MILJØDIREKTORATET

Microplastics in sediments on the Norwegian Continental Shelf II: Identification through FT-IR analysis

Report No.: 2018-1226, Rev. 00
M-1231/2018
Document No.: 231601
Date: 2018-10-01

Project name:	Microplastics in sediments on the Norwegian Coninental Shelf II: Identification trough FT-IR analysis	DNV GL AS Region Norway 5373, Region Norway P.O. Box 300,, Tel: +47 67 57 99 00 CNORDNV11
Report title:	Microplastics in sediments on the Norwegian Continental Shelf II.	
Customer:	Miljødirektoratet Brattørkaia 15B, 7010, Trondheim, Norway	
Customer contact:	Mihaela Ersvik	
Date of issue:	2018-10-01	
Project No.:	10096452	
Organization unit:	Environmental Monitoring	
Report No.:	2018-1226, Rev. 00	
Document No.:	231601	

Objective: Identification of polymer type of potential microplastics in offshore sediments. Follow up project of the project done reported in 2018.

Prepared by:	Verified by:	Approved by:
Hans Peter Arp (NGI)	Jens Laugesen (DNV GL)	Tor Jensen Vice President - Head of Section
Heidi Knutsen (NGI)		
Arne Pettersen (NGI)		
Møskeland, Thomas Digitally signed by Møskeland, Thomas Date: 2018.12.06 14:36:12 +01'00'		
Thomas Møskeland (DNV GL)		
Jon Huse (DNV GL)		

DNV GL Distribution:

☐ OPEN. Unrestricted distribution, internal and external.

☒ INTERNAL use only. Internal DNV GL document.

☐ CONFIDENTIAL. Distribution within DNV GL according to applicable contract.*

☐ SECRET. Authorized access only.

*Specify distribution:

Keywords:

Microplastics, sediment, FT-IR, NCS

Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
0	[yyyy-mm-dd]	First issue			

Table of contents

ACKNOWLEDGEMENT

This study presents sampling and analyses of sediments for microplastics. The sampling area covers large scale geographical areas on the Norwegian Continental Shelf (NCS). The samples have been collected as an extra task during the regional offshore sediment monitoring on the NCS on behalf of the Oil & Gas industry. This study had therefore not been initiated without the good will from oil & gas operators, especially Equinor and ConocoPhillips Norway, which allowed use of some additional time during field work to take these samples.

The Norwegian Environment Agency saw this as a good opportunity to acquire knowledge of microplastic abundances from the NCS and therefore funded the project.

The Norwegian Geotechnical Institute (NGI) has put in own effort, assisted through the projects FANTOM (RCN, 231736/F20) and JPI Oceans WEATHER-MIC (RCN, Project Grant 257433/E40), for the development of the analytical protocols and execution of the analysis and reporting. Through a relatively short period they have managed to deliver all results. A special thanks to Prof. Hans Peter Arp and Heidi Knutsen for the cooperation, as well as Emma Jane Wade, Sabnam Mahat and Veronica Castro Bustelo for lab assistance. Also, a special thanks to Øyvind Lilleeng at NMBU (Norwegian University of Life Sciences) who examined sediments from the Barents Sea as part of his MSc thesis, "The presence of microplastics on the Norwegian Continental Shelf and in Rio Almendares, Havana".

Høvik 5 th of December 2018

Thomas Møskeland – Project manager DNV GL

1 EXECUTIVE SUMMARY

During the regional environmental sediment monitoring on the Norwegian Continental Shelf on behalf of the oil & gas industry in 2017, 35 sediment samples from a large geographical area were sampled, covering the central North Sea, northern North Sea and the Barents Sea. The sediment samples were analyzed at the Norwegian Geotechnical Institute (NGI) for potential maximum microplastic abundance (with a particle size ranging from 45 µm to 5 mm) as described in DNV GL (2018). This earlier analysis was based on the assumption that all particles with a density less than the density separation fluid of 1.53 g/mL, having a size range between 45 µm and 5 mm, and resilience to an organic matter digestion process, potentially *could* be microplastics. As mentioned in the report, this conservative estimate could also include other materials such as soot, char, porous glass and ceramics, as well as resistant organic matter with regards to the organic matter digestion process.

As a follow-up, DNV GL initiated a project with the aim to identify plastic polymers within the material identified as "potential maximum microplastic" by the use of FT-IR microscopy. The analyses were performed by NGI, and the results are given in this report. Total microplastics are herein defined as total plastic, paint and rubber particles (the particle categories used in this report are given in Table 1-1). The lower estimated total microplastic concentrations are based on those confirmed by FT-IR using the applied quality index (≥ 60 % match score with reference library and expert judgement). The majority of particles could not be identified. Therefore, a revised and more reliable potential conservative estimate of microplastic concentrations are reported compared to the previous report (DNV GL, 2018), by eliminating particles that are confirmed to not be microplastics (minerals, organic materials, and petrogenic/pyrogenic particles) through FT-IR analysis, but including the unknown particle group. There is a possibility that the group unknown particles could include weathered microplastics or plastic composites that are not listed within the utilized FT-IR libraries.

Table 1-1. Particle categories used in this report.

Particle Category	Description
Unknown	Particles identified by FT-IR with a quality index < 0.6
Mineral	particles with no organic chemical bond visible in the IR spectrum (such as inorganic salts, glass, etc.)
Paint	particles identified to be composed of oxy-resins, adhesives, or paint additives such as epoxy resin, phenoxy resin, particles containing organo-tin, bisphenols, etc.
Petro-Pyro	typical petroleum substances, such as hydrocarbon resins, petroleum products, etc.
Plastic	commercial synthetic polymers, or a weathered derivative thereof, such as oxygenated polymers; semi-synthetics derived from biopolymers like cellulose, such as rayon, viscose etc are not included
Rubber	particles identified as rubbers, polymers used as rubbers (e.g. SBR, silicon rubber), or resins containing rubber compounding products
Organic	particles identified as organic macromolecules like cellulose, rayon, chitin, proteins, or in general particles containing organic carbon molecular bonds, that do not fit into any of the above categories

The obtained lower and conservative estimates of microplastic concentrations found in this report are summarized in the table below, and illustrated in Figure 1-1 and Figure 1-2. As evident, the conservative estimate was considerably higher than the lower estimate, which is due to a large number of particles that were categorized as unknown (see Figure 1-3). This shows the importance of performing polymer identification techniques, such as FT-IR, to verify if particles are microplastics and to identify the polymer types in order to

provide reliable information needed to make assumptions with regard to potential sources and the distribution of microplastics on the NCS.

Table 1-2. Overview of microplastic concentrations in sediment samples from the Norwegian Continental Shelf, in units of mg/kg dry sediment, mg/m^2 of grab area, items/kg dry sediment and items/m^2 grab area.

Location area	MP range* (confirmed MP – confirmed plus unknown particles)			
	mg/kg	**mg/m^2**	**Items/kg**	**Items/m^2**
All areas Average ± SD	6±11 to 58 ± 77	41±72 to 436±612	494±814 to 4408±5837	3149±5554 to 33416±47001
(min-max)	(<LOD-384)	(<LOD-2 996)	(0-29 020)	(0-234 031)
central North Sea Average ± SD	5±10 to 81±93	43±81 to 647±729	412±770 to 6155±7003	3 379±6 316 to 49 719±55 948
(min-max)	(<LOD-384)	(<LOD-2996)	(<LOD-29020)	(<LOD-234031)
northern North Sea Average ± SD	9±15 to 31±40	47±72 to 200±231	677±1064 to 2333±2920	3 628±5439 to 15164±17749
(min-max)	(<LOD-120)	(<LOD-626)	(<LOD-8 800)	(<LOD-48 130)
Barents Sea Average ± SD	6±5 to 21±15	18±12 to 64±36	452±385 to 1 570±1157	1 276±937 to 4706±2854
(min-max)	(0-42)	(0-106)	(0-3178)	(0-8068)

**The results are subject to various biases and should be interpreted with these in mind.*

Even though the reported lower and conservative estimated MP concentrations varied considerably, microplastic particles were confirmed in sediment samples widespread at the Norwegian Continental Shelf, which may confirm the widespread occurrence of microplastics in the marine environment, as is hypothesized in the scientific literature. Relatively higher average conservative estimate of MP in the central North Sea, compared to the northern North Sea and the Barents Sea supports our earlier results based on weight and visual analysis (DNV GL, 2018), where the revised conservative estimate of potential microplastics are 81 ± 93, 31 ± 40 and 21 ± 15 mg mMP/kg dry sediment, respectively. However, the results in this report have shown that this is largely due to the large fraction of particles that are unknown. The lower estimated MP concentration (confirmed by FT-IR) was on average highest in the northern North Sea (9 ± 15 mg MP/kg d.s.), followed by the Barents Sea (6 ± 5 mg MP/kg d.s.), and the central North Sea (5 ± 10 mg MP/kg d.s.), but statistically there is even less of a significant difference between the three areas (Figure 1-2). The trends were similar for MP concentrations reported as numbers of items/kg and items/m^2.

A study of microplastics in Arctic deep-sea sediments from the HAUSGARTEN Observatory (2 340 – 5 570 m depth) recorded concentrations of microplastics from 42 to 6 595 MP items/kg sediment dry weight, with an overall mean number of 4 356 (± 675 standard error) items/kg (Bergmann et al., 2017). This is about ten times higher than the reported lower estimate in this report (494±814 items/kg), but in the same range as conservative estimate (4 408±5 837 items/kg). However, it should be kept in mind that HAUSGARTEN study was able to quantify microplastics less than 10 µm and found the majority of particles to be less than 25 µm (which is below the 45 µm cut off of this study).

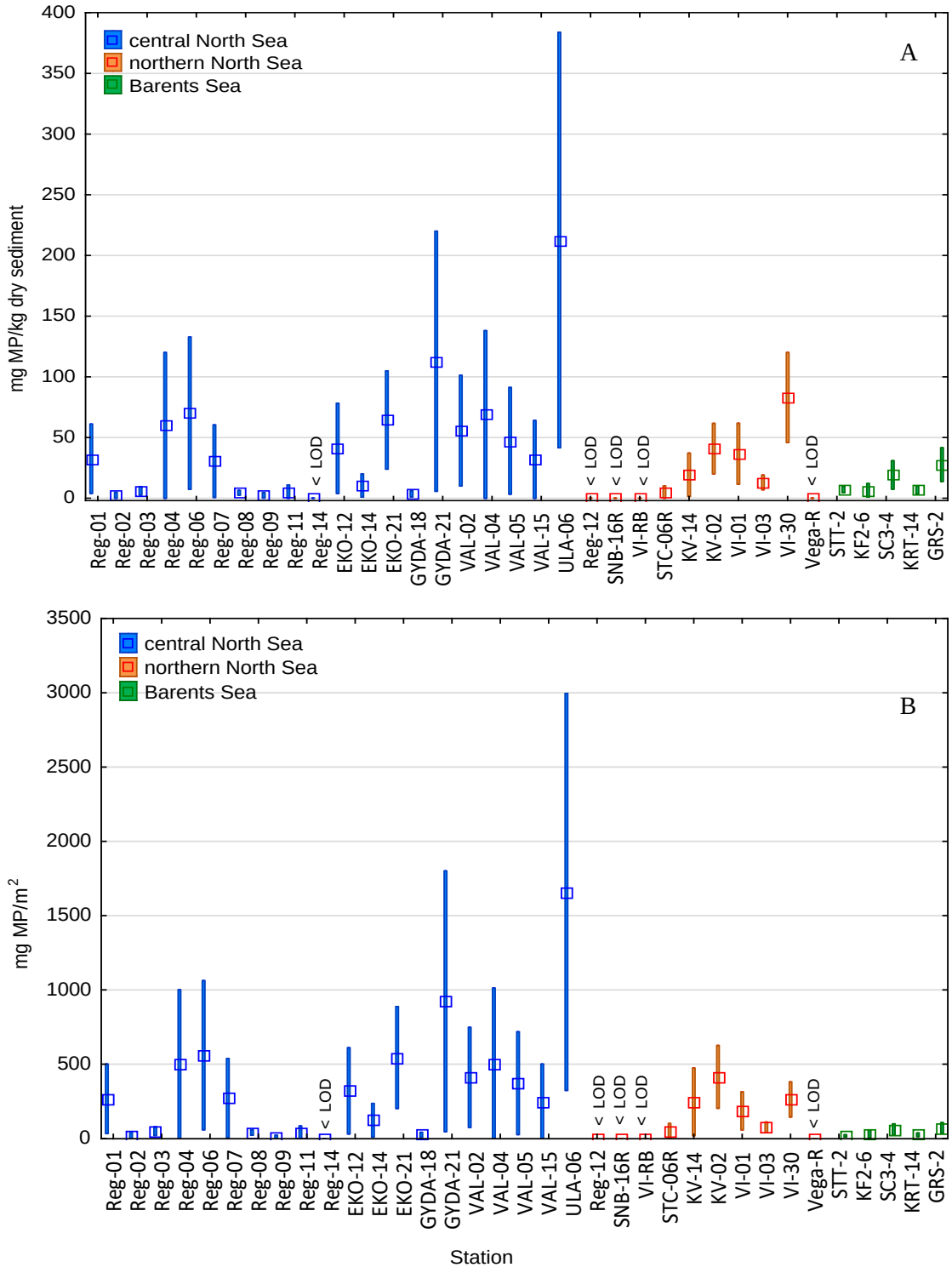


Figure 1-1. Microplastic concentration range (A: mg/kg dry sediment; B: mg/m^2). Boxes indicate median concentrations, while whiskers show lower and conservative estimate (lower estimate is based on those confirmed by FT-IR, while conservative estimate include particles whose FT-IR spectra did not correspond to anything in the library).

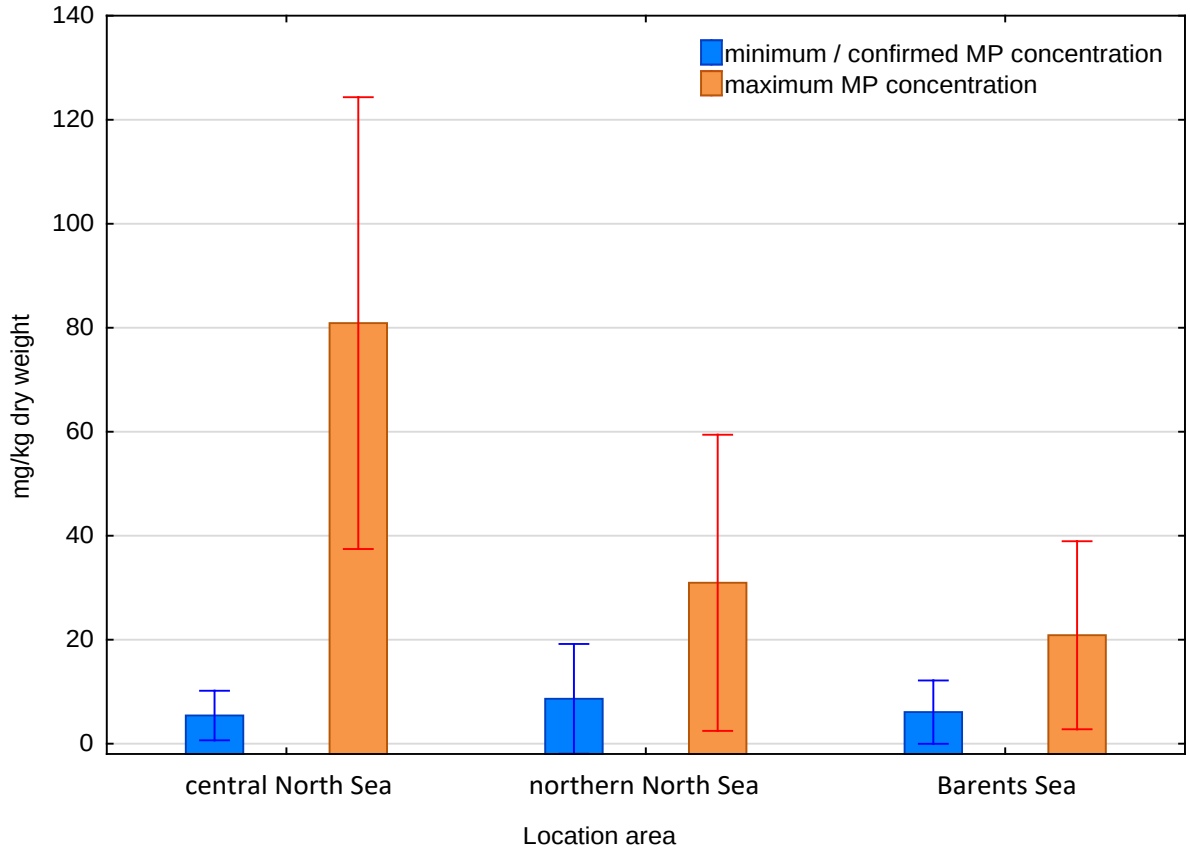


Figure 1-2. Average microplastic concentrations (mg/kg dry sediment). Boxes indicate average concentrations, while whiskers show 95 % interval. Lower estimate (blue): based on those confirmed by FT-IR; conservative estimated concentrations (orange bars): based on lower estimate plus particles whose FT-IR spectra did not correspond to anything in the library (match score < 0.6, "unknown" or possible plastic).

The FT-IR analysis found several different types of plastics present, but the most common ones were i) chlorinated polyolefines, and in particular chlorinated polyethylene, which appeared in many samples as black granules, ii) paint resins such as phenoxy resin, iii) rubber materials, iv) polyacrylamides, and v) PET (polyethylene).

Chlorinated polyethylene is a variation of polyethylene, but with a chlorine content. These polymers are used as major and minor components in a wide assortment of applications in industry. For instance, they can be used as process aid in rigid PVC foam applications as a partial replacement for acrylics. Applications include cable and wire coverings. Phenoxy resin is commonly used as a marine varnish. Chlorinated-PP is often used as coating/ adhesive. All these are high-density polymers, which are expected to sink in the oceans based on gravitational forces alone. Several low-density particles could also be found in some of the samples, however only in rare cases where these the majority. The average composition of particles in sediment samples from the central North Sea, northern North Sea and the Barents Sea is provided in Figure 1-3 (colouring in the figure corresponds to the colouring in Table 1-1).

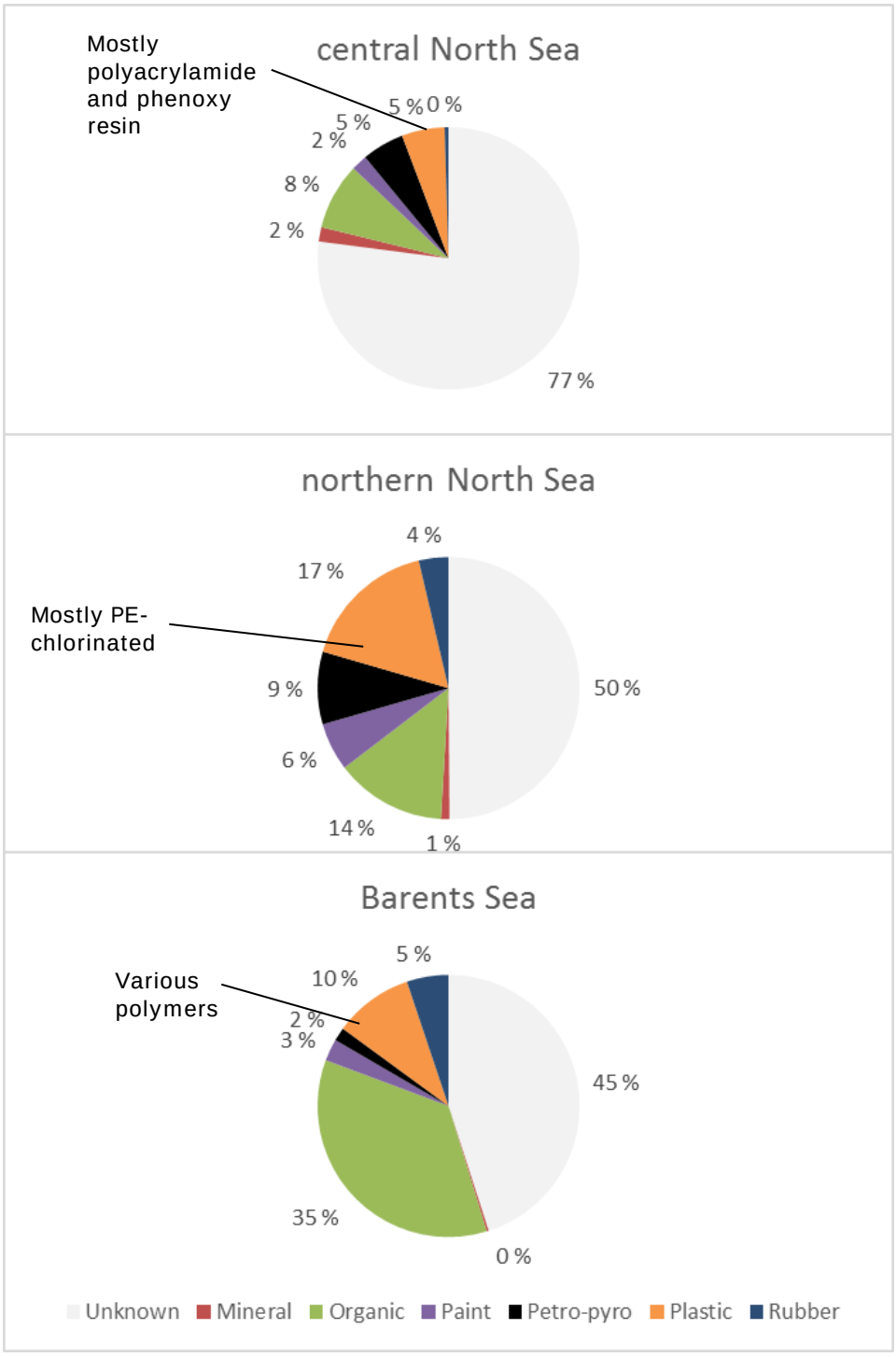


Figure 1-3. Average percentage composition of unknown (match score < 0.6 with the FT-IR library), mineral, organic, paint, petro-pyro, plastic (most frequent polymers are shown) and rubber particles. The color-coding is based on Table 1-1.

This study is one of the few studies to investigate the presence and identity of microplastics in deep sea sediments. Sediments in this area are of particular interest, because of their importance to the marine ecosystem. It has been hypothesized that the majority of plastics that have been emitted into the ocean are currently in sediments, and that sediments are the ultimate environmental sink for oceanic plastic (Woodall et al., 2014). The effects of this potentially accumulating concentration of microplastic in benthic ecosystems are unknown but need further investigation (Galloway et al. 2017). Because of their persistence, plastics accumulating continuously in the environment can be considered a planetary boundary threat (Jahnke et al. 2017).

