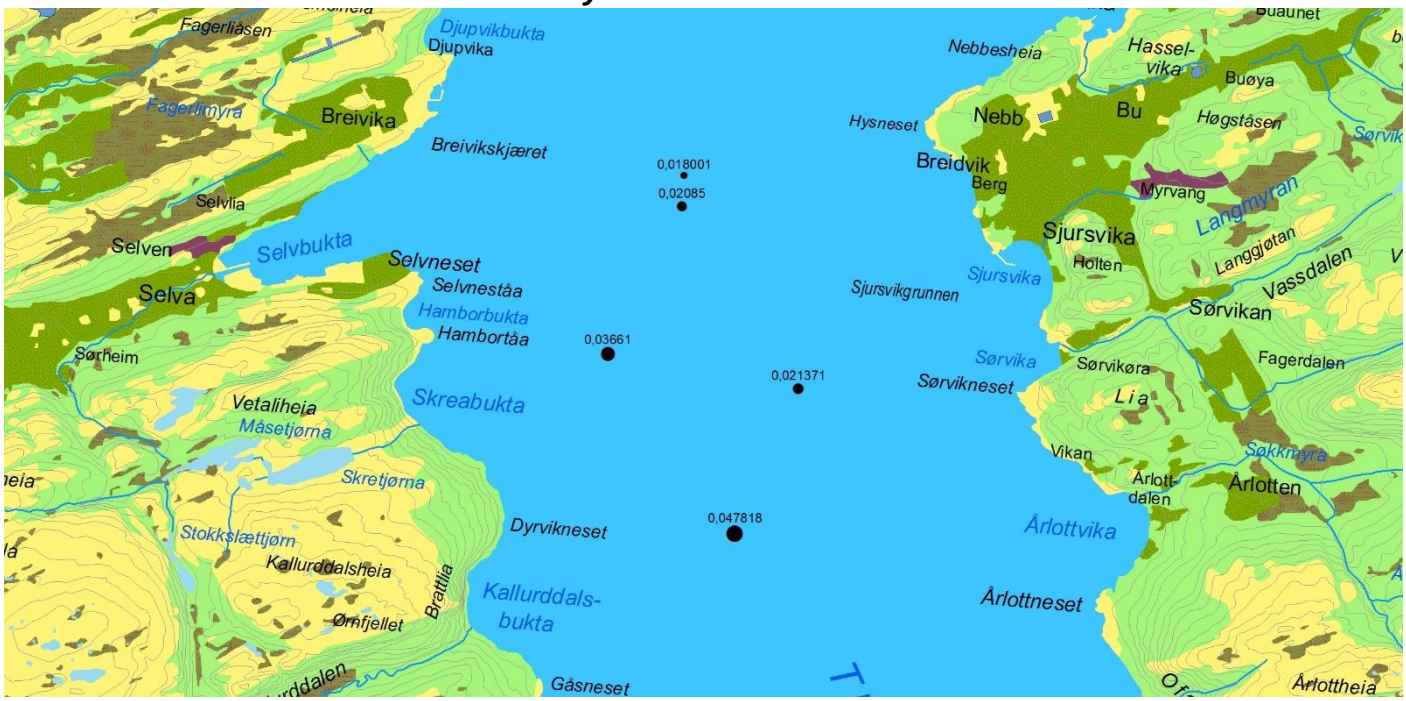

Figure C.5. The concentrations of mercury (in µg/g) found in the top sediment at each sampling location outside the dumping site.

C.1.6 Nickel

Figure C.6. The concentrations of nickel (in µg/g) found in the top sediment at each sampling location outside the dumping site.

C.1.7 Zinc

Figure C.7. The concentrations of zinc (in µg/g) found in the top sediment at each sampling location outside the dumping site.