Based on these concerns and the results of this report, the following research questions are recommended as follow-up activities:

1) **Sources of the dominating plastics.** Further investigation on the emissions and transport routes of dominating plastics (in this report identified as chlorinated-polyolefines, polyacrylamide, PET, paint resins and rubber resins) is worthy of prioritization for follow-up, as it is potentially these that accumulate in sediments the quickest.

2) **The unknown plastic**. Further analysis is needed to identify particles categorized as unknown, as some of them seemed to be morphologically similar, and with a high frequency. Different analytical techniques could be attempted. Comparison with FT-IR libraries not used in this study may also be of assistance.

3) **Ecological effects**. Future work should be performed to examine the impact of microplastics on deep sea or remote benthic ecosystem, such as possible effects to benthic fauna and impacts to the marine food chain.

4) **Temporal trends.** Monitoring campaigns that address how microplastic concentrations potentially increase over time are needed. Such studies can include sediment core studies or revisiting previous sampling sites, such as the areas in this study, to examine temporal changes. Currently, sediment core studies are a more direct way to answer this research question, as methods to quantify microplastics are continuously being optimized and improved, and currently there is a large variation and development in methods being utilized.

5) **Combining mapping and modelling to link emissions sources with sediment sinks.** The geographical distribution of microplastics on the seabed remains unknown, as well as the processes that control the marine distribution. With this report and others like it, we are beginning to acquire initial empirical information about the distribution of microplastics in deep sea. Further studies that link emission source with sediment sinks, in combination with dedicated fate and transport models that account for oceanic currents and particle settling processes, can be used to better establish in which regions microplastics accumulate in the sediments the most. Further, such studies could ultimately be used to identify management strategies that prevent microplastics from being a planetary boundary threat.

2 INTRODUCTION

In recent years, knowledge and an acknowledgement that plastic pollution in the marine environment is a global challenge, has grown. Plastic in the ocean is today high on the political agenda and has become a prioritized environmental issue with many research projects initiated. Norway is a global actor when it comes to protection and sustainable use of the oceans, and in 2017 the United Nations agreed on a proposal put forward by Norway which in essence means a long-term elimination of discharges of plastic to the oceans.

To understand the environmental effects of microplastic in the marine environment and to implement mitigating actions, knowledge about distribution and abundance are crucial. In 2017 DNV GL sampled 35 sediment samples from a large geographical area covering the central North Sea, northern North Sea and the Barents Sea. These samples were analyzed for potential maximum microplastic abundance as described in DNV GL (2018). As a follow-up to the project in 2017 DNV GL initiated a project with the aim to identify plastic polymers in the material identified as potential maximum microplastic in the investigation in 2017 by use of FT-IR microscopy. The analyses were performed by the Norwegian Geotechnical Institute (NGI), and the results are presented in this report.

3 MATERIALS AND METHODS

3.1 Sampling locations

During the regional environmental sediment monitoring on the Norwegian Continental Shelf on behalf of the oil & gas industry in 2017, 35 sediment samples from a large geographical area were sampled, covering the central North Sea, northern North Sea and the Barents Sea. A detailed overview of the sampling locations is presented in Figure 3-1.

All samples were collected with a van Veen grab with surface area 0.15 m^2, except for one sample from the central North Sea (EKO-14), where surface area sampled was 0.10 m^2. The whole 0-1 cm surface area of a dedicated grab was taken for each sample. The samples were stored in glass jars in air temperature during field work and stored in refrigerators at DNV GLs Biolab after demobilization until they were shipped to NGI for analysis.

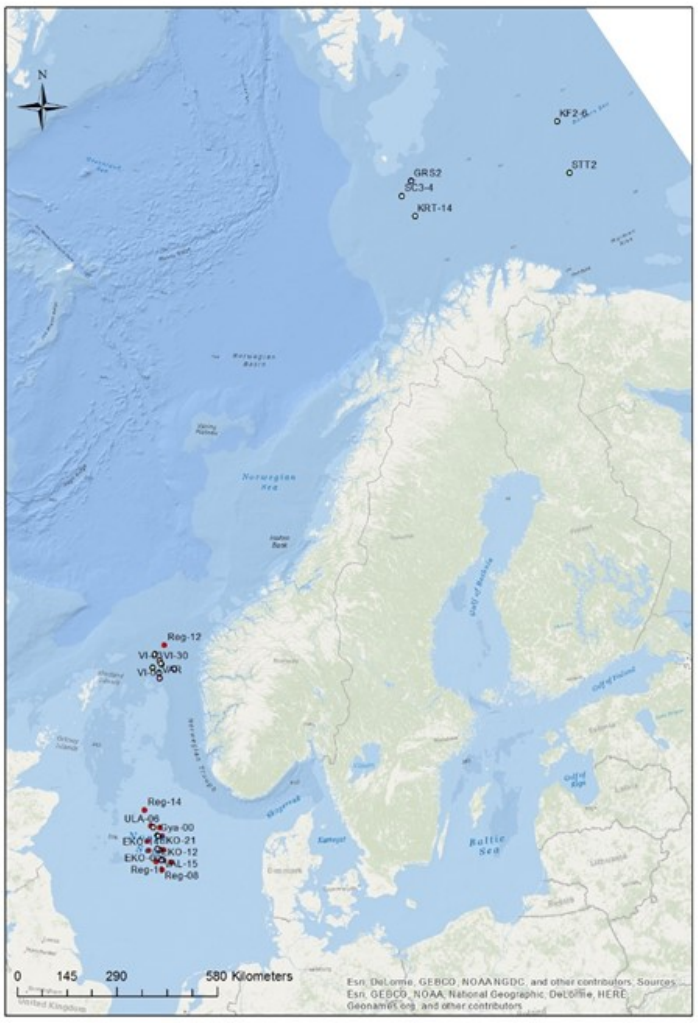


Figure 3-1. Overview of sampling areas with indications of sampling stations. Central North Sea in the south, northern North Sea in mid Norway and Barents Sea in the north.

3.1.1 Central North Sea

The central North Sea is a shallow area with a water depth of around 70 m. The sediments are mainly fine sand. Sediments were sampled at 20 stations in this area.

Ten of the samples were from so called regional stations. Regional stations are stations that represent the natural state in the area, meaning they are considered as not influenced by oil & gas activities, and as such can be considered reference stations. The remaining 10 stations are sampled around oil & gas fields, namely Ekofisk, Gyda, Valhall and the Ula field. Relevant station specific information is presented in Table 3-1 and a geographical overview is presented Figure 3-2.

Table 3-1. Station information, central North Sea.

Sampling station	Field	Direction[1)] (°)	Distance[2)] (m)	Depth (m)	Sediment characteristic	TOC (%)
Reg-01	Regional	n.r	n.r	73	Fine sand (MDΦ = 2.83)	0.30
Reg-02	Regional	n.r	n.r	68	Fine sand (MDΦ = 2.79)	0.31
Reg-03	Regional	n.r	n.r	68	Fine sand (MDΦ = 2.81)	0.37
Reg-04	Regional	n.r	n.r	71	Fine sand (MDΦ = 2.75)	0.32
Reg-06	Regional	n.r	n.r	72	Fine sand (MDΦ = 2.87)	0.33
Reg-07	Regional	n.r	n.r	73	Fine sand (MDΦ = 2.82)	0.36
Reg-08	Regional	n.r	n.r	70	Fine sand (MDΦ = 2.67)	0.32
Reg-09	Regional	n.r	n.r	66	Fine sand (MDΦ = 2.66)	0.19
Reg-11	Regional	n.r	n.r	71	Fine sand (MDΦ = 2.70)	0.29
Reg-14	Regional	n.r	n.r	80	Fine sand (MDΦ = 2.74)	0.24
EKO-12	Ekofisk	148	2500	78	n.a	n.a
EKO-14	Ekofisk	140	850	76	Very fine sand (MDΦ = 3.03)	0.48
EKO-21	Ekofisk	287	4000	71	n.a	n.a
Gyda-18	Gyda	135	250	67	Silt & clay (MDΦ = 5.12)	0.88
Gyda-21	Gyda	135	2000	67	n.a	n.a
VAL-02	Valhall	74	500	76	Fine sand (MDΦ = 2.82)	
VAL-04	Valhall	74	2000	72	n.a	n.a
VAL-05	Valhall	74	5000	70	n.a	n.a
VAL-15	Valhall	254	500	76	Fine sand (MDΦ = 2.80)	0.42
ULA-06	Ula	45	250	71	Fine sand (MDΦ = 2.86)	0.28

n.r: Not relevant

n.a: Not analysed

MDΦ = Median grain diameter (mm)

1) Direction/heading from oil & gas installation

2) Distance from oil & gas installation

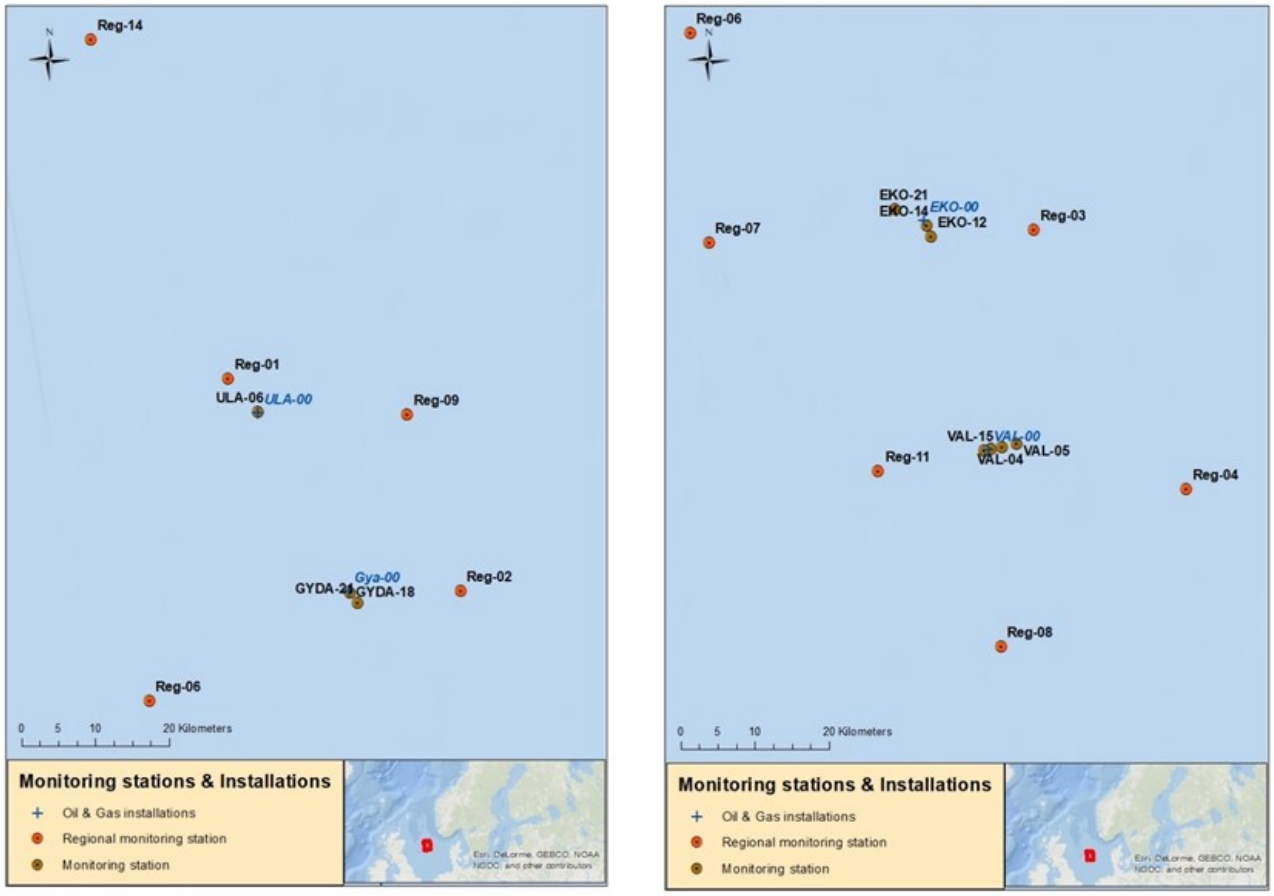


Figure 3-2. Overview of sampling stations in the central North Sea, southern part (left) and northern part (right).

3.1.2 Northern North Sea

The water depth in the sampling area varies from 100 m to above 400 m in general. The varying water depth results in different sediment characteristics such as sand and gravel, to finer material as clay and silt. Sediments were sampled at 10 stations in this region, where 5 were regional/reference stations and 5 were stations in the vicinity to oil & gas fields, namely the Kvitebjørn and the Visund fields. Relevant station specific information is presented in Table 3-2 and a geographical overview is presented in Figure 3-3.

Table 3-2. Station information, northern North Sea.

Sampling station	Field	Direction[1] (°)	Distance m[2]	Depth (m)	Sediment characteristic[3]	TOC (%)[4]
SNB-16R	Snorre B ref	315	10000	342	Silt (MDΦ = 4.23)	0.52
VI-RB	Visund Ref	330	10000	330	Silt (MDΦ = 4.91)	0.56
STC-06R	Statfjord C Ref	130	10000	137	Medium sand (MDΦ = 1.27)	0.4
Reg-12	Regional	n.r	n.r	400	Silt (MDΦ = 5.24)	0.11
Vega-R	Vega Ref	-	-	380	Silt (MDΦ = 5.94)	0.17
KV-14	Kvitebjørn	316	7224	187	Fine sand (MDΦ = 2.53)	0.22
KV-02	Kvitebjørn	140	500	185	Fine sand[3]	-[3]
VI-01	Visund	150	500	330	Silt (MDΦ = 5.18)	0.38
VI-03	Visund	150	1000	330	Silt and clay[3]	-[3]
VI-30	Visund	330	250	316	Silt (MDΦ = 5.6)	0.4

n.r: Not relevant

1) Direction/heading from oil & gas installation

2) Distance from oil & gas installation

3) Based on field description. Not analysed for grain size and TOC in 2017.

Figure 3-3. Overview of sampling stations in northern North Sea.

3.1.3 Barents Sea

The samples taken in the Barents Sea were collected in relation to baseline investigations covering relatively large areas in the northern area of the Norwegian Continental Shelf. The water depth in the region is variable, from 200 m to above 500 m. The varying water depth results in different sediment characteristics such as sand and gravel, to finer material as clay and silt. Sediments were sampled at 5 stations in this region. Relevant station specific information is presented in Table 3-3 and a geographical overview is presented in Figure 3-4.

Table 3-3. Station information, Barents Sea.

Sampling station			Field	Direction (°)[1)]	Distance m[2)]	Depth (m)	Sediment characteristic	TOC %
STT-2			Stangnestind	90	250	251	Silt and clay (MDΦ=5.31)	1.93
KF2-6			Korpfjell	85	900	242	Silt and clay (MDΦ=4.05)	1.76
SC3-4			Scarecrow3	270	100	461	Silt and clay (MDΦ=5.57)	1.56
KRT-14			Kråketind	n.r	n.r	440	Silt and clay (MDΦ=5.70)	1.34
GRS-2			Gråspett	90	250	508	Silt and clay (MDΦ=5.93)	2.09

n.r: Not relevant

MDΦ = Median grain diameter

1) Direction/heading from oil & gas installation

2) Distance from oil & gas installation

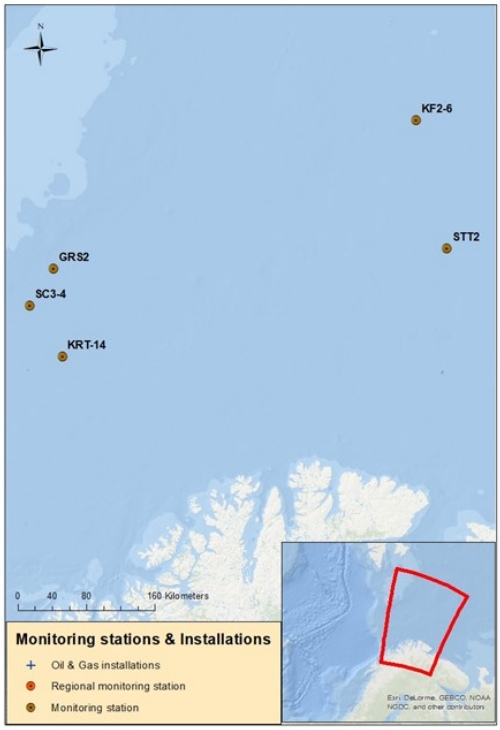


Figure 3-4. Overview of sampling stations in the Barents Sea.

3.2 Polymer identification

3.2.1 Sample preparation and analytics

A detailed description of sample preparation and quantification of microplastic in the sediment samples is described in DNV GL (2018) and not repeated here; further details are to be presented in an upcoming publication (Olsen et al. in prep). As described in the report, the processed sediment samples were filtered onto steel mesh filters with a pore size of 45 µm, then placed between two clear 10x10 cm acryl plates (Clas Ohlson, Sweden) for flattening and to enable investigation with a microscope (see Figure 3-5). Based on the visual microscopy, potential microplastic particles were counted, and maximum microplastic (mMP) concentrations were reported (particles with a density lower than the density separation fluid (1.53 g/mL), size range between 45 µm and 5 mm, and resilience to an organic matter digestion process). In this report, the same samples were further analyzed for polymer identification using micro FT-IR spectroscopy.

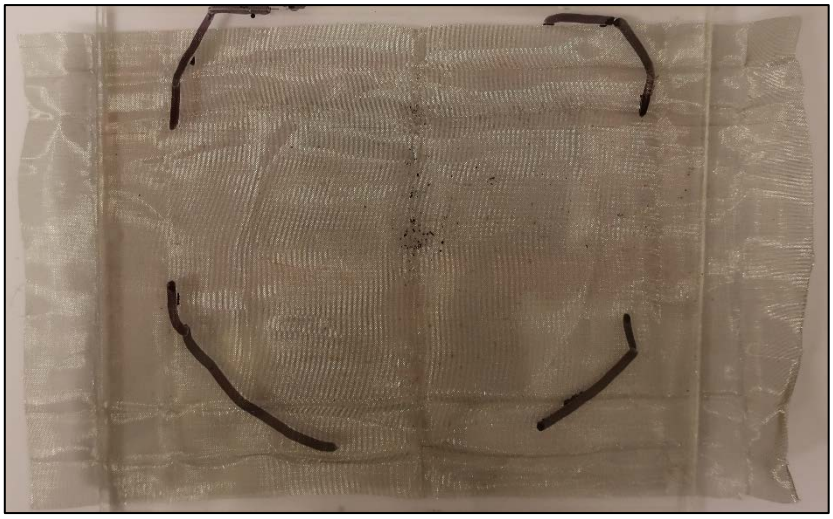


Figure 3-5. Photo of processed sediment sample, collected on a 45 µm steel mesh and placed between two acryl plates for visual microscopy.

The micro FT-IR system used here was a Perkin Elmer Spotlight 200i FT-IR microscope, equipped with a Frontier FT-IR spectrometer. The system consists of a microscope, spectrometer, PC, stage controller and joystick (Figure 3-6).

Figure 3-6. Spotlight 200 – microscope and Frontier IT System

Prior to analysis, the Spotlight 200 was set up, and the microscope was focused as described in the Spotlight 200 User's Guide. The scan parameters were set to the following settings:

Table 3-4. FT-IR scan parameters setup

Resolution	8 or 16 cm^{-1}
Wave number range	4 000 – 600 cm^{-1}
Number of accumulations	4 for the sample image

The acryl plates containing the samples after density separation and digestion were carefully opened. For samples with larger particles, large enough to be picked up by tweezers, their length was measured using Vernier callipers, and thereafter individual particle analyses using the Frontier ATR assembly was conducted. For particles too small to be picked up by tweezers, a subsample was carefully transferred using a spatula onto either a pre-cut, spherical steel mesh (pore size of 45 µm) with a diameter of 13 mm for analysis in transmittance mode or onto a 13 mm gold plate for analysis using the micro-ATR crystal mode (see Figure 3-7). Effort was done to collect a subsample with the same particle composition as the main sample. For samples with low numbers of particles, as complete transfer as possible was done (though some particles remained stuck to the original filter, on the acryl plate, or were lost during transfer).

In transmittance mode, the infrared radiation penetrates the particle before arriving at the detector, giving an infrared spectrum of the entire volume of the particle. This mode works best with thin or translucent particles. For micro ATR analysis, the ATR crystal makes direct contact with the sample, and the infrared radiation is reflected through the crystal. Using the ATR technique allows for the analysis of materials that are too opaque for transmission measurements and too strongly absorbing for good reflectance measurements; it further gives in general better-quality FT-IR spectra (less noise) than transmission mode. This method mainly

measures the surface of the particle. The contact area of the crystal is 100 µm in diameter. According to the manufacturer, the micro FT-IR system ensures spectra from sample areas down to the diffraction limit of 10 µm. Both the transmission mode and the ATR mode were used for all samples, though the majority of data is from transmission mode. This is primarily because transmission analysis is much quicker than ATR (and does not require ATR-crystal cleaning and maintenance), so it was less time consuming to scan large numbers of particles.

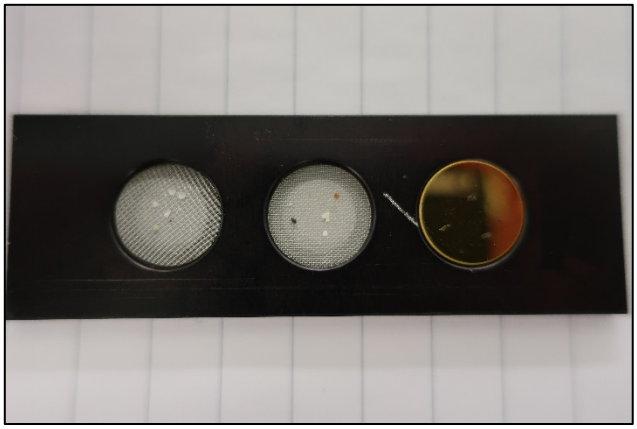


Figure 3-7. Picture of random selection of particles from a sample (VI03) placed on steel mesh filters and a gold plate for FT-IR analysis.

The obtained IR spectrums were compared with libraries of polymer spectra available through Perkin-Elmer, namely "Polymer", "ATR-Spectra", "Transmission-Spectra" and "Fluka". Particle identification is done through the software, which compares the obtained spectrum with those in the spectrum libraries, which includes a wide variety of plastic polymers, organic substances, salts and minerals, many of which are highly unlikely to be a major component of marine samples. The "Polymer" library also included typical polymer blends (e.g. polyethylene and polypropylene blends). Samples with a quality index <0.7 and ≥ 0.6 were considered individually for acceptance, while matches with scores > 0.7 were accepted. Though there is no established quality index for what is considered known/unknown, a value of 0.6 was considered acceptable to allow for weathering/surface degradation and possibly also coating of polymers, as well as the presence of additives. A further discussion on the use and implications of this quality index is presented in the next section. In cases with several matches above 0.6, usually the best match was chosen. Exceptions were when the spectra with the highest quality index was different from several other spectra with a similar score. For instance, if there was one match with "polymer a" with a quality index of 0.91 from one library and diverse matches for "polymer b" were present from all libraries, with scores ranging between 0.8-0.9, substance b was chosen. Further analysis for ambiguous data was used via the "multi-search" function provided by the software, that compared the spectra to combinations of 2 to 3 different spectra in different concentrations (from 10 to 90% per component), such that the main component could potentially be identified. Spectra were manually checked to ensure that IR peaks were visually distinguishable above noise. If they were not, the spectra were rejected regardless of the quality index and not considered further. Matches with a score less than 0.6 were rejected and are denoted as "unknown" particles in the report. The identified items where categorized into the following groups in Table 3-5.

Table 3-5. Particle categories used in this report. The colouring of the categories corresponds to the colours used in Figure 4.4.

Particle Category	Description
Unknown	Particles identified by FT-IR with a quality index < 0.6
Mineral	particles with no organic chemical bond visible in the IR spectrum (such as inorganic salts, glass, etc.)
Paint	particles identified to be composed of oxy-resins, adhesives, or paint additives such as epoxy resin, phenoxy resin, particles containing organo-tin, bisphenols, etc.
Petro-Pyro	typical petroleum substances, such as hydrocarbon resins, petroleum products, etc.
Plastic	commercial synthetic polymers, or a weathered derivative thereof, such as oxygenated polymers; semi-synthetics derived from biopolymers like cellulose, such as rayon, viscose etc are not included
Rubber	particles identified as rubbers, polymers used as rubbers (e.g. SBR, silicon rubber), or resins containing rubber compounding products
Organic	particles identified as organic macromolecules like cellulose, rayon, chitin, proteins, or in general particles containing organic carbon molecular bonds, that do not fit into any of the above categories

Particles identified as plastic were further subdivided into the plastic types in Table 3-6. In case of blends, the main polymer in the composition was chosen.

Table 3-6. Plastic particle categories used in this report.

Plastic Category	Description
PE	polyethylenes (E.g. LDPE,HDPE, LLDPE, etc.)
PE-chlorinated	Chlorinated polyethylenes
PE-chlorosulfonated	Chlorosulfonated polyethylenes
PE-oxidized	Oxidized polyethylenes
PE:PP	Blends of polyethylene:polypropylene
PP	polypropylenes
PET	polyesters, polyethylene terephthalates
PS	polystyrenes
PTFE	Polytetrafluoroethylenes
PP-chlorinated	Chlorinated polypropylenes
Polyacrylamide	Polyacrylamides
PMMA	Polymethylmethacrylate and other polyacrylates
PU	Polyurethane foams
PVF	Polyvinyl fluorides
PVC	Polyvinyl chlorides
Melamine	Melamines (all resin blends)
Zonyl	Type of PTFE resin
Others	Synthetic polymers not belonging to the above list

3.2.2 Method limitations and quality assurance

There are several limitations to the method used in terms of identifying all microplastic particles in a sample. These include density (below 1.53 kg/L), particle size (45 µm - 5 mm) and chemical digestion limitations (recalcitrant particles other than plastic), which are described in detail in the previous report (DNV GL, 2018). There are further limitations with regard to the FT-IR analysis used as described in this section.

Firstly, there is a chance of losing sample material when removing the acrylic plates sealing the concentrated sample, as some of the particles might get lost or stick to the original filter when transferring them to the FT-IR filter. Thus, the subsample analyzed for FT-IR may not be representative of the entire sample. For example, it is difficult to transfer small particles, and especially fibers, as these often are coiled up and difficult to detect with the naked eye.

There are also limitations with regards to the FT-IR analysis, such as the chosen quality index cutoff of 0.6. In literature, it is common to use a quality index of 0.7 as the limit (e.g. Obbard et al., 2014). However, Obbard et al. (2014) individually inspected and interpreted any matches with scores < 0.7 but ≥ 0.6, while any matches with quality index ≥ 0.7 were accepted. The same method was used in this report, as it can be difficult to obtain spectra with high score if the plastics have been present in the environment for a considerable time such as for the sediment samples from the NCS. Weathering of the polymers affect their surface and thereby their spectra, which makes comparison with reference spectra more difficult. Such a score limit of 0.7 could lead to an underestimation of plastics, as particles with a lower score in fact could be plastics. At the same time, the score limit of 0.6 could also lead to an overestimation of plastics if the limit is not conservative enough, as the uncertainty increases with decreasing score. Another important consideration is the number of reference spectra in the chosen libraries. According to Perkin-Elmer (private communication), their "Polymer" library was the currently most expansive that they offer and is their standard for microplastic and polymer research; however, they are in the process of integrating other existing polymer libraries for the purpose of expansion. Future comparisons with more expansive libraries that include, for instance, weathered microplastics, will likely lead to fewer numbers of particles with quality index cutoffs less than 0.6 as well as a fewer number of misidentified spectra.

As described in DNV GL (2018), precautions were taken throughout the method protocol to account for laboratory contamination. Several contamination strategies were performed, such as thorough washing of equipment with MilliQ water or ultrasonic cleaning in MilliQ water, proper sealing of the samples as much as possible etc. Further, the ATR crystal was cleaned with methanol between each analysis to reduce the chance of cross-contamination between samples. To account for impurities, two different types of blank samples were included for quality control in 2017: method- and spiked blanks. The method blank sample protocol included the same laboratory steps at the sediment samples, but with no sediment. Blanks were then controlled by weight and by visual microscopy. For the purpose of this report, the method blanks were also analysed by FT-IR to evaluate polymer contamination resulting from the preparation and analytical procedure, and to correct for this. The spiked blank protocol involved taking a sample of "settled sediment", after the density separation step to remove floating materials, and spiking it with a known amount of microplastics. These spiked blanks were processed as normal samples and used to adjust recovery concentrations based on weight and number of particles, though not based on FT-IR data.

The number of a specific types of particles (e.g. PTFE, glass, organic) in the analysed sediment subsamples (n_p) were corrected due to the number of counted particles of the same FT-IR spectra in the method blanks as shown in Formula 1.

$$n_p = n_{p,sample} - n_{p,blank}$$ *Formula 1*

Where:

- $n_{p,sample}$ = number of particle, p, identified with FT-IR to belong to one of the categories in Table 3-5 and Table 3-6 in the sample.
- $n_{p,blank}$ = number of particle, p, identified with FT-IR to belong to the categories in Table 3-5 and Table 3-6 in in the blanks. This value for different particle type was obtained using data from different method blanks, placed on 9 different FT-IR sample holders. The value used in Formula 1 one would be corrected for the number of sample filters. For example, if three sample filters were used for $n_{p,sample}$, then the three x the average number of particles per method blank filter were used as $n_{p,blank}$.

For unknown, organic, mineral and petro-pyro particles, the individual type was not included in calculating n_p; however, for plastic, paint and rubber, this was first done for individual particle type (e.g. PE, PET, phenoxy resin, etc.). Then, the n_p for all plastic, paint and rubber particles was calculated by summing the n_p values for individual types (as listed in Table 3-6).

Based on the positively identified particles, a *lower* estimated microplastic (MP low) concentration was calculated per kg dry sediment and per m^2 sediment surface, based on the results given in DNV GL (2018), and the assumptions that the analysed subsamples were representative for the main samples and that all particles had a similar weight, as follows:

$$c_{MP\ low}\left(\frac{mg\ MP\ low}{kg\ d.w.}\right) = c_{mMP}\left(\frac{mg\ mMP}{kg\ d.w.}\right) * \frac{n_{plastic}}{n_{tot}}$$ *Formula 2*

$$c_{MP\ low}\left(\frac{mg\ MP\ low}{m^2}\right) = c_{mMP}\left(\frac{mg\ mMP}{m^2}\right) * \frac{n_{plastic}}{n_{tot}}$$ *Formula 3*

Where:

- c_{mMP} = maximum microplastic concentration after density separation and chemical oxidation, with the assumption that all these particles are plastic. These concentration values are given in DNV GL (2018).
- $n_{plastic}$ = the total number of all confirmed plastic polymers, paint and rubber in the analysed samples (match score ≥ 0.6, after internal quality check).
- n_{tot} = the total number of all particles (including unknown)

The same approach was used for estimation of lower microplastic concentrations in units of items/kg dry sediment and items/m^2 sediment surface:

$$c_{MP\ low}\left(\frac{items\ MP\ low}{kg\ d.w.}\right) = c_{mMP}\left(\frac{items\ mMP}{kg\ d.w.}\right) * \frac{n_{plastic}}{n_{tot}}$$ *Formula 4*

$$c_{MP\ low}\left(\frac{items\ MP\ low}{m^2}\right) = c_{mMP}\left(\frac{items\ mMP}{m^2}\right) * \frac{n_{plastic}}{n_{tot}}$$ *Formula 5*

In addition, revised conservative microplastic (MP max) estimates were calculated based on the assumption that all unknown particles ($n_{unknown}$) were highly weathered or unidentifiable plastic.

$$c_{MP\ max}\left(\frac{mg\ MP\ max}{kg\ d.w.}\right) = c_{mMP}\left(\frac{mg\ mMP}{kg\ d.w.}\right) * \frac{n_{plastic}+n_{unknown}}{n_{tot}} \quad \textit{Formula 6}$$

$$c_{MP\ max}\left(\frac{mg\ MP\ max}{m^2}\right) = c_{mMP}\left(\frac{mg\ mMP}{m^2}\right) * \frac{n_{plastic}+n_{unknown}}{n_{tot}} \quad \textit{Formula 7}$$

$$c_{MP\ max}\left(\frac{items\ MP\ max}{kg\ d.w.}\right) = c_{mMP}\left(\frac{items\ mMP}{kg\ d.w.}\right) * \frac{n_{plastic}+n_{unknown}}{n_{tot}} \quad \textit{Formula 8}$$

$$c_{MP\ max}\left(\frac{items\ MP\ max}{m^2}\right) = c_{mMP}\left(\frac{items\ mMP}{m^2}\right) * \frac{n_{plastic}+n_{unknown}}{n_{tot}} \quad \textit{Formula 9}$$

3.2.3 Testing of TG FT-IR

In addition to the main analytical procedure FT-IR, some samples have been tested for analysis with TG-FTIR. This is a combination technology that in addition to FT-IR uses thermogravimetric analysis (TG) which measures changes in mass as a function of temperature and/or time. TG gives characteristic information about the composition of the measured sample, in particular the amounts of the various components and their thermal behaviour. Gases released from TG can be further identified by analysis with FT-IR. The gases are analysed continuously under heating of the sample and by comparison towards reference measurements identification substances in the sample can be identified. TG-FTIR may therefore give quantitative information of the substances in the sample in addition to identification of the substances.

TG-FTIR was tested on samples from station ULA-06 (central North Sea), station Reg-06 and station GRS2 (Barents Sea). Prepared samples were sent from DNV GL to NETZSCH Thermal Analysis Applications Laboratories, Selb in Germany. The samples were dried before analysis by Dr. Jan Hanss.

4 RESULTS

4.1 Quality control

In total, nine method blanks were analyzed for impurities with FT-IR. The average abundance of particles is shown in Table 4-1.

Table 4-1. Average abundance (± standard deviation) of particles in method blanks (n = 9), $n_{p,blank}$, within each defined FT-IR category.

Plastic						Unknown	Organic	Mineral	Total
PTFE	PS	PVF	PET	PMMA	Zonyl				
1.6±2.4	0.11±0.33	0.11±0.33	0.11±0.33	0.22±0.44	0.33±1	3.6±3.6	1.7±2.5	0.11±0.33	13±3.3

As evident from Table 4-1, there was very low contamination of plastic in the blank samples, with plastics like PS, PVF and PET only appearing in one of nine blanks. Each blank contained an average of 3.6 unknown particles and 1.7 organic particles. PTFE fibers were the most commonly observed plastic particle in the blanks. The method blanks were used for correction of microplastic concentrations in the sediment samples, as described in the Materials and Method section.

4.2 Identified microplastics

4.2.1 Microplastic concentrations

Total microplastics are herein defined as total plastic, paint and rubber particles (Table 3-5). The lower total microplastic estimate are based on those confirmed by FT-IR using the applied quality index. Conservative microplastic estimate are those that are confirmed by FT-IR (lower) as well as particles whose FT-IR spectra did not correspond to anything in the library with a sufficient quality index, as we do not have sufficient evidence to conclude on the identity of these particles (they could be for instance highly weathered plastic, plastic composites, etc.).

The range of lower to conservative estimate of microplastic particles is presented in Table 4-2 and Figure 4-1 to Figure 4-3 for the samples collected in this study.

Table 4-2. Range of microplastic concentrations in each sample. Lower estimate: based on those confirmed by FT-IR (quality index >0.6). Conservative estimate: those confirmed by FT-IR and particles whose FT-IR spectra did not correspond to anything in the library ("unknown" quality index < 0.6, possible plastic, e.g. highly weathered plastic).

Station	Location area	MP range (confirmed MP – confirmed plus unknown particles)			
		mg/kg	mg/m²	Items/kg	Items/m²
Reg-01	central North Sea	4-61	34-500	309-4600	2552-38000
Reg-02		0-5	0-42	0-372	0-3165
Reg-03		3-10	21-78	192-720	1600-6000
Reg-04		0-120	0-1000	0-9200	0-79000
Reg-06		7-133	59-1062	542-9734	4586-82299
Reg-07		1-60	6-537	52-4617	456-40518
Reg-08		2-6	22-58	188-490	1690-4400
Reg-09		0-5	1-21	29-730	137-3400
Reg-11		0-11	0-84	0-829	0-6447
Reg-14		< LOD	< LOD	50-423	419-3541
EKO-12		4-78	31-610	301-5930	2352-46408
EKO-14		1-20	11-236	72-1540	845-18 122
EKO-21		24-105	203-888	1842-8070	16026-70 211
GYDA-18		1-6	8-41	69-361	463-2 438
GYDA-21		6-220	47-1800	445-17000	3406-130000
VAL-02		10-101	75-748	756-7553	5693-56 843
VAL-04		0-138	0-1012	0-10118	0-77261
VAL-05		3-91	27-718	259-6984	2016-54320
VAL-15		0-64	0-500	0-4817	0-37980
ULA-06		42-384	324-2996	3141-29020	25330-234 031
Reg-12	northern North Sea	< LOD	< LOD	16-180	61-700
SNB-16R		< LOD	< LOD	435-435	1650-1650
VI-RB		< LOD	< LOD	101-101	205-205
STC-06R		0-10	0-100	0-737	0-7 459
KV-14		2-37	19-473	117-2876	1478-36181
KV-02		20-62	204-626	1540-4717	15711-48130
VI-01		12-62	59-313	885-4698	4610-24468
VI-03		7-19	41-110	203-550	1180-3200
VI-30		46-120	146-380	3370-8800	11106-29000
Vega-R		< LOD	< LOD	101-235	277-647
STT-2	Barents Sea	5-10	12-25	346-737	885-1883
KF2-6		1-12	4-56	71-941	319-4235
SC3-4		7-31	24-98	581-2410	1744-7230
KRT-14		4-10	13-37	210-585	758-2115
GRS-2		14-42	35-106	1054-3178	2 675-8068
All areas Average ± SD (min-max)		6±11 to 58 ± 77 (<LOD-384)	41±72 to 436±612 (<LOD-2 996)	494±814 to 4408±5837 (0-29 020)	3149±5554 to 33416±47001 (0-234 031)
central North Sea Average ± SD (min-max)		5±10 to 81±93 (<LOD-384)	43±81 to 647±729 (<LOD-2996)	412±770 to 6155±7003 (<LOD-29020)	3 379±6 316 to 49 719±55 948 (<LOD-234031)
northern North Sea Average ± SD (min-max)		9±15 to 31±40 (<LOD-120)	47±72 to 200±231 (<LOD-626)	677±1064 to 2333±2920 (<LOD-8 800)	3 628±5439 to 15164±17749 (<LOD-48 130)
Barents Sea Average ± SD (min-max)		6±5 to 21±15 (0-42)	18±12 to 64±36 (0-106)	452±385 to 1 570±1157 (0-3178)	1 276±937 to 4706±2854 (0-8068)

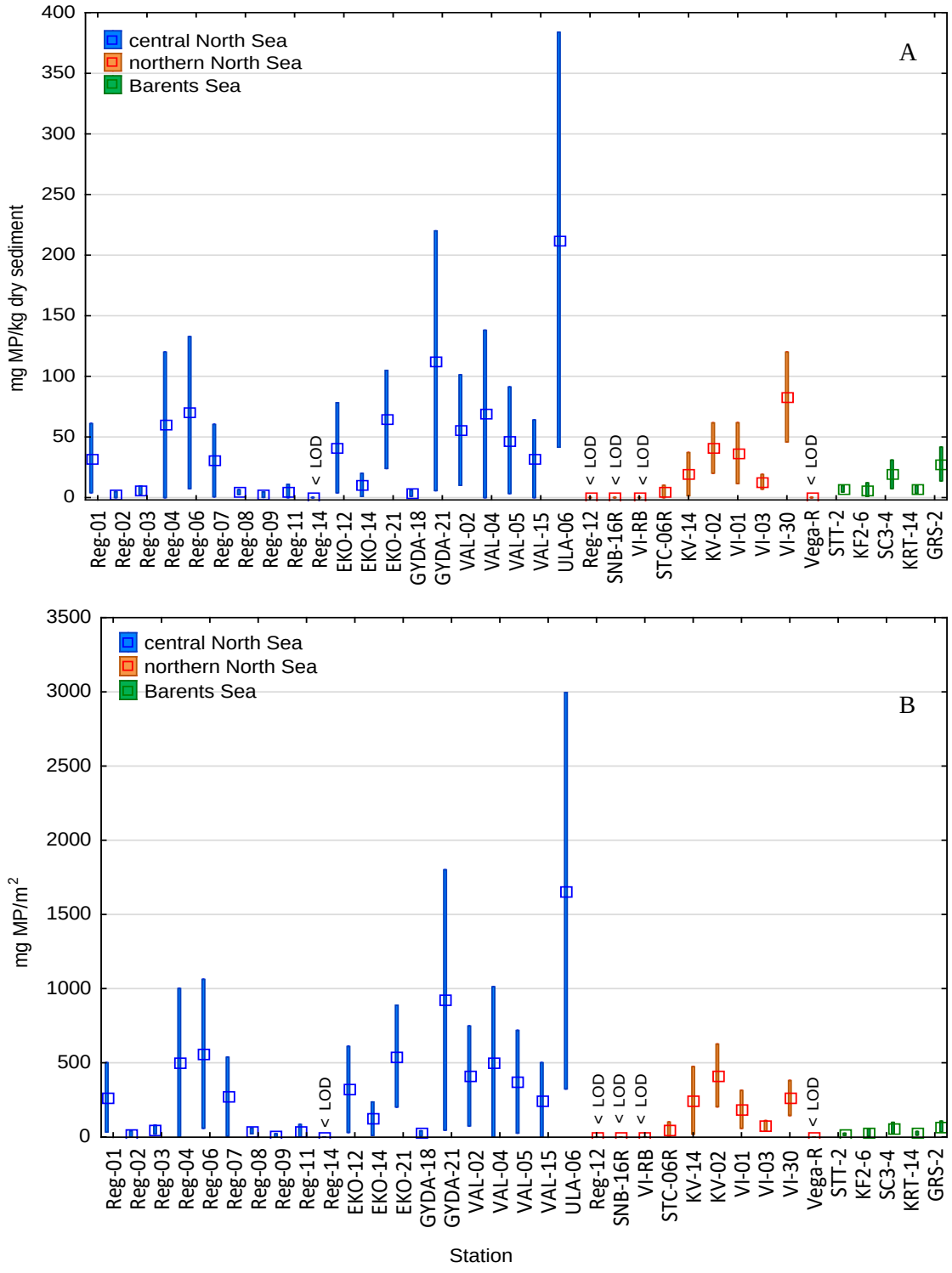


Figure 4-1. Microplastic concentration range (A: mg/kg dry sediment; B: mg/m2). Boxes indicate median concentrations, while whiskers show lower and conservative estimates (lower estimate are based on those confirmed by FT-IR, while conservative estimate include particles whose FT-IR spectra did not correspond to anything in the library).

As presented in Figure 4-1 and Table 4-1, the range of MP concentration on a weight basis varied substantially between lower and conservative estimate, especially in the samples from the central North Sea (< LOD to 384 mg/kg /< LOD to 2 996 mg/m^2) compared to the northern North Sea (< LOD to 120 mg/kg / < LOD to 626 mg/m^2) and the Barents Sea (0 – 42 mg/kg / 0 – 106 mg/m^2).

When considering conservative MP estimate, central North Sea was the area with the highest average MP concentration (81 ± 93 mg/kg), compared to the northern North Sea (31 ± 40 mg/kg) and the Barents Sea (21 ± 15 mg/kg), as shown in Figure 4-2. The samples with the eight highest conservative estimated MP concentrations were all from the central North Sea. However, the lower MP concentration (confirmed by FT-IR) was highest in the northern North Sea (9 ± 15 mg/kg), followed by the Barents Sea (6 ± 5 mg/kg) and the central North Sea (5 ± 10), but the geographical differences were considerable lower compared to the conservative concentrations (Figure 4-2). The trends were similar for MP concentrations reported as numbers of items/kg and items/m^2 (Figure 4-3).