Appendix D

D.1 GC-MS Results

D.1.1 Sample no. 5

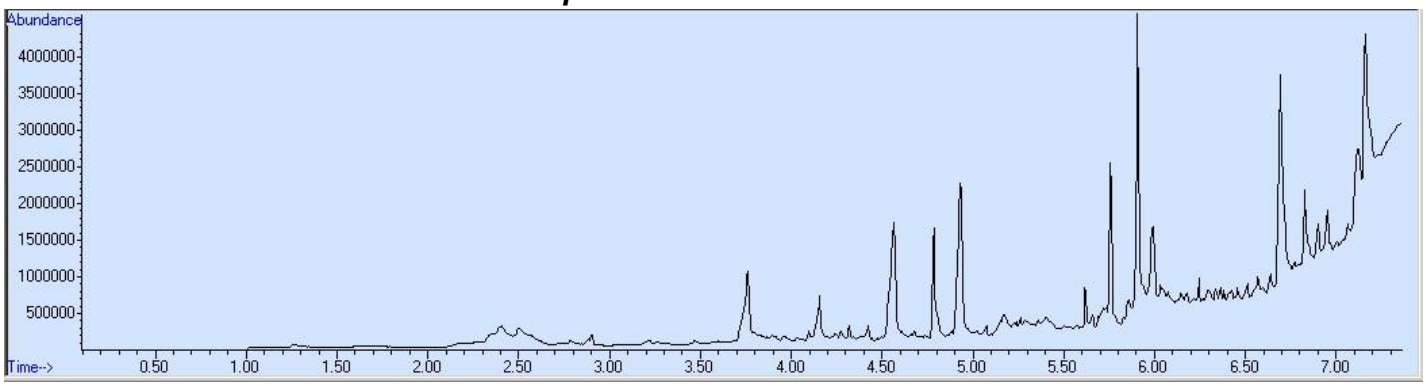

Figure D.1. The GC-MS chromatogram for a methanol extract of sediment sample no. 5. The same sample had been run beforehand on a LC-MS/MS system.

D.1.2 Sample no. 6:

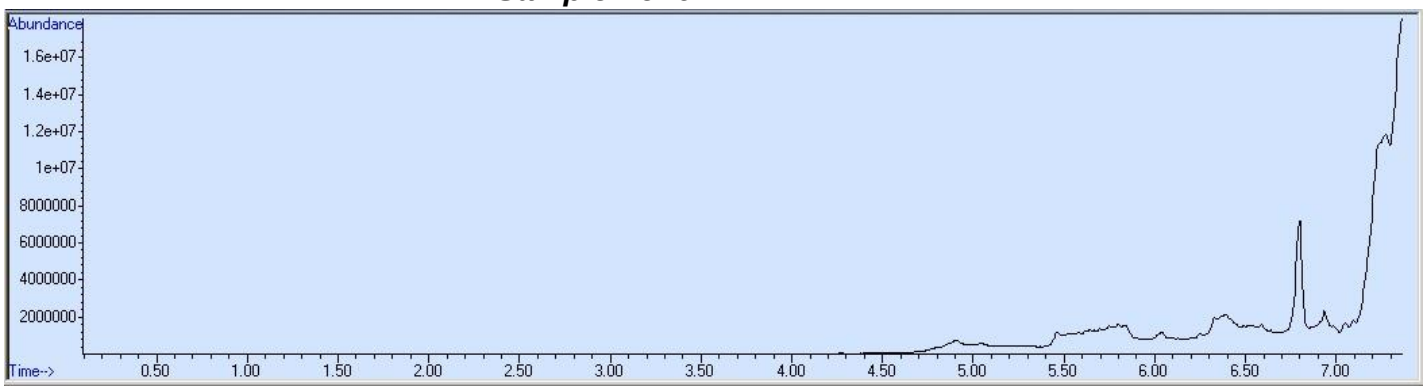

Figure D.2. The GC-MS chromatogram for sediment sample no. 6. No sample preparation was performed.