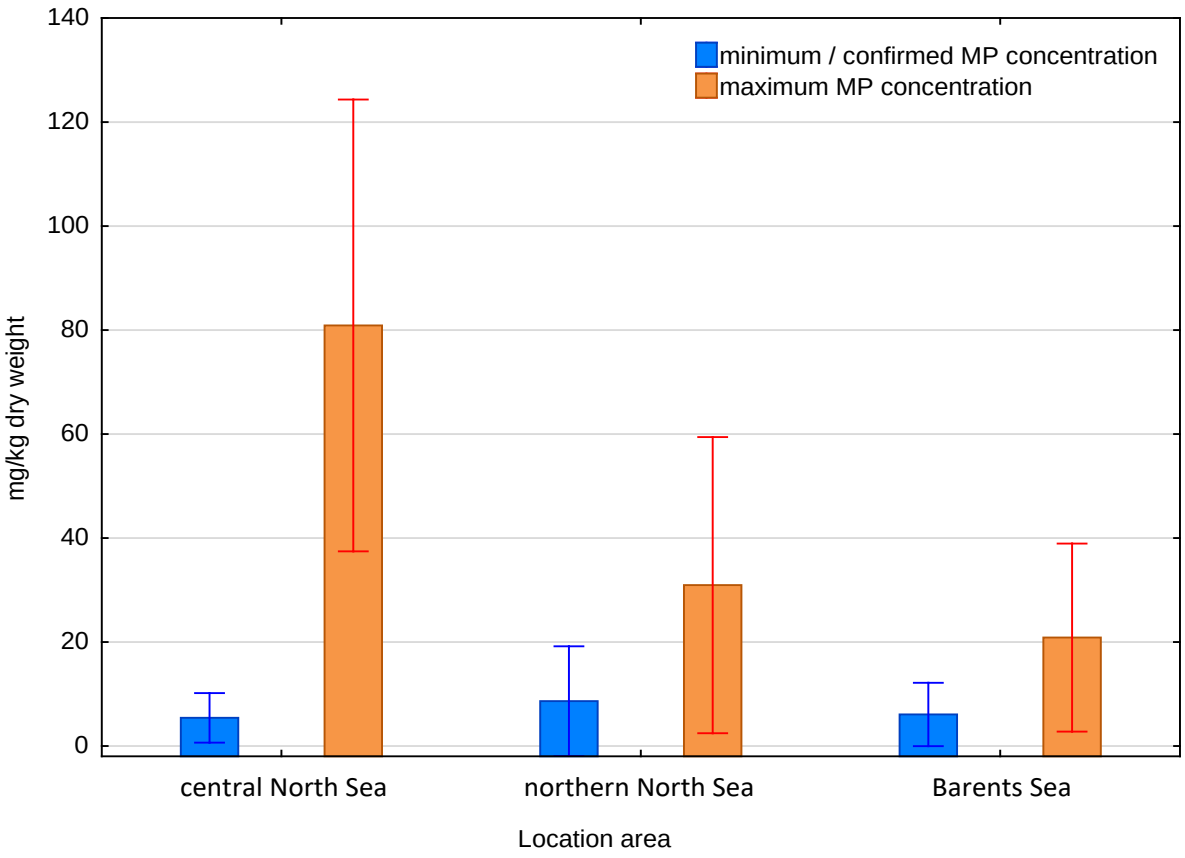


Figure 4-2. Average microplastic concentrations (mg/kg dry sediment). Boxes indicate average concentrations, while whiskers show 95 % confidence interval. Lower estimate (blue): based on those confirmed by FT-IR; conservative estimate (orange bars): based on lower estimate plus particles whose FT-IR spectra did not correspond to anything in the library (match score < 0.6, possible plastic).

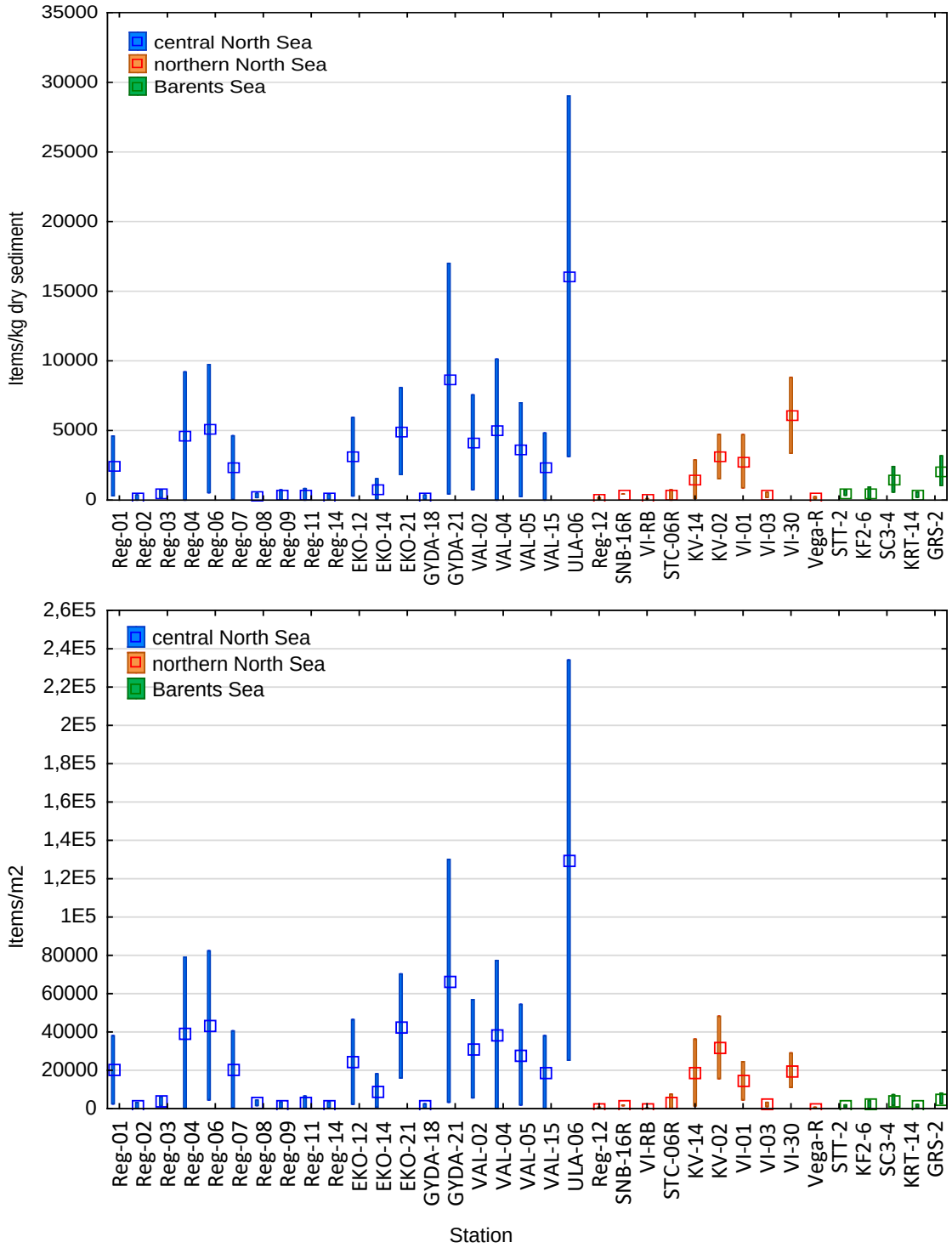


Figure 4-3. Microplastic concentration range (A: items/kg dry sediment; B: items/m²). Boxes indicate average concentrations, while whiskers show lower and conservative estimated concentrations, where lower estimate are based on those confirmed by FT-IR, while conservative estimate include particles whose FT-IR spectra did not correspond to anything in the library (match score < 0.6, possible plastic).

4.2.2 Sample composition

The percentage composition of identified particles categorized as unknown (match score < 0.6 with the FT-IR library), mineral, organic, paint, petro-pyro, plastic and rubber, is listed in Table 4-3. Pie charts with relative compositions of identified particles are shown for each analyzed sample (see Figure 4-4). The majority of particles were classified as unknown or organic (on average: 65 ± 29 % and 14 ± 19 %, respectively). Regarding the presence of organic materials, this implies that the digestion method was not fully effective at removing 100% of all organic material. The most frequently found plastic polymer in the samples from the central North Sea was polyacrylamide, whereas PE-chlorinated was the most abundant polymer in the northern North Sea. The other most common types of particles were chlorinated and chlorosulfonated-PEs, paints and rubbers. In the Barents Sea, there was not a clear pattern with regards to which polymers were most abundant, as several different ones could be found. Plastic polymers categorized as "others", which includes a diverse mixture, appeared in sediment samples from all areas. In most cases, this category represents polymers containing high concentrations of plasticizers or additives, which often have commercial product names, according to the FT-IR libraries used. A further discussion on the uses these polymer types is presented below.

As shown Figure 4-4, the number of organic particles was relatively higher in the samples from the Barents Sea compared to the central- and northern North Sea. Further, petro-pyro particles were most frequent in the samples from the northern- and central North Sea, compared to the Barents Sea.

Table 4-3. Percent composition of the particles in the samples, as classified by FT-IR. nd = not detected.

Station	Location area	Un-known	Identified						Most frequent plastic* identified	Second most frequent plastic* identified	Most frequent plastic* identified
			Mineral	Organic	Paint	Petro-pyro	Plastic	Rubber			
Reg-01	central North Sea	93 %	0 %	0 %	0 %	0 %	7 %	0 %	Polyacrylamide	Paint	Polyacrylamide and paint particles (particularly phenoxy resins)
Reg-02		75 %	0 %	20 %	0 %	5 %	0 %	0 %	Paint	nd	
Reg-03		44 %	16 %	24 %	0 %	0 %	16 %	0 %	PET	Paint	
Reg-04		100 %	0 %	0 %	0 %	0 %	0 %	0 %	nd	nd	
Reg-06		84 %	0 %	12 %	2 %	0 %	2 %	0 %	Paint	PP-chlorinated	
Reg-07		93 %	1 %	5 %	0 %	0 %	1 %	0 %	Polyacrylamide	Paint	
Reg-08		15 %	0 %	0 %	31 %	43 %	12 %	0 %	Paint	Plastics (other)	
Reg-09		96 %	0 %	0 %	0 %	0 %	4 %	0 %	PE-chlorosulfonated	Paint	
Reg-11		62 %	0 %	16 %	0 %	21 %	0 %	0 %	Paint	nd	
Reg-14		66 %	0 %	14 %	0 %	10 %	10 %	0 %	Plastics (other)	Paint	
EKO-12		79 %	3 %	11 %	2 %	3 %	3 %	0 %	Paint	PP-chlorinated	
EKO-14		82 %	4 %	6 %	0 %	4 %	4 %	0 %	Plastics (other)	Polyacrylamide	
EKO-21		61 %	2 %	17 %	1 %	1 %	17 %	0 %	Polyacrylamide	Paint	
GYDA-18		79 %	2 %	0 %	0 %	0 %	19 %	0 %	PE-chlorinated	Paint	
GYDA-21		97 %	0 %	0 %	0 %	0 %	0 %	3 %	Rubber	Paint	
VAL-02		66 %	3 %	20 %	0 %	3 %	3 %	5 %	Rubber	Plastics (other)	
VAL-04		83 %	2 %	6 %	0 %	9 %	0 %	0 %	Paint	nd	
VAL-05		90 %	0 %	3 %	2 %	4 %	0 %	2 %	Paint	Rubber	
VAL-15		93 %	1 %	6 %	0 %	0 %	0 %	0 %	nd	nd	
ULA-06		83 %	1 %	5 %	1 %	1 %	9 %	0 %	Plastics (other)	PET	
Reg-12	northern North Sea	91 %	0 %	0 %	0 %	0 %	9 %	0 %	Plastics (other)	Paint	PE-chlorinated, rubber and "other" plastics
SNB-16R		0 %	0 %	25 %	19 %	0 %	38 %	19 %	PE-chlorinated	Paint	
VI-RB		0 %	0 %	84 %	0 %	0 %	16 %	0 %	PE-chlorinated	Paint	
STC-06R		88 %	8 %	1 %	0 %	3 %	0 %	0 %	Paint	nd	
KV-14		89 %	2 %	5 %	0 %	0 %	3 %	1 %	Rubber	PE-chlorosulfonated	
KV-02		58 %	0 %	4 %	2 %	7 %	16 %	13 %	Rubber	Plastics (other)	
VI-01		76 %	0 %	2 %	0 %	3 %	15 %	3 %	Plastics (other)	PET	
VI-03		44 %	0 %	0 %	0 %	19 %	37 %	0 %	PE-chlorinated	PS	
VI-30		52 %	0 %	0 %	38 %	10 %	0 %	0 %	Paint	Rubber	
Vega-R		0 %	0 %	16 %	0 %	48 %	36 %	0 %	Plastics (other)	Paint	
STT-2	Barents Sea	14 %	0 %	73 %	0 %	0 %	5 %	7 %	Rubber	PE-chlorinated	Various (PE-chlorinated, PE:PP, rubber and paint)
KF2-6		62 %	1 %	31 %	0 %	0 %	5 %	0 %	PE-chlorinated	Paint	
SC3-4		54 %	0 %	25 %	6 %	3 %	7 %	6 %	Paint	Rubber	
KRT-14		43 %	0 %	29 %	5 %	3 %	18 %	3 %	PE:PP	Paint	
GRS-2		52 %	0 %	19 %	3 %	3 %	14 %	10 %	Rubber	PE-oxidized	

**Plastic is here defined as plastic polymers, rubber and paint.*

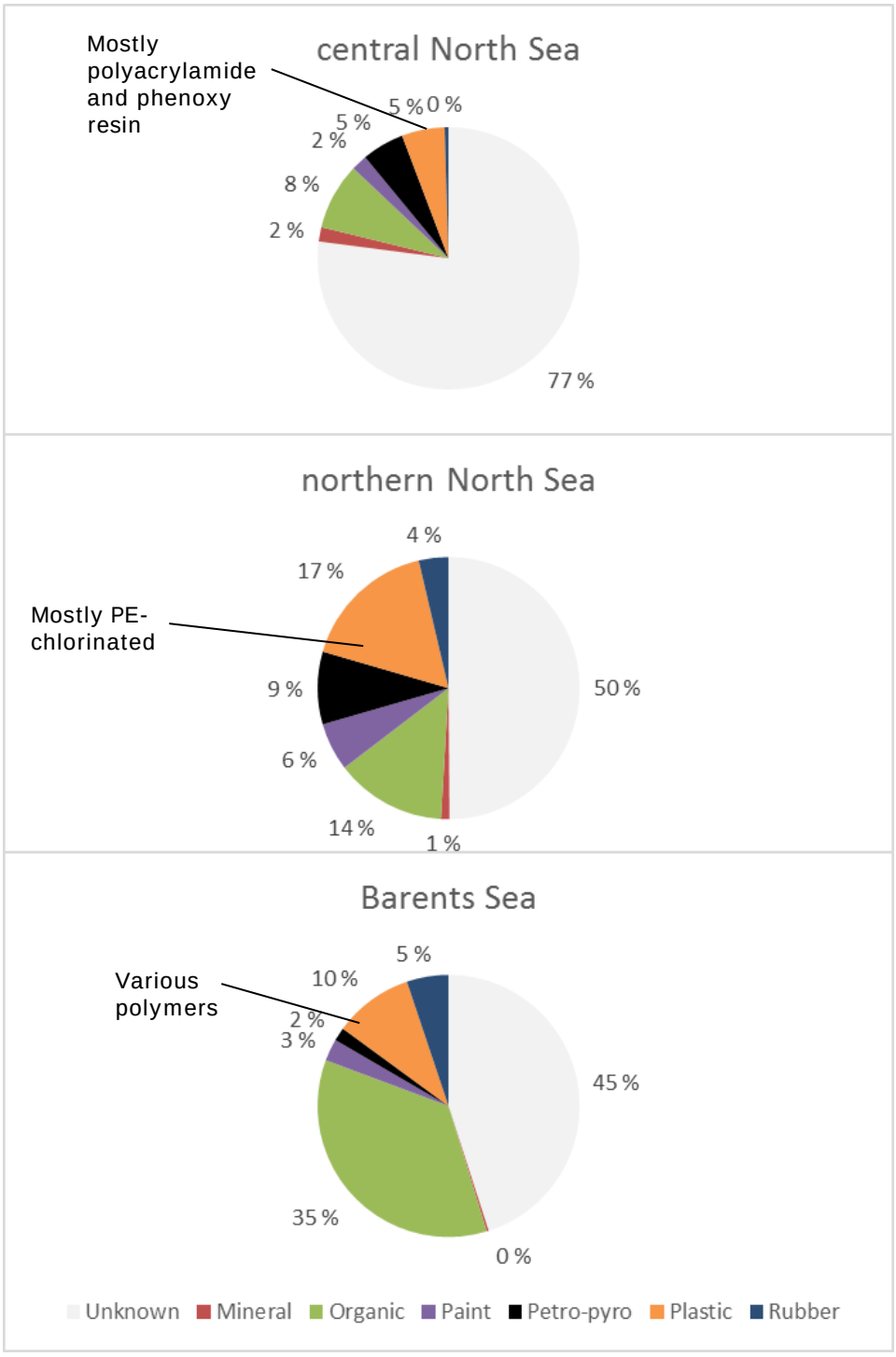


Figure 4-4. Average percentage composition of unknown (match score < 0.6 with the FT-IR library), mineral, organic, paint, petro-pyro, plastic (most frequent polymers are shown) and rubber particles.

In Table 4-4, the average percentage of confirmed (identified by FT-IR – search score ≥ 0.6) anthropogenic particles (petro-pyro, paint, rubber and plastic) vs non-anthropogenic particles (organic, mineral), per area is presented. It is ambiguous whether "petro-pyro" particles are to be considered anthropogenic or natural, as they can be both; therefore, data classifying "petro-pyro" particles as anthropogenic is also presented.

Overall it appears that an average of 14% ± 16% of the particles that were present after the applied sediment separation and digestion method can be considered plastic (as paint, rubber and synthetic plastics), and within individual samples this could vary from 0-75%. Plastics were the most dominant type of particle identifiable in the northern North Sea, but in the central North Sea and Barents Sea the most dominant type was organic particles resistant to chemical digestion.

Table 4-4. Overview of statistics – composition of anthropogenic and non-anthropogenic particles (particles identified and classified with FT-IR analysis).

Location area	Confirmed anthropogenic particles (petro-pyro, paint, rubber, plastic)	Confirmed paint, rubber, plastic	Confirmed non-anthropogenic particles (organic, mineral)
All areas **Average ± SD** **(min-max)**	20% ± 23% (0-84%)	14% ± 16% (0-75%)	15% ± 19% (0-84%)
central North Sea **Average ± SD** **(min-max)**	13% ± 18% (0-84%)	8% ± 9% (0-38%)	10% ± 10% (0-40%)
northern North Sea **Average ± SD** **(min-max)**	35% ± 30% (3-84%)	26% ± 22% (0-75%)	15% ± 26% (0-84%)
Barents Sea **Average ± SD** **(min-max)**	19% ± 10% (5-30%)	18% ± 9% (5-27%)	36% ± 21% (19-73%)

5 DISCUSSION

5.1 Analysis with TG-FTIR

Despite several attempts with TG FTIR analysis it must be concluded that for the sediment analysis it was not successful. The amount of plastic in the samples was too small leading to a too small signal to noise ratio, which lead to a significant source of error which is amplified if several types of plastic are present in the sample.

An alternative method that has been applied for analysis of microplastic in other studies is TG-thermal desorption-GCMS (gas chromatography- mass spectrometry, see Dümichen et al. 2015 and 2017). In this method, the substances or products from the TG are collected in an absorbent, followed by thermal desorption and transfer to a GCMS for separation, identification and quantification. This method has increased sensitivity for individual components. Another similar technique is pyrolysis GCMS (E. Fries et al 2013).

5.2 Accuracy of FT-IR data

As described in the results section, a relatively large quantity of analyzed particles were classified as unknown, due to no match (score < 0.6) with reference spectra in the library database provided by the manufacturer. In addition to a possibly incomplete library, the low score could be caused by other factors, such as differences between the surface of the reference sample and measurement target. For example, if the surface of the sample is weathered and thereby oxidized, the spectrum of the sample will not match well with the reference sample. A relatively poor match is also expected if an analyzed plastic particle consists of a mixture of different polymers and additives, such as many paints and epoxides.

In this report, we revise the maximum MP concentrations presented in the previous report (DNV GL 2018), based on MP particles confirmed with FT-IR, as well as particles whose FT-IR spectra did not correspond to anything in the library (“unknown”, match score < 0.6, possible plastic, e.g. highly weathered plastic). This value is still considered conservative. If there were no unknown particles, the reported MP concentration would be somewhere between the reported lower and conservative value. However, it is important to mention that there also are uncertainties regarding the identification of particles with a quality index ≥ 0.6. As mentioned in the Materials and Methods section, FT-IR spectra with any matches with scores < 0.7 but ≥ 0.6 were individually inspected and interpreted, as an attempt to reduce this uncertainty. However, it cannot be ruled out that misinterpretations may have been made. In addition, response testing was performed on known plastic polymers to check the quality index with the reference library. E.g. reference PET powder (<300 µm, Goodfellow UK) was analysed in transmission mode, and the resulting match score (or quality index) was 0.98 with the PET polymer in the library (see Figure 5-1). However, a thorough library check was not conducted.

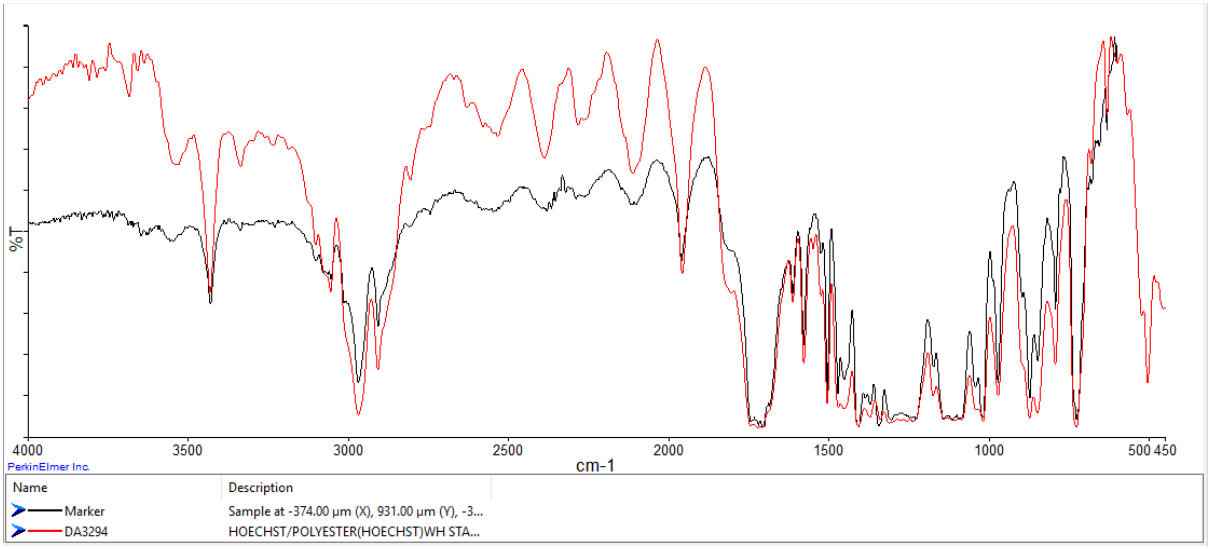


Figure 5-1. FT-IR spectra of analysed PET powder (black line) and reference FT-IR spectra of PET-polymer from the library (red line) (match score of 0.98 in transmission mode)

Furthermore, there are uncertainties associated with the actual FT-IR apparatus. E.g. to obtain high quality spectra in transmission mode, samples should be ideally < 50 microns thick and sit as flat as possible on the slide. However, particles from environmental samples, as those in this project, are often irregularly shaped and with an uneven surface, which may reduce the quality of the recorded spectra using ATR, and some might be highly opaque and thick. Chemical oxidation as part of the sample preparation was performed as described in DNV GL (2018), for enriching the percentage of plastic in the samples, removing biological/organic coatings, and therefore facilitating FT-IR analysis; this may have also oxidized the surface of some polymers to some extent, which would affect the FT-IR spectra.