D.1.3 Sample no. 7

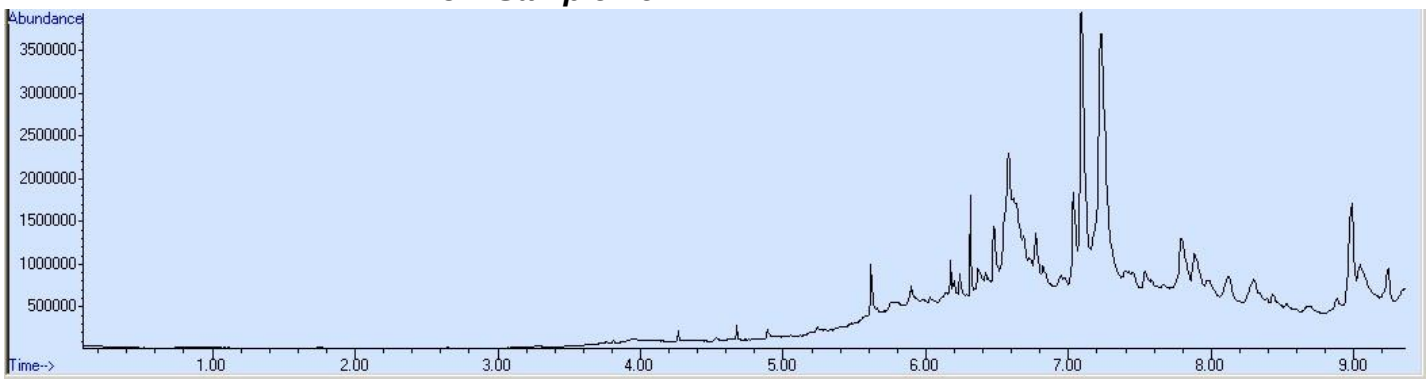

Figure D.3. The GC-MS chromatogram for sediment sample no. 7. No sample preparation was performed, but the analysis duration was extended by two minutes.

D.1.4 Sample no. 8

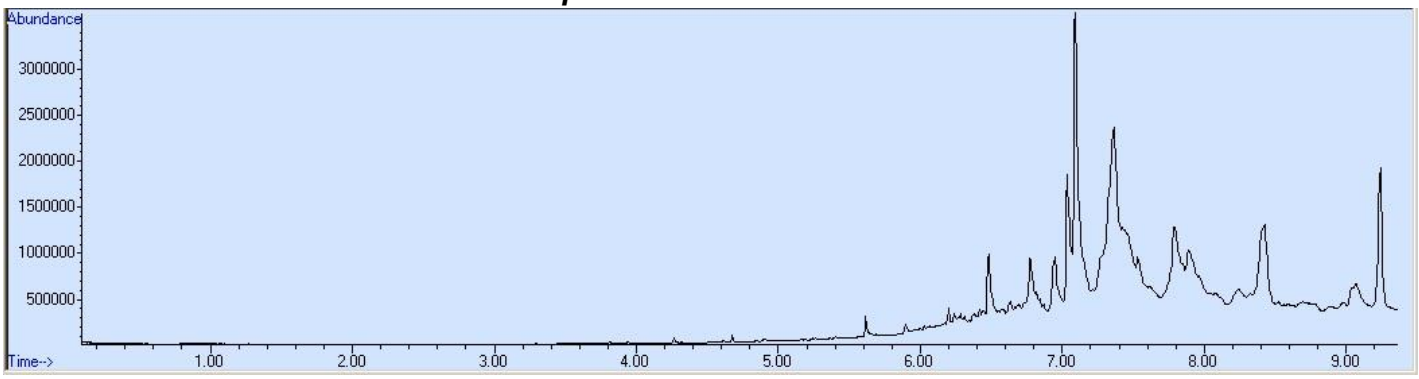

Figure D.4. The GC-MS chromatogram for sediment sample no. 8. No sample preparation was performed.

D.1.5 Sample no. 9

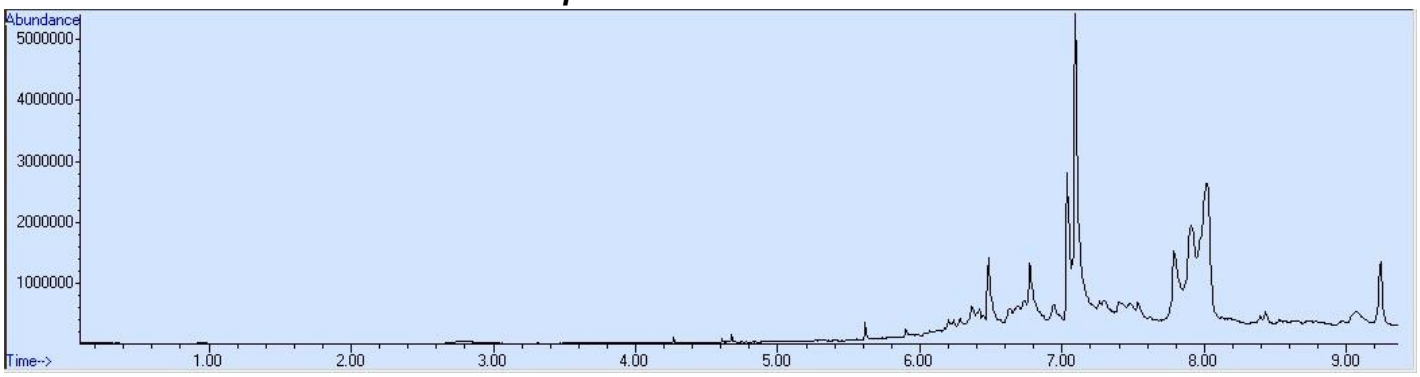

Figure D.5. The GC-MS chromatogram for sediment sample no. 9. No sample preparation was performed.

D.1.6 Sample no. 10

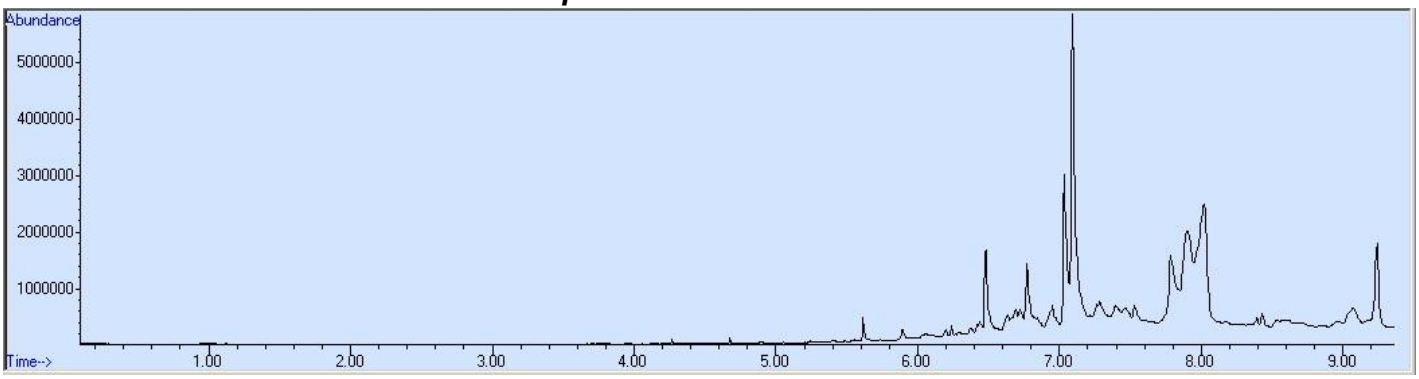

Figure D.6. The GC-MS chromatogram for sediment sample no. 10. No sample preparation was performed.