5.3 Revised microplastic concentrations

As previously mentioned, maximum MP concentrations have earlier been reported in DNV GL (2018) based on the assumption that all particles that were found in the sediments, particles with a density less than the density separation fluid of 1.53 g/mL, having a size range between 45 µm and 5 mm, and resilience to an organic matter digestion process, potentially *could* be microplastics. As mentioned in the report, this conservative estimate could also include other materials such as soot, char, porous glass and ceramics, as well as resistant organic matter with regards to the organic matter digestion process. In this report, it was shown that a substantial number of identified particles were organic particles that survived the digestion process and were not microplastic polymers. A large number of particles were also categorized as “unknown”, meaning we still don’t know what these particles are. Thereby, the confirmed (or lower) microplastic concentrations in this report are substantially lower than what was reported in DNV GL (2018). As stated in the earlier report, this shows the importance of performing polymer identification techniques, such as FT-IR, to verify if particles are microplastics and to identify the polymer types in order to provide reliable information needed to make assumptions with regard to potential sources and the distribution of microplastics on the Norwegian Continental Shelf (NCS).

In DNV GL (2018), the sediment sample from station ULA-06 from the central North Sea, was reported as the sample with the highest mMP concentration of 410 mg/kg (3 200 mg/m^2, corresponding to 31 000 items/kg or 250 000 items/m^2). ULA-06 was one of the samples with highest microplastic concentration also in this

report (42-384 mg/kg and 324-2 996 mg/m^2, corresponding to 3 141-29 020 items/kg and 25 330 – 234 031 items/m^2). In addition, relatively high concentrations were found in the samples from VI-30, KV-02 from the northern North Sea This was also the area with the highest percentage of identified microplastic polymers, for individual samples (SNB-16R: 38 % and VI-03: 37 %, as shown in Table 4-3).

As mentioned in the results section, the average conservative estimated MP concentrations in this report was highest in the central North Sea (81 ± 93 mg/kg), compared to the northern North Sea (31 ± 40 mg/kg) and the Barents Sea (21 ± 15 mg/kg). This supports our earlier results based on visual analysis (DNV GL, 2017), where the concentration of potential or maximum microplastics were 90 ± 100, 30 ± 40 and 30 ± 20 mg mMP/kg dry sediment for the central North Sea, the northern North Sea and the Barents Sea, respectively. However, the results in this report have shown that this is largely due to the large fraction of particles that are unknown. The lower estimated MP concentration (confirmed by FT-IR) was on average highest in the northern North Sea (9 ± 15 mg/kg), followed by the Barents Sea (6 ± 5 mg/kg) and the central North Sea (5 ± 10), but statistically there is even less of a significant difference between the three areas (Figure 4.2). The trends were similar for MP concentrations reported as numbers of items/kg and items/m^2 (Figure 4-3).

Even though some of the regional samples from the central North Sea had relatively high microplastic concentrations (see Figure 4-2 and Figure 4-3), the average lower and conservative estimated concentrations ranged from 3 to 5 times lower compared to the other samples from the central North Sea.

5.4 Revised literature comparison

As mentioned in DNV GL (2018), differences in sampling and analytical methodologies make comparisons with previous studies difficult, although magnitude-scale comparisons may be reasonable. In the following table, there is a list of reported MP abundances in sediments worldwide.

Table 5-1. Abundance of microplastics in sediments worldwide. The concentrations are expressed as mg or items per kg dry sediment, as well as mg or items per m² sediment.

Location	Location specification	Particle size	Measured concentration	Reference
Brazil	Beach	2 – 5 mm	60 items/kg	Ivar do Sul et al., 2009
Chile	Beach	1 - 4.75 mm	<1-805 items/m^2	Hidalgo-Ruz & Thiel, 2013
India	Ship-breaking yard	1.6µm – 5 mm	81.4 mg/kg	Reddy et al., 2006
India	Beach	1 – 5 mm	10 – 180 items/m^2	Jayasiri et al., 2013
Singapore	Mangrove	1.6 µm – 5 mm	36.8 items/kg	Nor & Obbars, 2014
NW Pacific	Deep sea trench	300 µm – 5 mm	60 – 2 020 items/m^2	Fisher et al., 2015
South Korea	Beach	50 µm – 5 mm	56 – 285 673 items/m^2	Kim et al., 2015
Belgium	Continental Shelf	38 µm – 1 mm	97.2 items/kg	Claessens et al., 2011
Italy	Subtidal	0.7 µm – 1 mm	672 – 2 175 items/kg	Vanello et al., 2013
Worldwide	Deep sea	5 µm – 1 mm	50 items/m^2	Van Cauwenberghe et al., 2013
Slovenia	Beach	0.25 – 5 mm	177.8 items/kg	Laglbauer et al., 2014
Arctic	Deep sea	-	42 - 6 595 items/kg dry	Bergmann et al., 2017
Norway	*Norwegian Continental Shelf*	*45 µm – 5 mm*	*< LOD – 380 (min: 6±11 to max: 58±77) mg/kg* *< LOD – 3000 (min: 41±72 to max: 436±612) mg/m^2* *0 – 29 000 (min: 494±814 to max: 4 400±5 840) items/kg* *0 – 234 000 (min: 3 150±5 550 to max: 33 420±47 000) items/m^2*	*This report*

As seen in the table above, reported MP concentrations in sediments vary widely. Except for this report, only one of the studies above reported concentration data on a weight basis (mg/kg or mg/m^2): a large ship-breaking yard in India (Reddy et al., 2006), with measured MP concentration of 81 mg/kg sediment. This concentration is higher than the lower estimated MP concentration in this report (6±11 mg/kg). However, the conservative estimated MP concentrations in this report (58±77 mg/kg), is in the same range as the concentrations found in the intertidal sediments of this ship-breaking yard (Reddy et al., 2006). This may indicate relatively high MP concentrations along the Norwegian Continental Shelf, as plastics contribute to 40 – 50 % of the ship-breaking waste that enters the marine environment, according to Reddy et al. (2006); though the uncertainty in the conservative estimated MP concentrations reported is considered relatively large.

A study of microplastics in Arctic deep-sea sediments from the HAUSGARTEN Observatory (2 340 – 5 570 m depth) recorded concentrations of microplastics from 42 to 6 595 MP items/kg sediment dry weight, with an overall mean number of 4 356 (± 675 standard error) items/kg (Bergmann et al., 2017). This is about ten times higher than the reported lower concentrations in this report (494±814 items/kg), but in the same range

as conservative estimated concentrations (4 408±5 837 items/kg). However, it should be kept in mind that HAUSGARTEN study was able to quantify microplastics less than 10 µm and found the majority of particles to be less than 25 µm (which is below the 45 µm cut off of this study).

As mentioned above, some of the observed differences in quantified microplastic concentrations may be due to the use of different methodologies, as there is a wide variety of approaches used to identify and quantify microplastics. For meaningful comparisons, it is important to define specific methodological conditions, such as the density of the solution used in the separation process and the size range of microplastics quantified.

Even though the reported lower and conservative MP concentrations varied considerably (see the above table), microplastic particles were confirmed in sediment samples widespread at the Norwegian Continental Shelf, which may confirm the widespread occurrence of microplastics in the marine environment. According to a review paper of microplastics in the marine environment (Hidalgo-Ruz et al., 2012), values for abundances ranged from 0.21 to more than 77 000 items per m^2 in sediment, which is several orders of magnitude higher than in the sea surface. This shows that a substantial amount of microplastics can be found in sediments, as also is indicated by this study. Sediments are proposed as the final destination of microplastics and other pollutants in the environment. This is due to natural processes such as simple gravity for high density particles or biofouling, clay-aggregation or marine snow aggregation processes that can lead to the setting of low density particles.

5.5 Microplastic composition and origin

Plastic has diverse uses that vary from food packaging and other consumer products, plastic bags, drinking cups, to plates and laminates, foundations of road constructions, from clothes, cosmetics and hygiene articles to surgical implants, prosthesis and more. According to a report written by Mepex (2014), very few commercial-use products with primary microplastics are documented, and only brief mentions of some unspecified use in petroleum industry are reported. In oil, gas or other kinds of rock drilling, drilling fluids based on plastic microbeads have been used for a few decades (Skall et al., 1999), as well as Teflon strengthened particles have been patented and marketed for drilling purposes internationally for the last ten years.

Microplastic composition for each individual sample is provided in appendix A. Looking at this data as a whole, it is evident that although there was a large array of plastics found in the samples, the following groups were the most common: paint resins, synthetic rubbers, chlorinated-polyethylene, polyacrylamide and PET. A description of some of the most frequently detected polymers/plastics is as follows (it is noted that the written densities are typical and may vary depending on filler type and amount).

- *Paint resins (e.g. density 1.18 kg/L, phenoxy resin)* were the most common plastic in Reg-02, Reg-06, Reg-08, Reg-011, Val-04, Val-05, STC-06R, and KFT-4, and second most common in Reg-01, Reg-03, Reg-07, Reg-09, Reg-12 Reg-14, Eko-21, Eko-18, Gyda-21, SRB-16R, V1-RB, Vega-R, KFT-6, KRT-14. Phenoxy resin, which was one of the most typical paint-particulates, is commonly used as a marine varnish. Chlorinated-PP (second most common plastic particle in Eko 12) is often used as coating/ adhesive; though this could be a miss assignment of chlorinated-PE (see below)
- *Synthetic rubber*s– were the most common plastic particle in Gyda-21, Val-02, KV-02, KV-14, STT-2 and GRS-2, and the second most in Val-05, VI-30 and SRC-3. Chlorosulfonated-PE is a

chemically stable rubber (density 1.2 kg/L) and was the most frequently found in Reg-09 and second most in KV-14. Note that the Chlorosulfonated-PE FT-IR spectra is quite similar to chlorinated-PE.

- *Chlorinated-PEs* (*density 1.16 kg/L*) were the most common plastic type in Gyda-18, SNB-16R, VI-03, V1-RB and KFT-6, and second most common in Eko-12 and STT-2. In VI-03, Chlorinated-PE particles were abundant as black granules, between 1 – 2 mm in length. This was the most abundant particle in the sediment samples from the northern North Sea. Chlorinated polyethylene is a variation of polyethylene, but with a chlorine content. These polymers are used as major and minor components in a wide assortment of applications in industry. For instance, they can be used as process aid in rigid PVC foam applications as a partial replacement for acrylics. Applications include cable and wire coverings, which could explain why these polymers were found in the sediment samples.
- *Polyacrylamides* (*density 1.11 kg/L*) – was the most frequent plastic particle in Reg-01, Reg-07, Eko-21, second most frequent in Eko-14, and was found in several other samples. Polyacrylamides are commonly used as a flocculant in water and wastewater treatment, as a soil conditioner, and as a viscosity modifier and friction reducer in both enhanced oil recovery and high volume hydraulic fracturing. Polyacrylamides are considered a water-soluble polymer, and thus their presence in sediments may be due to i) large particle size, preventing dissolution or ii) polyacrylamide coated clays/composites or other flocs with a high density. It is noted that many of the findings, such as on regional stations and in the Barents Sea, are far away from oil & gas installations, potentially indicating long range transport.
- *PET (density 1.38 kg/L)* – was the most frequent plastic particle in Reg-03 and the second most abundant particle in ULA-06 and VI-01. PET is used in a wide variety of applications, including clothing fibers.

One general commonalities from these groups is that they are all high-density polymers, and thus are the type that would be expected to sink to the sediments on their own, in the absence of flocculation with e.g. biota, aquatic fecal matter or clay minerals. However, some low density particles were also spotted (e.g. PE:PP copolymer particles were the most frequent particle in the Barents Sea sample KRT-14). The occurrence of such particles would be through flocculation with higher density particles, such as aggregation in marine snow. Previous studies have shown that the accumulation of biofilm on plastic affects its sinking behavior, in addition to the effects of UV-light and mechanical abrasion (Andrady, 2011; Singh and Nisha Sharma, 2008; Woodall et al., 2014).

In addition to the above four categories, there was another type of particle that was visually common in many samples, but could not be characterized conclusively by FT-IR. These particles were white / clear granules of approximately the same shape and size (100 - 500 µm), that were found in many of the samples with the highest abundance of conservative microplastic concentrations", such as Ula-06, Gyda-21, Val-05 as described in DNV GL (2018). An example is presented in Figure 5-2 for Ula-06.

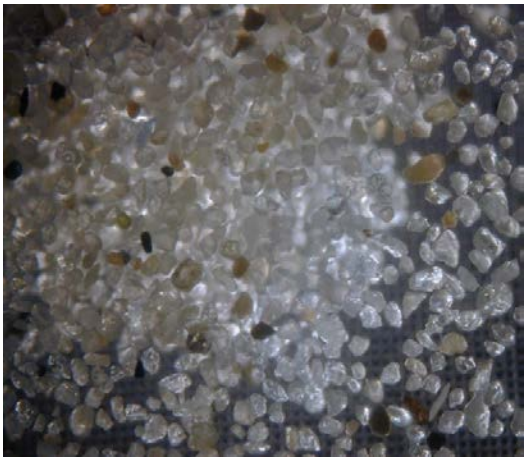


Figure 5-2. 100-500 µm clear, white granules in Ula-06 and observed in several other samples that could not be identified by FT-IR

In the samples where these were observed, there was a very high abundance of particles that had a very similar FT-IR spectrum (see Figure 5-3), which gave a consistent match with the library entry for the polyphenyl ether "POLY(2,5-DIMETHYL-1,4-PHENYLENE-3,3'-DIOXO-5,5'-BIINDOL-2,2'-DIYL) 2/40", though usually with scores between 0.4 – 0.6. We cannot conclude from this spectrum if it is in fact a polyphenyl ether. Based on the FT-IR spectrum, it appears to be a highly oxidized organic material. This FT-IR spectrum was found in high frequency in the following samples: ULA-06 (comprising the majority of the "unknown" particles), VI-30, KV-02, Val-05 and EKO-21.

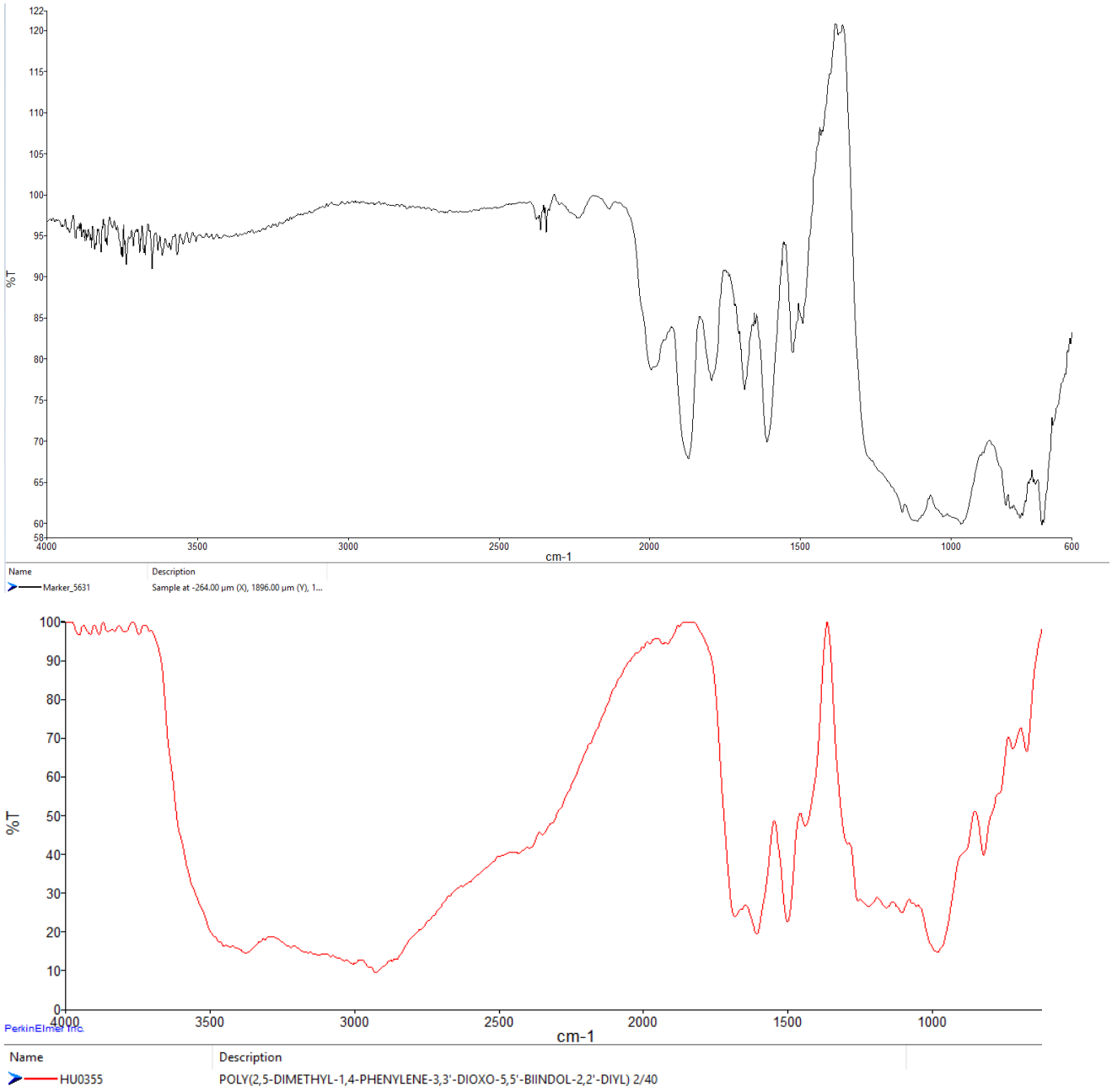


Figure 5-3. FT-IR spectra of a 100-500 µm clear, white granule from Ula-06. There was a very high abundance of particles with very similar FT-IR spectra as shown in this figure, which gave a consistent match with the polyphenyl ether "POLY(2,5-DIMETHYL-1,4-PHENYLENE-3,3'-DIOXO-5,5'-BIINDOL-2,2'-DIYL) 2/40" in the library (bottom), though usually with scores between 0.4-0.6. The most similarities of the unknown particle with the matched polyphenol ether are at 1700 1/cm-1 or lower.

The large difference in average lower and conservative estimated MP concentration in samples from especially the central North Sea, is due to the fact that many of the particles in these samples were categorized as unknown and / or organic particles, rather than plastic. For these samples, the range in min-max concentrations was especially large for samples from the stations Gyda, Valhall, Ula and Kvitebjørn. Interestingly, white / clear granules of approximately the same shape and size (100 - 500 µm) were found in all these samples, as mentioned especially for sample ULA-06, GYDA-21 and VAL-05 in DNV GL (2018), corresponding to the unknown particle in Figure 5-2. The low scores could be a consequence of weathering, as weathering changes the surface of the particles, complicating comparison with reference spectra. In addition, they could be complex mixtures of different polymers, which are difficult to classify with FT-IR, even when using the "multisearch function" through Perkin-Elmer. For comparison, these particles were much less frequent in the regional samples.

In DNV GL (2018), the sediment sample from station ULA-06 from the central North Sea, was reported as the sample with the highest mMP concentration of 410 mg/kg (3 200 mg/m^2, corresponding to 31 000 items/kg or 250 000 items/m^2). ULA-06 was one of the samples with highest microplastic concentration also in this report (42-384 mg/kg and 324-2 996 mg/m^2, corresponding to 3 141-29 020 items/kg and 25 330 – 234 031 items/m^2). It is suspected that this is a polymeric flocculant, similar to polyacrylamide, though with an unknown composition.

The only other study we are aware of to look at deep sea sediments from the North Atlantic with methodology similar to ours is Bergmann et al. (2017). This study looked at microplastics near the HAUSGARTEN observatory, west of Svalbard, though they used a different size fraction (10-500 µm). That study found chlorinated ethylene to be one of the most abundant particles (827 to 2106 particles/kg), similar to this study, and they also appeared generally as black granules. The second most abundant was "polyamide" (316 – 1739 particles/kg), which could refer to nylon or possibly polyacrylamide in addition. Several different rubber types were also reported in their samples. The clearest discrepancy with this study is that no paint particulates (e.g. epoxy/phenoxy resins) or polyacrylamide were reported; however, the protocols used for FT-IR spectra library comparisons was not identical, and may have played a role in this discrepancy.

6 CONCLUSIONS AND RECOMMENDATIONS

The results of this study provide further insight into the conclusions of the previous report (DNV 2018), where "maximum MP concentrations" were provided previous to instrumental attempts at microplastic identification. In this report, more reliable "conservative estimate of MP concentrations" are reported by eliminating particles that are confirmed to not be microplastics (minerals, organic materials, and petrogenic/pyrogenic particles) through FT-IR analysis. However, there are still many particles that remained unidentified. Therefore, results are presented as lower estimated MP concentrations (those identified with FT-IR as microplastics), and a revised conservative estimated of MP concentration (the sum of FT-IR identified microplastics and particles that could not be identified by FT-IR). Further, the identity of many of the microplastics could be elucidated. This extra analysis has led to the following conclusions:

- ✓ The average lower estimated MP concentration of 6 ± 11 mg microplastics/kg dry sediment (corresponding to a conservative estimate of 3149 ± 5554 items/m^2 sediment surface) of potential microplastics were found in the sediment samples from the Norwegian Continental Shelf.
- ✓ The revised conservative estimated MP concentrations for the Norwegian Continental Shelf are herein reported as conservative estimates of 58 ± 77 mg microplastics/kg dry sediment (corresponding to a conservative estimate of 33400 ± 47000 items/m^2 sediment surface).
- ✓ Only when considering the revised conservative estimated MP concentrations, the central North Sea and surrounding regional area had more MP than in the northern North Sea or Barents Sea areas, on average 81 ± 93, 31 ± 40 and 21 ± 15 mg microplastics/kg dry sediment, respectively. However, considering lower estimated MP concentrations, all areas have similar concentrations, being 5 ± 10, 9 ± 15 and 6 ± 5 mg microplastics/kg dry sediment, for the central North Sea, northern North Sea and the Barents Sea, respectively.
- ✓ There is a tendency for higher microplastics concentrations at locations close to oil & gas installations compared to regional stations, even when considering the lower estimated concentrations, but the results vary and are not statistically conclusive.
- ✓ The FT-IR analysis found several different types of plastics present, but the most common ones were i) chlorinated polyolefines, and in particular chlorinated polyethylene, which appeared in many samples as black granules, ii) paint resins such as phenoxy resin, iii) rubber materials, iv) polyacrylamides, and v) PET. These are all high-density polymers, which are expected to sink in the oceans based on gravitational forces alone.
- ✓ Several low-density particles could also be found in some of the samples, however only in rare cases where these the majority (KRT-14 from the Barents Sea).
- ✓ The results of this study have revealed relatively high conservative estimated concentrations of potential microplastics, which may confirm the widespread occurrence of microplastics in the marine environment. This is a similar conclusion to other studies in the literature, such as Bergman et al. (2017), which also looked at sediments in the North Atlantic.
- ✓ The results above are subject to various biases and should be interpreted with these in mind.