D.1.7 Sample no. 16

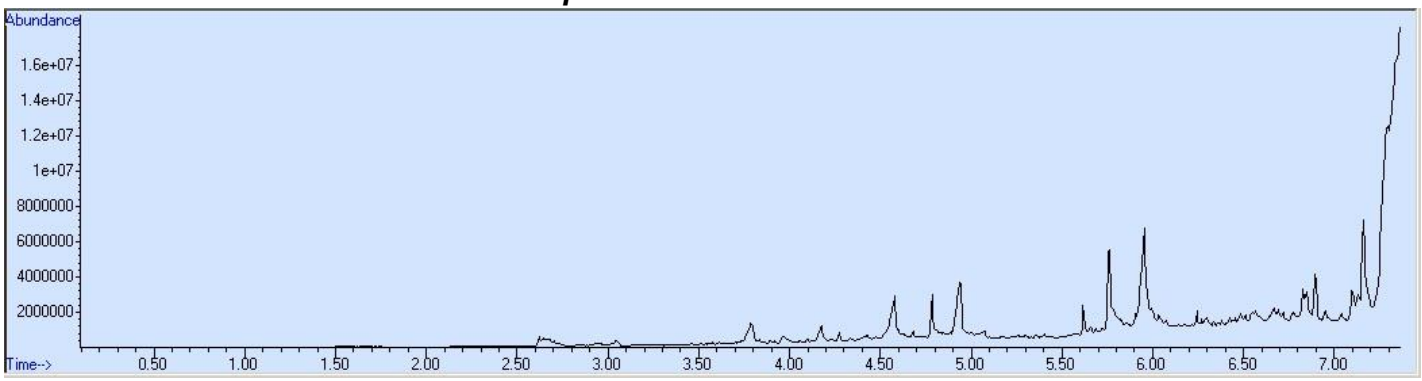

Figure D.7. The GC-MS chromatogram for a methanol extract of sediment sample no. 16. The same sample had been run beforehand on a LC-MS/MS system.

D.1.8 Sample no. 17

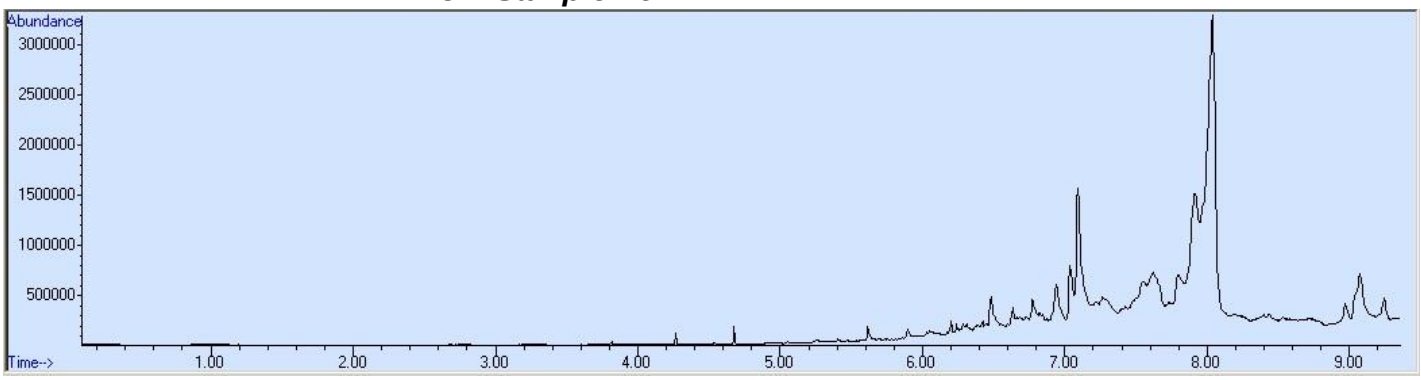

Figure D.8. The GC-MS chromatogram for sediment sample no. 17. No sample preparation was performed.

D.1.9 Sample no. 18

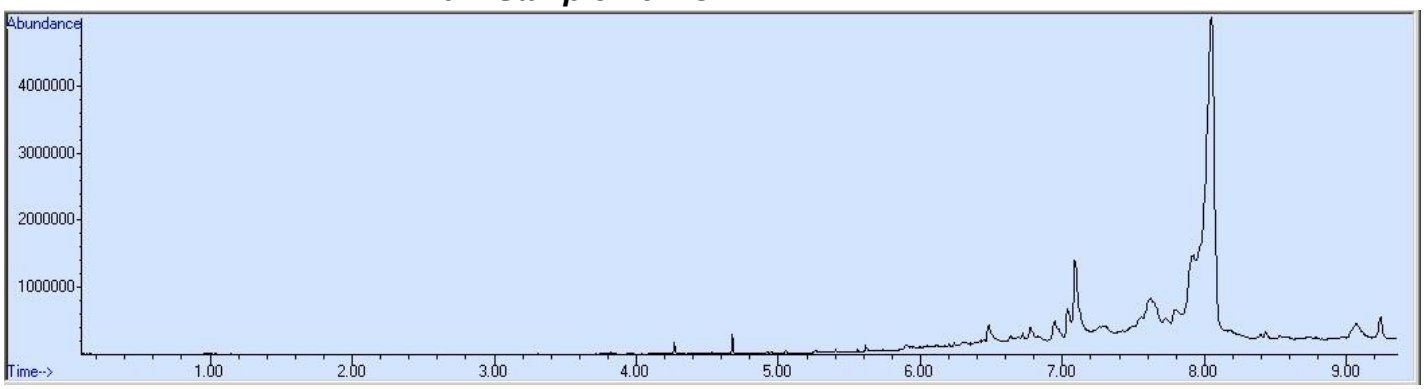

Figure D.9. The GC-MS chromatogram for sediment sample no. 18. No sample preparation was performed.