Follow-up work

This study is one of the few studies to investigate the presence and identity of microplastics in deep sea sediments. Sediments in this area are of particular interest, because of their importance to the marine ecosystem, as they can be contaminated by both long-range transport sources (via ocean currents) as well as marine activities (e.g. oil & gas, mining, fishing and shipping). It has been hypothesized that the majority of plastics that have been emitted into the ocean are currently in sediments, and that sediments are the ultimate environmental sink for oceanic plastic (Woodall et al., 2014). The effects of this potentially accumulating concentration of microplastic in benthic ecosystems are unknown but need further investigation (Galloway et al. 2017). Because of their persistence, plastics accumulating continuously in the environment can be considered a planetary boundary threat (Jahnke et al. 2017).

Based on these concerns and the results of this report, the following research questions are recommended as follow-up activities:

1) **Sources of the dominating plastics.** Considering the predominant plastics identified being chlorinated-polyolefines, polyacrylamide, PET, paint resins and rubber resins; this gives indication that these plastics are those that could be accumulating in sediments the quickest. In particular, chlorinated-polyethylene (Bergmann et al. 2017) and PET (Woodall et al., 2014) have been reported as dominating sediment microplastics. Further investigation on the emissions and transport routes of dominating plastics is worthy of prioritization for follow-up, as it is potentially these that accumulate in sediments the quickest.

2) **The unknown plastic**. As described above, several samples contained a homogenous, white, translucent particle, typically between 100-500 µm, showing a consistent FT-IR spectrum of a highly oxidized organic material. Further analysis is needed to identify this particle as it seems to be quite common. Different analytical techniques could be attempted. Comparison with FT-IR libraries not used in this study may also be of assistance.

3) **Ecological effects**. There are very few studies examining the impact of microplastics on deep sea or remote benthic ecosystems. Future work should be considered along this context, such as possible effects to benthic fauna and impacts to the marine food chain.

4) **Temporal trends.** Considering the potential of microplastics to be a planetary boundary threat (Jahnke et al. 2017), monitoring campaigns that address how microplastic concentrations change over time are needed. In this way, it can be confirmed if microplastic concentrations in sediments increase over time, or not, and ultimately how reduced or increased plastic emissions in future will effect microplastic concentrations in sediments over time. Such studies can include sediment core studies or revisiting previous sampling sites, such as the areas in this study, to examine temporal changes. Currently, sediment core studies are a more direct way to answer this research question, as methods to quantify microplastics are continuously being optimized and improved, and currently there is a large variation and ongoing development in methods being utilized.

5) **Combining mapping and modelling to link emissions sources with sediment sinks.** The geographical distribution of microplastics on the seabed remains unknown, as well as the processes that control the marine distribution. With this report and others like it, we are beginning to acquire initial empirical information about the distribution of microplastics in deep sea and remote areas. Further studies that link emission sources with sediment sinks, in combination with fate modelling, can be used to better establish in which regions microplastics accumulate in the

sediments the most. Further, such studies could ultimately be used to identify management strategies that prevent microplastics from being a planetary boundary threat.

7 REFERENCES

Andrady, A. L., 2011. Microplastics in the marine environment. *Marine Pollution Bulletin*, 62 (8): 1596-1605.

Bergmann, M., Wirzberger, V., Krumpen, T., Lorenz, C., Primpke, S., Tekman, M. B., & Gerdts, G. (2017). High quantities of microplastic in Arctic deep-sea sediments from the HAUSGARTEN observatory. Environmental science & technology, 51(19), 11000-11010.

Claessens, M., De Meester, S., Van Landuyt, L., De Clerck, K., Janssen, C. R., 2011. Occurence and distribution of microplastics in marine sediments along the Belgian coast. *Marine Pollution Bulletin,* 62 (2011), 2199-2204.

DNV GL (2018a). Microplastics in sediments on the Norwegian Continental Shelf. Report no: 2018-0050, Rev.01. Date: 2018-02-23.

Dümichen E, Barthel AK, Braun U, Bannick CG, Brand K, Jekel M, Senz R, Analysis of polyethylene microplastics in environmental samples, using a thermal decomposition method, Water Research, November 2015

Dümichen E, Braun U, Bannick CG, Eisentraut P, Fast identification of microplastics in complex environmental samples by a thermal degradation method, Chemosphere 174, February 2017

Fisher, V., Elsner, N. O., Brenke, N., Schwabe, E., Brandt, A., 2015. Plastic pollution of the Kuril-Kamchatka Trench area (NW Pacific). *Deep Sea Research II,* 111, 399-405.

Fries, E. et al., Identification of polymer types and additives in marine microplastic particles using pyrolysis-GC/MS and scanning electron microscopy, Environmental Science: Processes Impacts 15 (2013)

Hidalgo-Ruz, V., Gutow, L., Thompson, R. C., Thiel, M., 2012. Microplastics in the Marine Environment: A Review of the Methods Used for Identification and Quantification*. Environmental Science & Technology*, 40, 3060-3075.

Ivar do Soul, J. A, Spengler, Â., Costa, M. F., 2009. Here, there and everywhere. Small plastic fragments and pellets on beaches of Fernando de Noronha (Equatorial Western Atlantic). *Marine Pollution Bulletin*, 58, 1236-1238.

Jahnke, A., Arp, H. P. H., Escher, B. I., Gewert, B., Gorokhova, E., Ku¨hnel, D., Toorman, E., 2017. Reducing uncertainty and confronting ignorance about the possible impacts of weathering plastic in the marine environment. *Environmental Science & Technology Letters*, 4(3), 85-90.

Jayasiri, H. B., Porushothaman, C. S., Vennila, A., 2013. Quantitative analysis of plastic debris on recreational beaches in Mumbai, India. *Marine Pollution Bulletin,* 77, 107-112.

Kim, I. S., Chae, D. H., Kim, S. K., Coi, S-. Woo, S. B., 2015. Factors influencing the spatial variation of microplastics on high-tidal coastal beaches in Korea. *Archives of Environmental Contamination and Toxicology.* Advanced online publication.

Laglbauer, B. J., Franco-Santos, R. M., Andreu-Cazenave, M., Brunelli, L., Papadatou, M., Palatinus, A., ... & Deprez, T. (2014). Macrodebris and microplastics from beaches in Slovenia. Marine Pollution Bulletin, 89(1-2), 356-366.

Nor, N. H. M., Obbard, J. P., 2014. Microplastics in Singapore's coastal marine environment. *Marine Pollution Bulletin,* 79, 278-283.

Obbard, R. W., Sadri, S., Ying, Q. W., Khitun, A. A., Baker, I. and Thompson, R. C. (2014). Global warming releases microplastic legacy frozen in Arctic Sea ice. *Earth's Future.* 2, 315-320.

Olsen, L. M. B., Knutsen H., Lilleeng Ø, Mahat S., Wade E. J., Arp H.P.H., Facilitating microplastic quantification in marine samples through the introduction of a cellulose dissolution step (in prep.)

Reddy, M. S., Basha, S., Adimurthy, S., Ramachandraiah, G., 2006. Description of the small plastics fragments in marine sediments along the Alang-Sosiya ship-breaking yard, India. *Estuarine Coastal and Shelf Science,* 68, 656-660.

Singh, B. & Nisha Sharma, N., 2008. Mechanistic implications of plastic degradation. 93: 561-584.

Van Cauwenberghe, L., Vanreusel, A., Mees, J., & Janssen, C. R. (2013). Microplastic pollution in deep-sea sediments. Environmental Pollution, 182, 495-499.

Vianello, A., Boooldrin, A., Guerriero, P., Moschino, V., Rella, R., Sturaro, A., Da Ros., L., 2013. Microplastic particles in sediments of Lagoon of Venice, Italy: First observations on occurrence, spatial patterns and identification. *Estuarine, Coastal and Shelf Science,* 130, 54-61.

Woodall, L. C., Sanchez-Vidal, A., Canals, M., Paterson, G. L. J., Coppock, R., Sleight, V., Calafat, A., Rogers, A. D., Narayanaswamy, B. E. & Thompson, R. C., 2014. The deep sea is a major sink for microplastic debris. *Royal Society Open Science*, 1 (4).

APPENDIX A
Microscope pictures and polymer composition

The sediment samples listed in Table A1 were investigated under a light microscope for detection of possible microplastic, after sample work up via density separation and chemical digestion, as described in the report. To confirm if particles were microplastics, subsamples were analysed by FT-IR. Both light microscopy images and FT-IR results for each individual sample are provided in this Appendix.

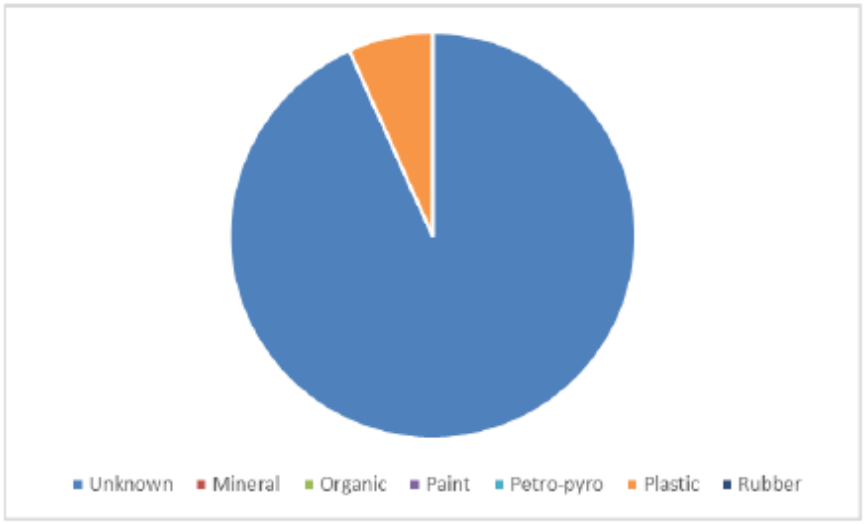
The FT-IR results presented here are simplified to "general categories": unknown, mineral, organic, paint, petro-pyro, plastic and rubber as presented Chapter 3 and Chapter 4 of the report. Further, the "polymer composition of the plastic fraction" results for are subdivided further into the following categories, also presented in Chapter 3 of the report: PE, PE-chlorinated, PE-chlorosulfonated, PE-oxidized, PE:PP, PP, PET, PS, PTFE, PP-chlorinated, Polyacrylamide, PMMA, PU, PVF, PVC, Melamine & Others.

Percentages of identified plastic polymers in each sample is shown in Table A2. This data combined with particle number concentrations or weight concentrations for the entire sample could be used to derive similar concentrations for the individual plastic particles

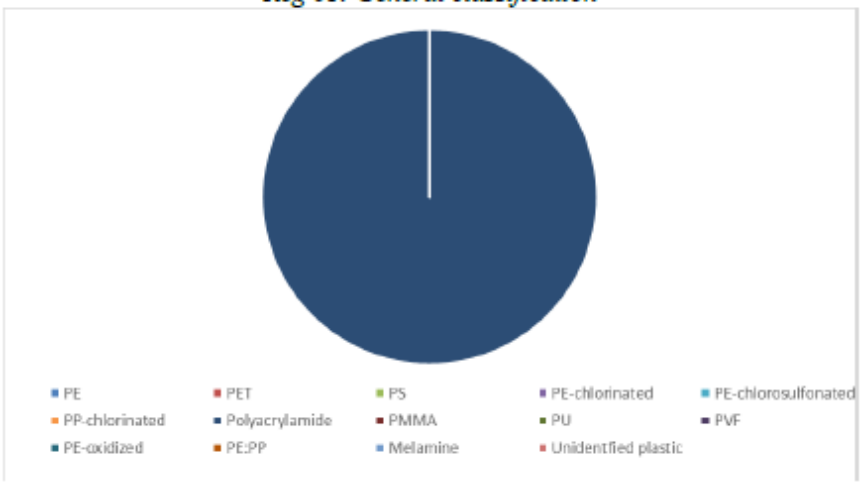
Table A1. List of samples used for visual identification of potential microplastics. All samples listed in the table were investigated FT-IR for determination of plastic polymers.

Sample-ID	Location	Station	Microscope Analysis
Reg-01	central North Sea	Regional	FT-IR only
Reg-02	central North Sea	Regional	FT-IR only
Reg-03	central North Sea	Regional	FT-IR only
Reg-04	central North Sea	Regional	FT-IR only
Reg-06	central North Sea	Regional	FT-IR only
Reg-07	central North Sea	Regional	FT-IR only
Reg-08	central North Sea	Regional	FT-IR only
20171005-Reg-09	central North Sea	Regional	Light & FT-IR
Reg-11	central North Sea	Regional	FT-IR only
20171002-Reg-14	central North Sea	Regional	Light & FT-IR
20171026-EKO-12	central North Sea	Ekofisk	Light & FT-IR
EKO-14	central North Sea	Ekofisk	FT-IR only
EKO-21	central North Sea	Ekofisk	FT-IR only
20171103-GYDA-18	central North Sea	Gyda	Light & FT-IR
20171106-GYDA-21	central North Sea	Gyda	Light & FT-IR
VAL-02	central North Sea	Valhall	FT-IR only
VAL-04	central North Sea	Valhall	FT-IR only
20171102-VAL-05	central North Sea	Valhall	Light & FT-IR
VAL-15	central North Sea	Valhall	FT-IR only
20171019-ULA-06	central North Sea	Ula	Light & FT-IR
20171117-Reg-12	northern North Sea	Regional	Light & FT-IR
20171113-SNB-16R	northern North Sea	Snorre B ref/regional	Light & FT-IR
20171117-VI-RB	northern North Sea	Visund ref/regional	Light & FT-IR
STC-06R	northern North Sea	Statfjord C ref	FT-IR only
20171121-KV-14	northern North Sea	Kvitebjørn	Light & FT-IR
20171120-KV-02	northern North Sea	Kvitebjørn	Light & FT-IR
VI-01	northern North Sea	Visund	FT-IR only
20171120-VI-03	northern North Sea	Visund	Light & FT-IR
VI-30	northern North Sea	Visund	FT-IR only
2017116-Vega-R	northern North Sea	Vega	Light & FT-IR
20171122-STT-2	Barents Sea	Stangnestind	Light & FT-IR
20171122-KF2-6	Barents Sea	Korpefjell	Light & FT-IR
20171122-SC3-4	Barents Sea	Scarecrow3	Light & FT-IR
20171127-KRT-14	Barents Sea	Kråketind	Light & FT-IR
20171124-GRS-2	Barents Sea	Gråspett	Light & FT-IR

A1 Reg-01



Reg 01: General classification

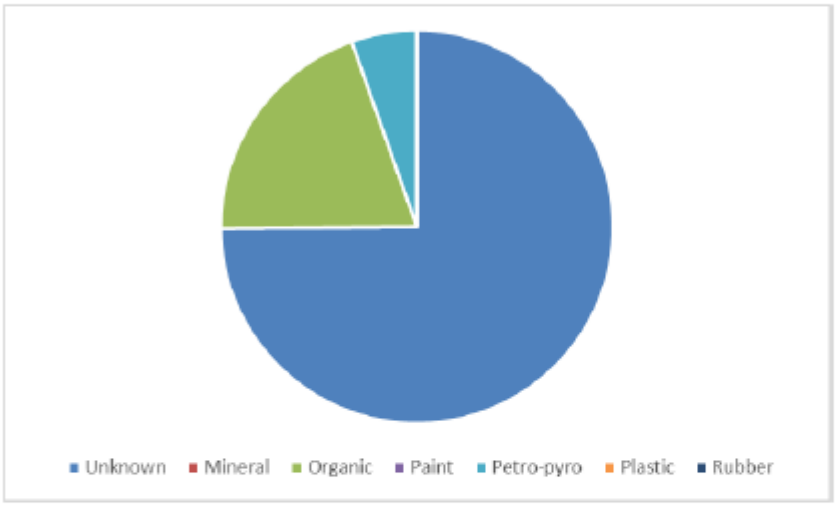


Reg 01:Polymer composition of plastic fraction

Mostly unknown particles due to match score < 0.6 with the reference library.

Plastic polymers identified: polyacrylamide (7 % of total sample).

A2 Reg-02

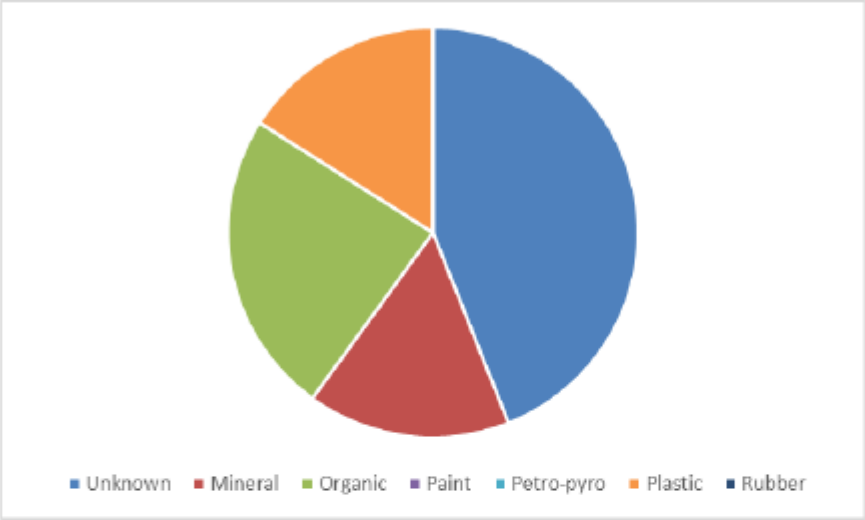


Reg 02: General classification

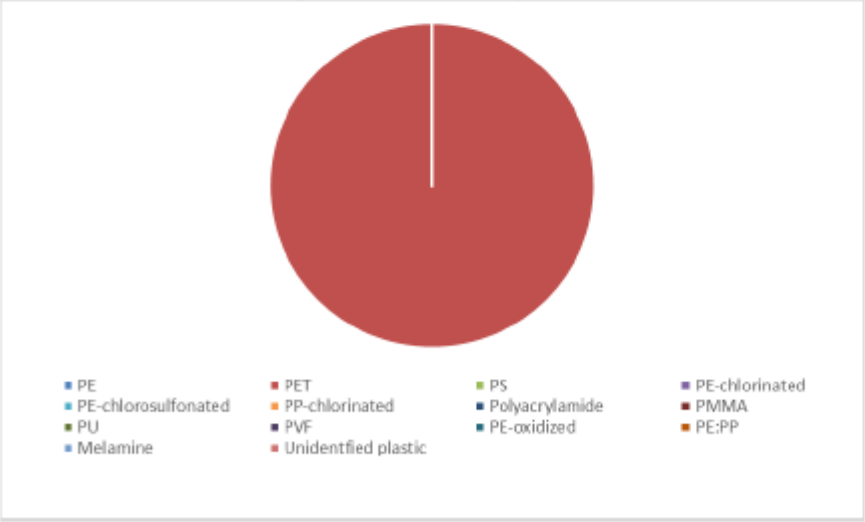
Mostly unknown particles due to match score < 0.6 with the reference library. Of the remaining particles, 20 % were classified as organic and 5 % as petro-pyro.

Plastic polymers identified: none.

A3 Reg-03



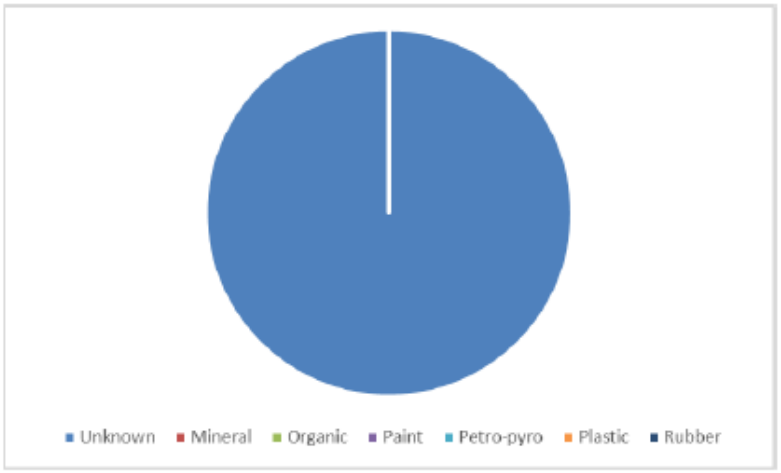
Reg-03: General classification



Reg-03: Polymer composition

A heterogenous sample comprised of unknown particles (score < 0.6) as well as microplastic, organic and mineral particles. The only identified plastic polymer was PET (polyethylene terephthalate / polyester).

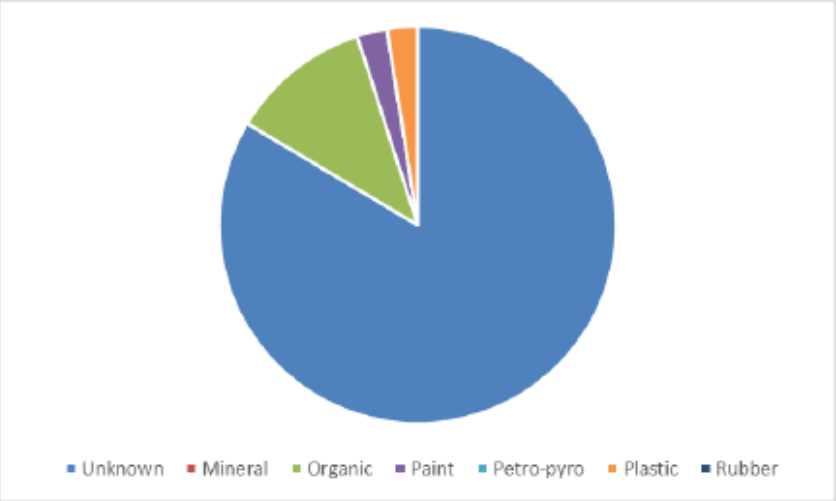
A4 **Reg-04**



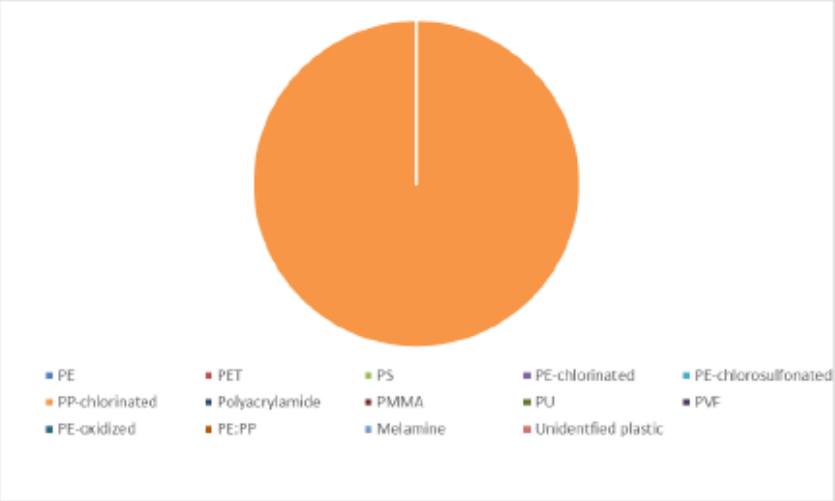
Reg-04: General classification

No microplastic was identified in sample Reg-04.

A5 Reg-06



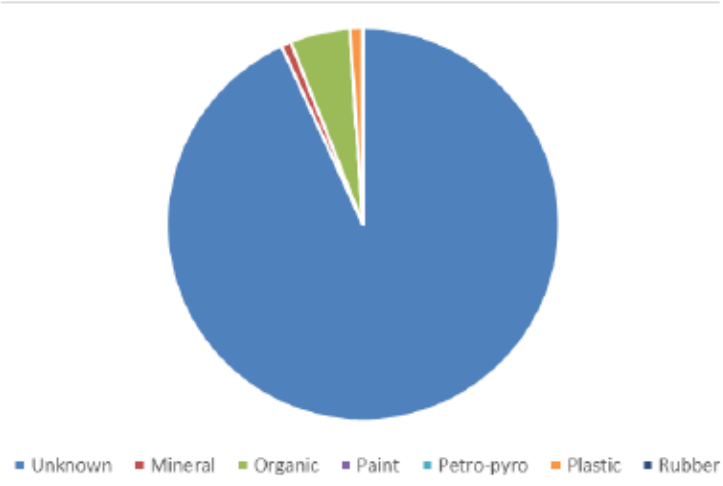
Reg-06: General classification



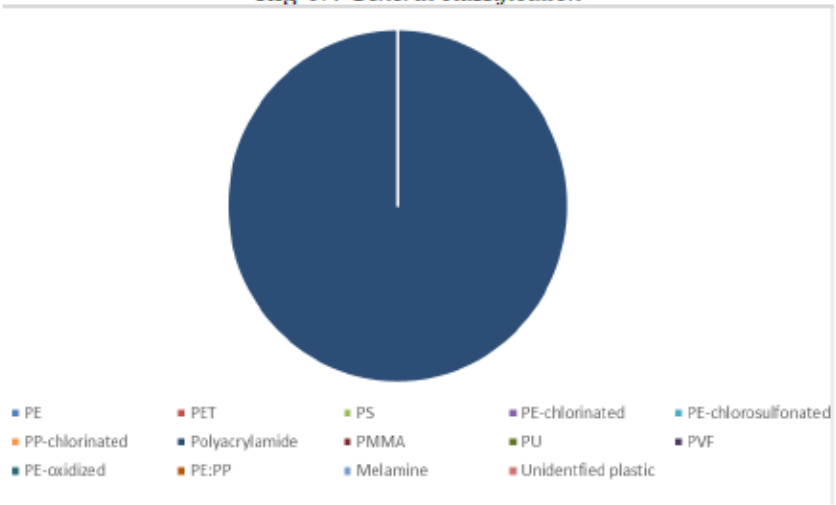
Reg-06: Polymer composition

Most of the particles were classified as unknown (score < 0.6) (84 %) or organic (12 %). Some of the organic particles could, according to the reference library, be perfluorinated compounds. The identified plastic polymers (3 % of total composition) was chlorinated polypropylene (PP-chlorinated).

A6 Reg-07



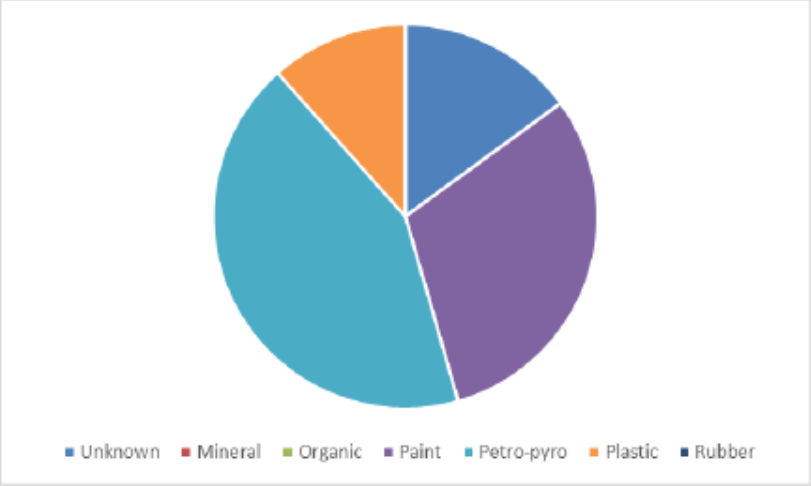
Reg-07: General classification



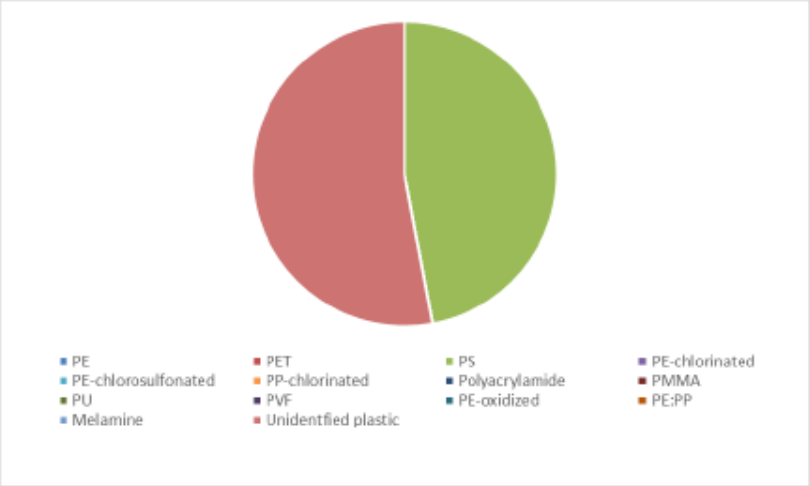
Reg-07: Polymer composition

Mostly unknown particles (score < 0.6) (93 %). Microplastic (1 %) identified as polyacrylamide.

A7 Reg-08



Reg-08: General classification



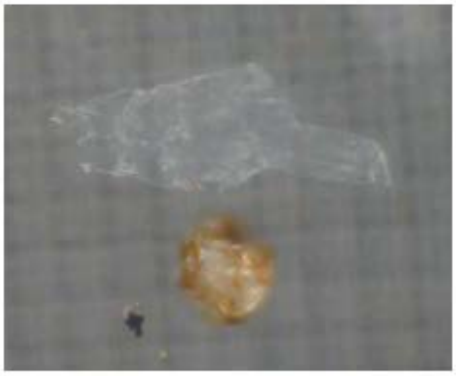
Reg-08: Polymer composition

Most of the particles were classified as petro-pyro (43 %), perhaps attributable to oil and drilling activity or proximity to an oil field, even though this sample is from a regional (background) station. The identified plastic polymers (12 %) were PS (polystyrene) and "other" plastics. In this samples, there was also a substantial amount of paint (12%, mostly phenoxy resins).

A8 **Reg-09**

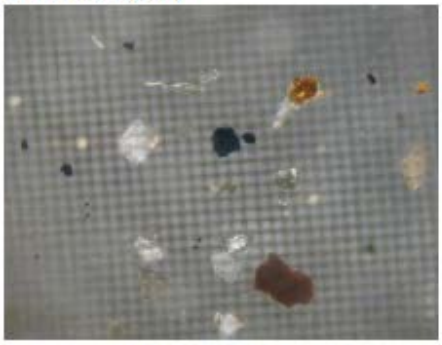
Pictures from visual microscopy:

Overview



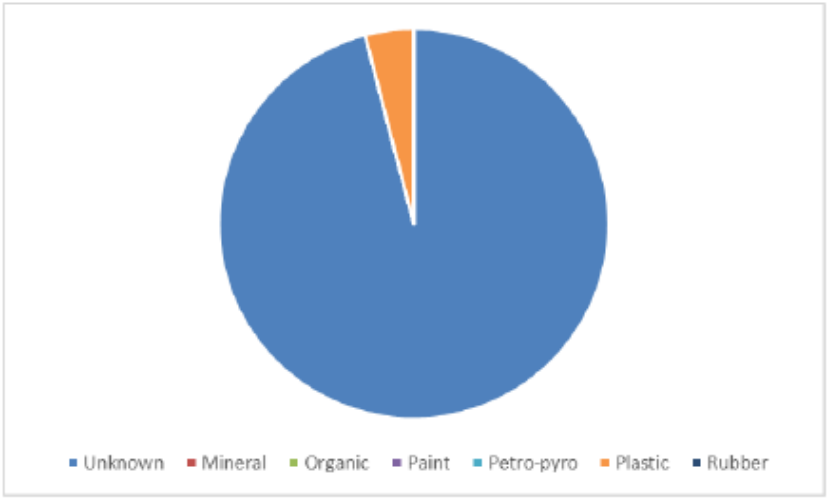
Clear layer (µm)

White fibre (> 500 µm)

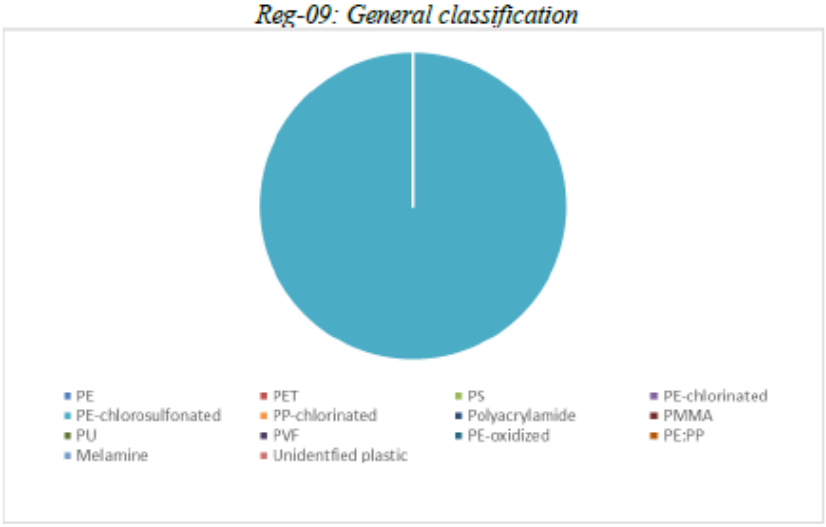


Heterogenous distribution of particles

Most of the particles in Reg-09 were classified as unknown particles (score < 0.6) (96 %). Chlorosulfonated polyethylene (PE-chlorosulfonated) was found (plastic particles: 4 % of the total composition).

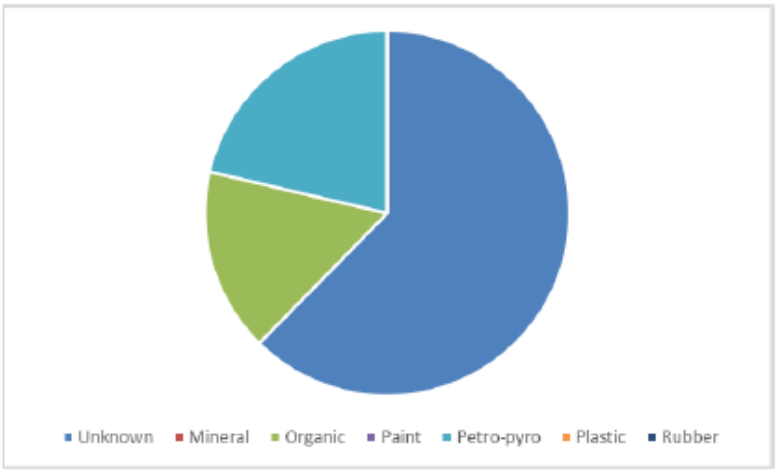


Reg-09: General classification



Reg-09: Polymer composition

A9 Reg-11

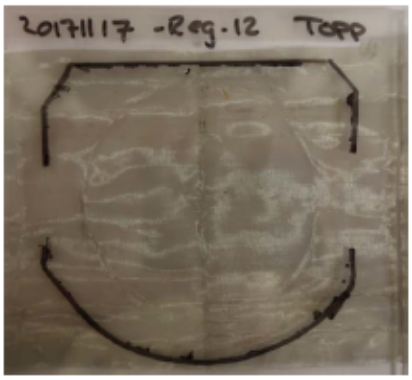


Reg-11: General classification

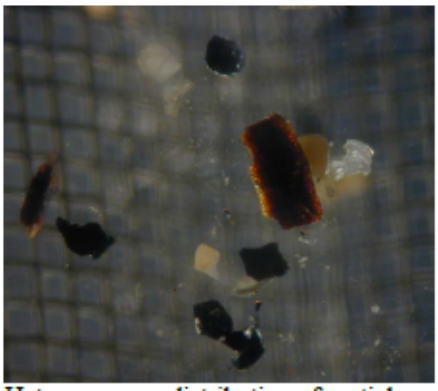
In this sample, no microplastic particles were found. The analysed particles were classified as unknown (score < 0.6) (62 %), organic (16 %) or petro-pyro (hydrocarbon resins, 21 %).

A10 **Reg-12**

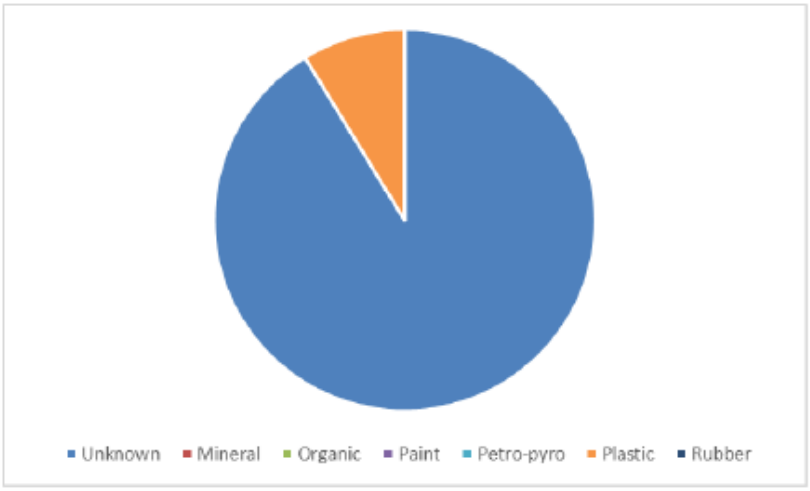
Pictures from visual microscopy:



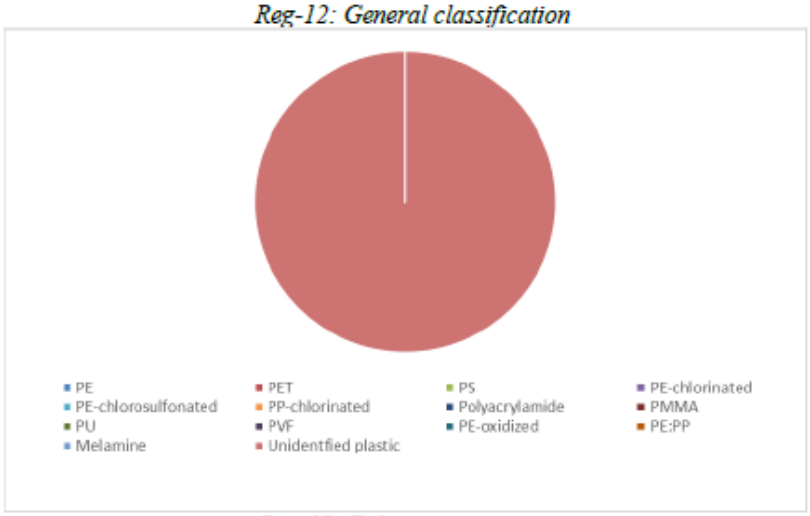
Overview


Heterogeneous distribution of particles

Particles were identified as either unknown (score < 0.6) (91 %) or plastic polymers (9 %) which were categorized as "other", having FT-IR frequencies conforming to polymers with plasticizer components (see figure on next page).



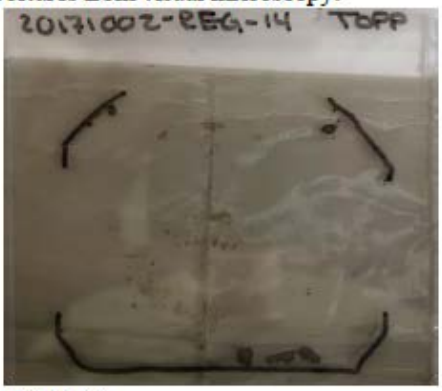
Reg-12: General classification



Reg-12: Polymer composition

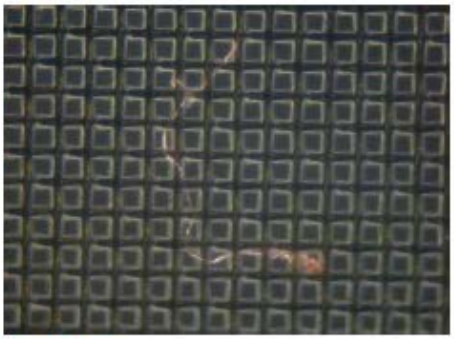
A11 **Reg-14**

Pictures from visual microscopy:

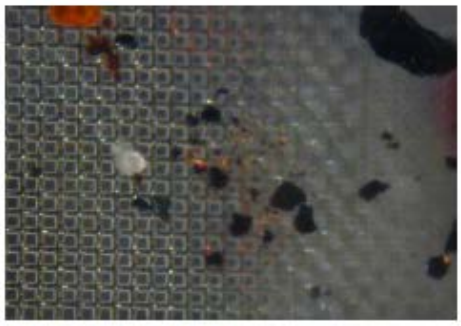


Overview

Blue fibre

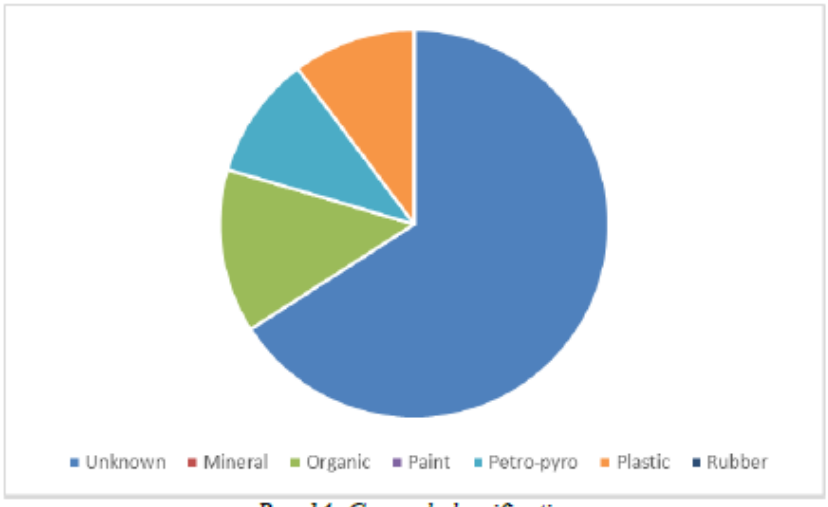


Red fibre

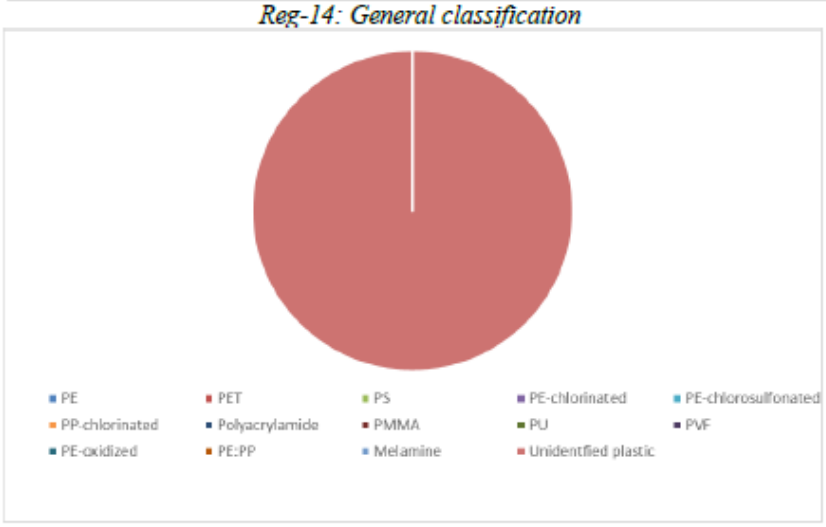


Mostly black particles

As seen on the next page, the particles in this sample were characterized as mostly unknown (66 %) or organic (14 %), as well as petro-pyro (10 %) and plastics (10 %). Plastic polymers had FT-IR spectrum influenced with plasticizer ingredients in an unresolved polymer matrix ("other plastics"). The fibers were mostly organic.