D.1.10 Sample no. 19

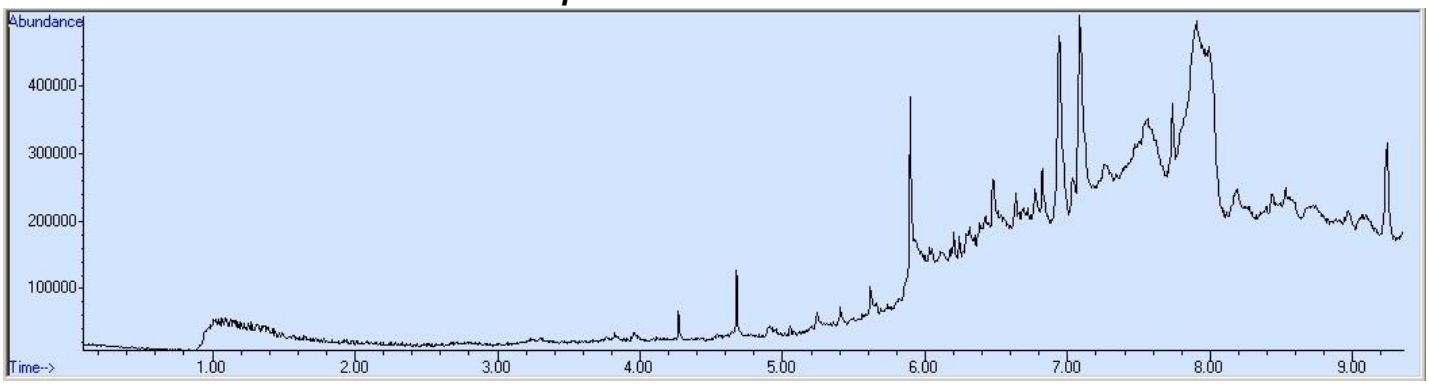

Figure D.10. The GC-MS chromatogram for sample 19. No sample preparation was performed.

D.1.11 Sample no. 20

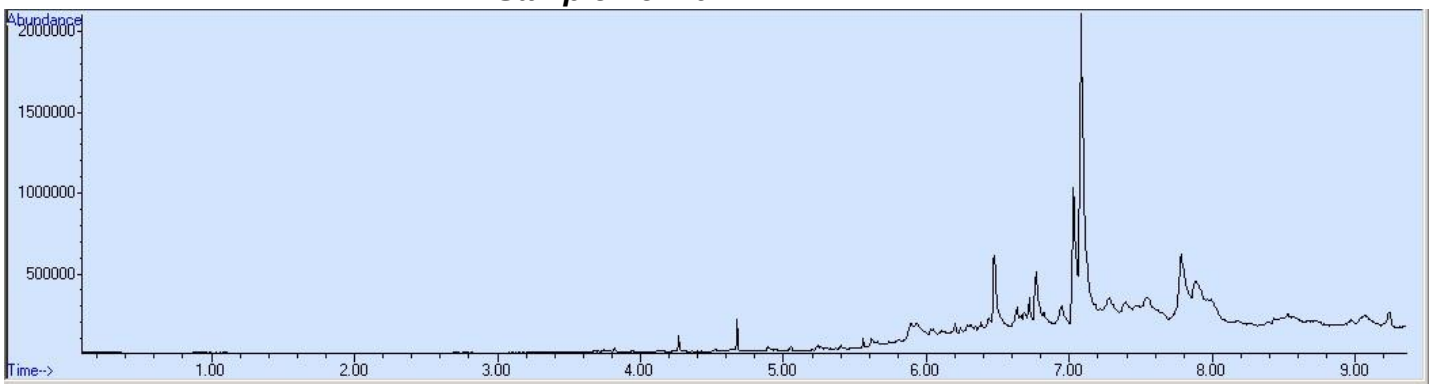

Figure D.11. The GC-MS chromatogram for sample 20. No sample preparation was performed.