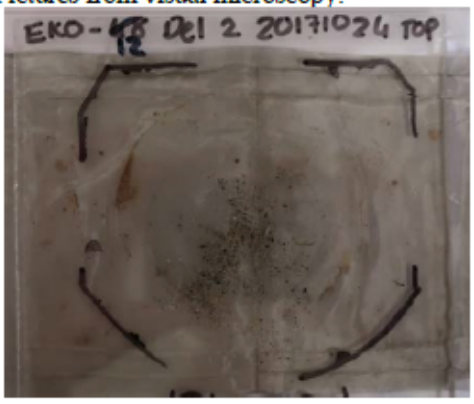
Reg-14: General classification



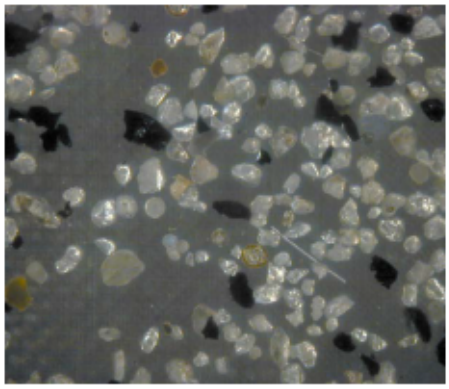
Reg-14: Polymer composition

A12 **EKO-12**

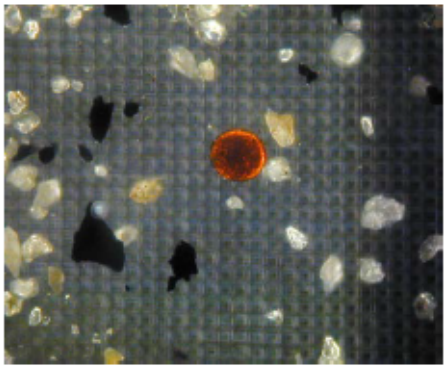
Pictures from visual microscopy:



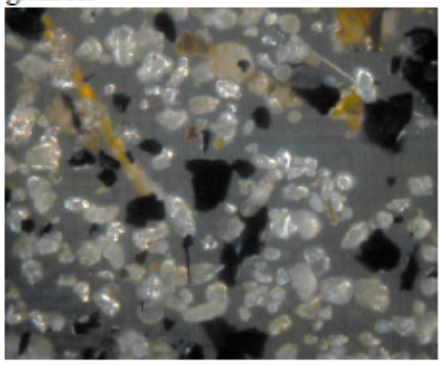
Overview



Spherical and irregularly shaped granules

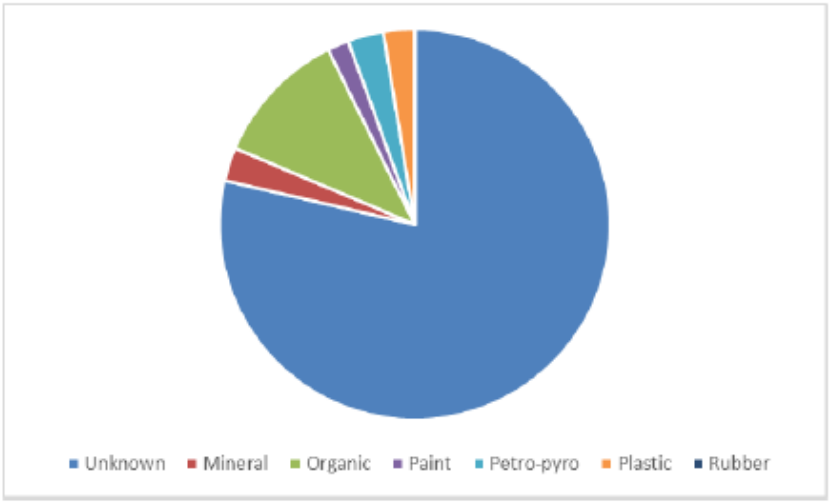


Red, spherical granule

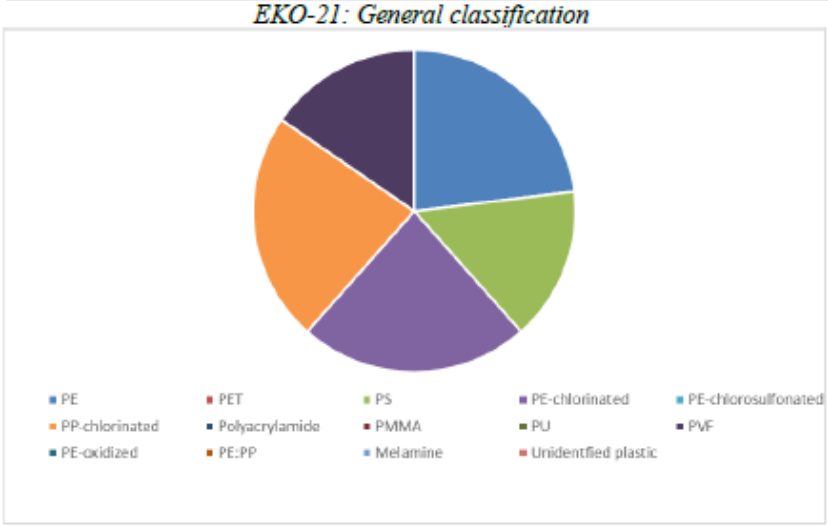


Spherical and irregularly shaped granules

Visual microscopy => relatively homogenous composition of white/clear granules of approximately the same size (100-300 µm). FT-IR results showed that the sample composition was heterogeneous (see next page), consisting of unknown (score < 0.6), organic, mineral, paint, petro-pyro and plastic particles. ATR analysis of a red granule (as shown in the picture above), showed that this particle was paint (phenoxy resin). Analyses of several white and black granules of approximately the same shape and size mostly resulted in matches with reference organic particles (11 %), but also plastic (3 %). Various plastic polymers were identified: chlorinated PE and PP, PS, PVF and PE. Approximately 79 % of the total composition was unknown particles.

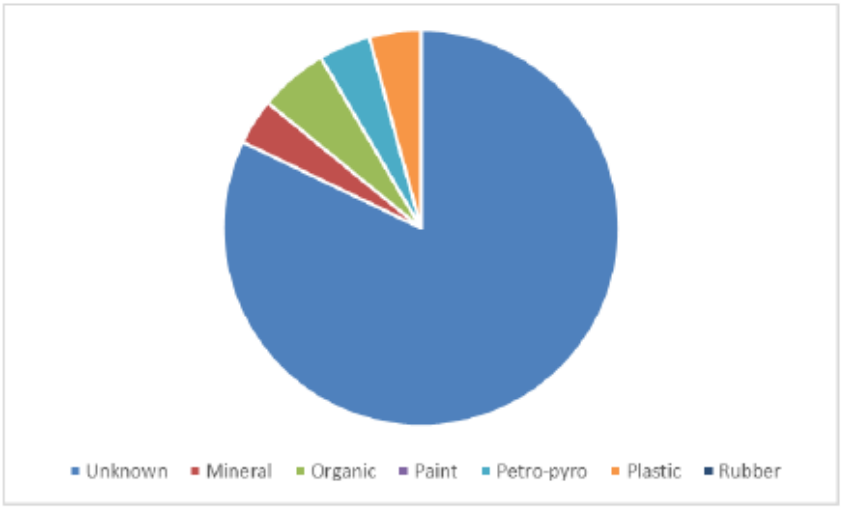


EKO-21: General classification

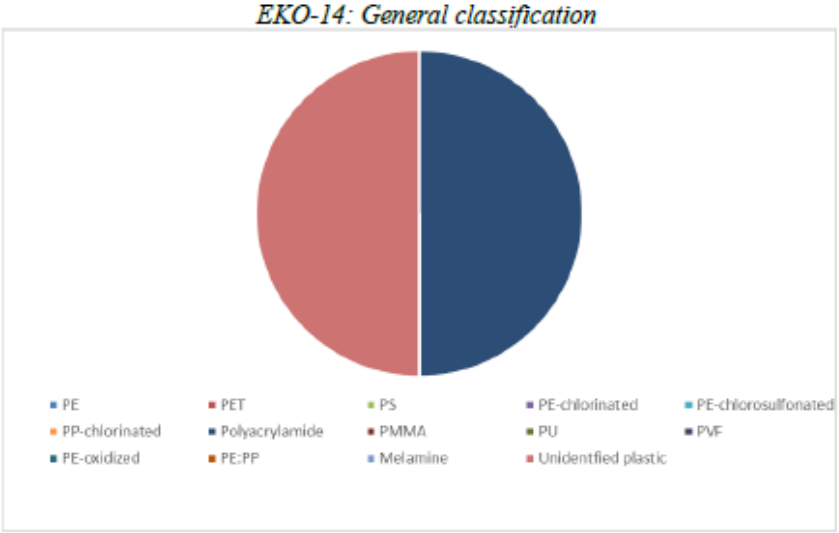


EKO-21: Polymer composition

A13 EKO-14



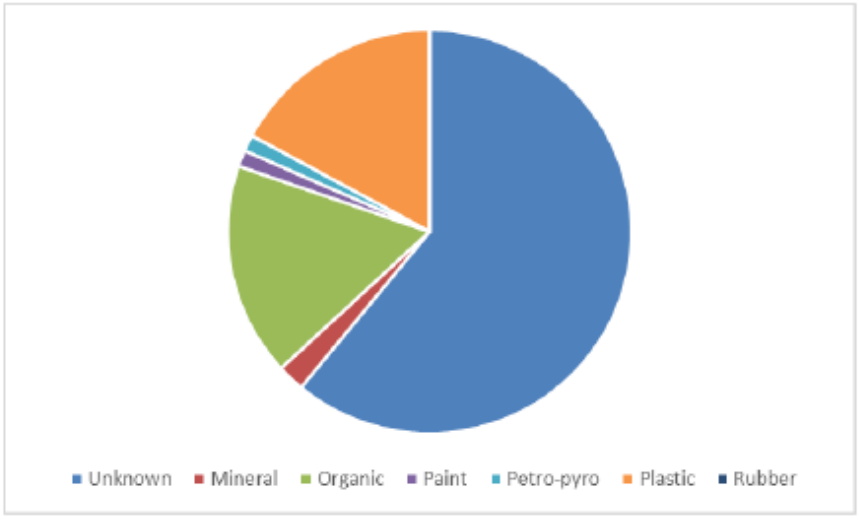
EKO-14: General classification



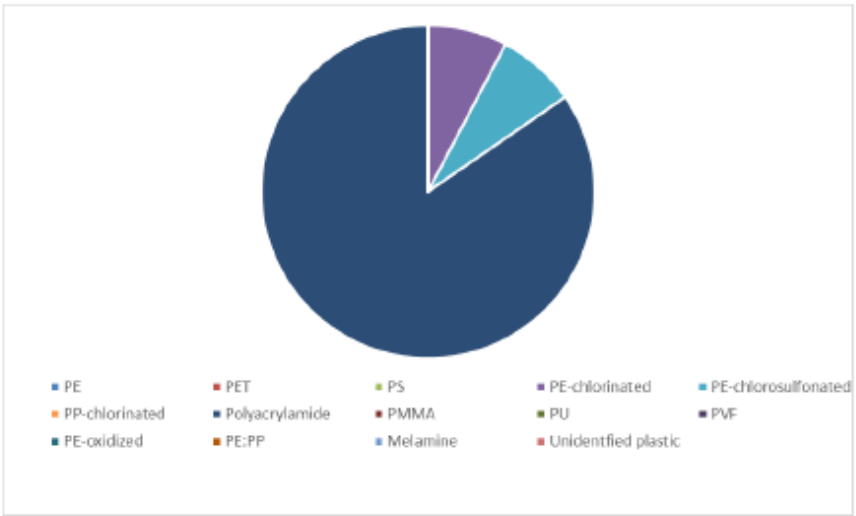
EKO-14: Polymer composition

Relatively small fractions of mineral, organic, petro-pyro and plastic particles (in total: 18 %) were identified, compared to the amount of unknowns (score < 0.6) (82 %). The plastic polymers found were polyacrylamide and polymers containing plasticizers. As polyacrylamide is common to use in subsurface applications such as Enhanced Oil Recovery, this might explain its presence in many of the samples analysed. Polyacrylamide is a water soluble polymer; however, some larger particles may be insoluble, similarly particles may be surface coated with polyacrylamide.

A14 **EKO-21**



EKO-21: General classification



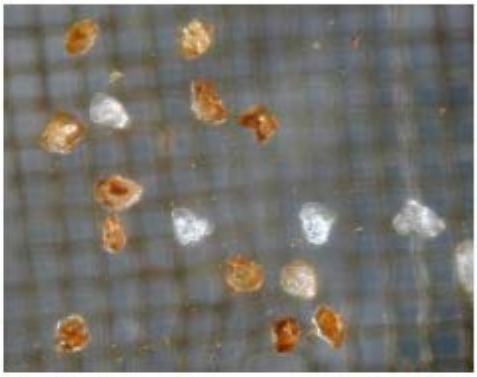
EKO-21: Polymer composition

In this sample, a substantial amount of the analysed particles were characterized as microplastics (17 %), where polyacrylamide was the major component.

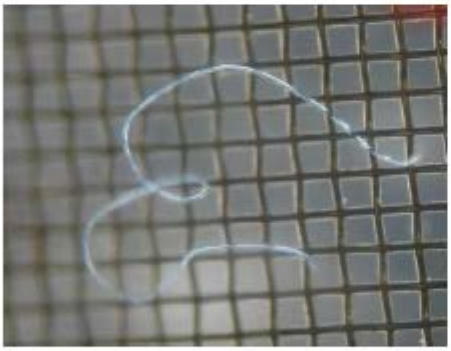
A15 **GYDA-18**

Pictures from visual microscopy:

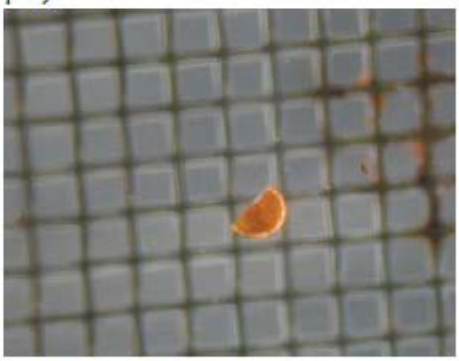
Overview



Mostly clear and brown granules (100-300 µm)

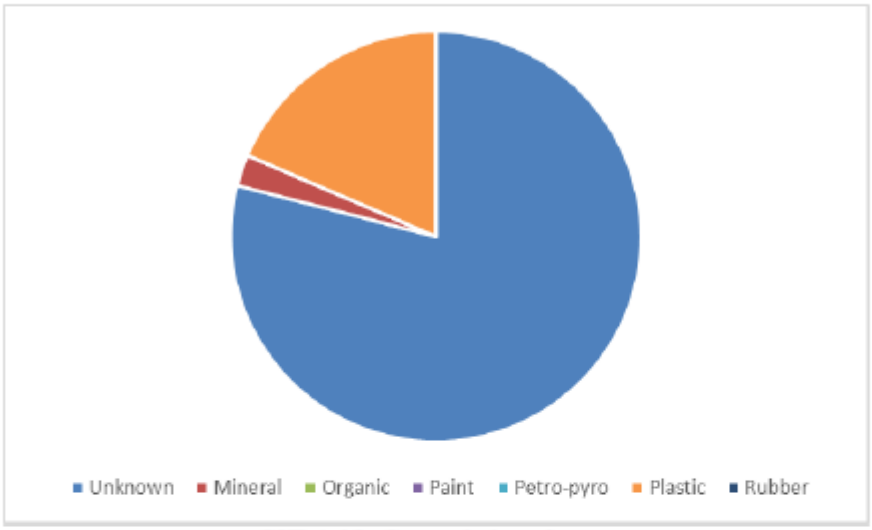


Blue fibre

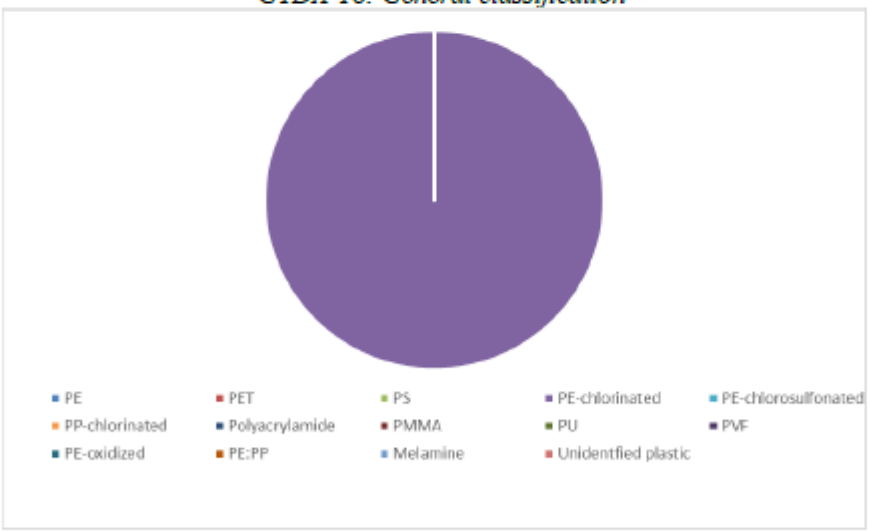


Brown granule with sharp edges

As seen by the figure on the next page, most particles were classified as unknown (score < 0.6) (79 %) or plastic particles (PE-chlorinated) (19 %).



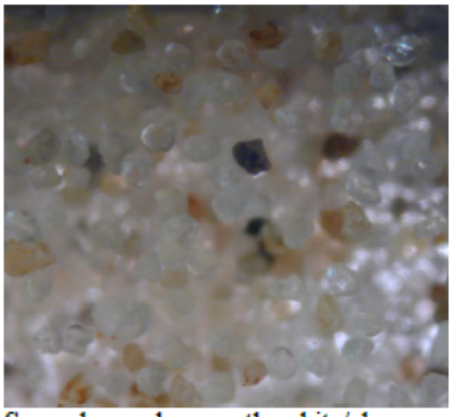
GYDA-18: General classification



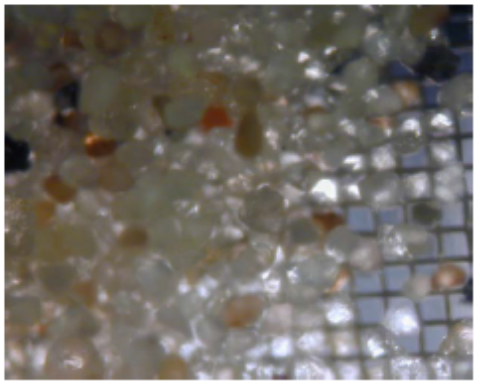
GYDA-18: Polymer composition

A16 **GYDA-21**

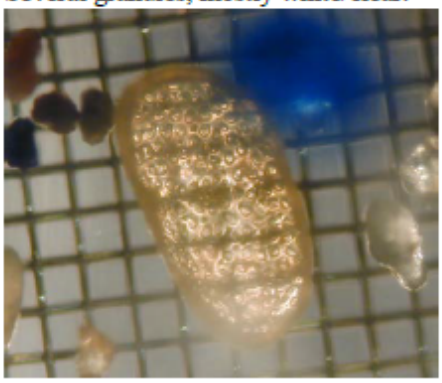
Overview



Several granules, mostly white/clear.

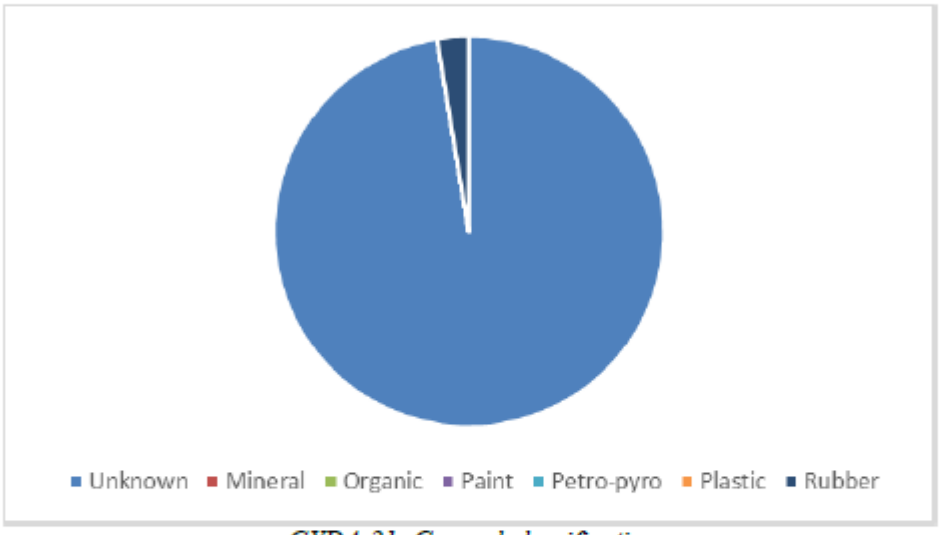


Several granules, mostly white/clear.



Probably organic matter due to cellular structure

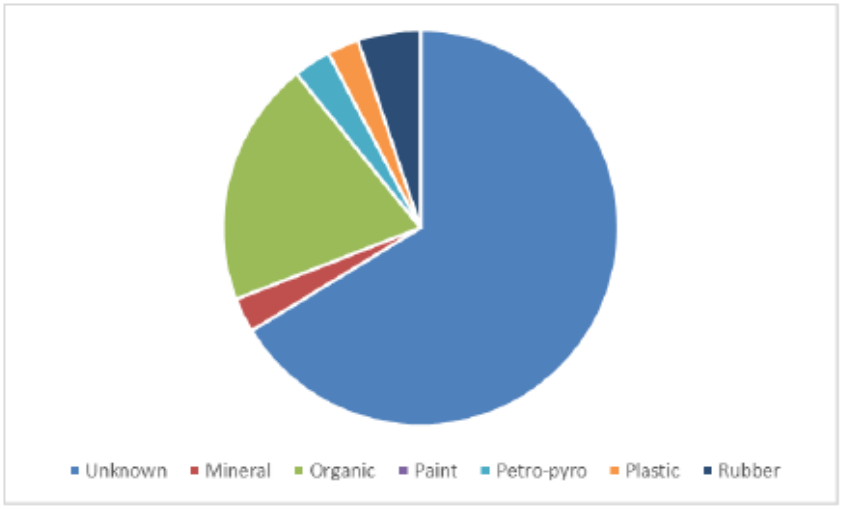
Relatively homogenous composition of white/clear granules of approximately the same size (100-300 µm). Surprisingly, 97 % of the particles were classified as unknown due to low scores with the reference library (< 0.6) (3 % rubber). Interestingly, most of these particles (over 30 %) were identified as the polymer "POLY(2,5-DIMETHYL-1,4-PHENYLENE-3,3'-DIOXO-5,5'-BIINDOL-2,2'-DIYL) 2/40", which is a type of polyphenol ether, by the reference library, which indicates that these particles consists of the same material (potentially microplastic polymers or complex mixture products), and that maybe they originate from the same source. For instance, they could be proppants, as these are widely used in the petroleum industry. However, the match scores with the reference spectra were low (from 0.4 to 0.6), and thus they are denoted as unknowns in the report, even though it is not excluded that they could be microplastics (hence, the reported maximum microplastic concentrations in the report).



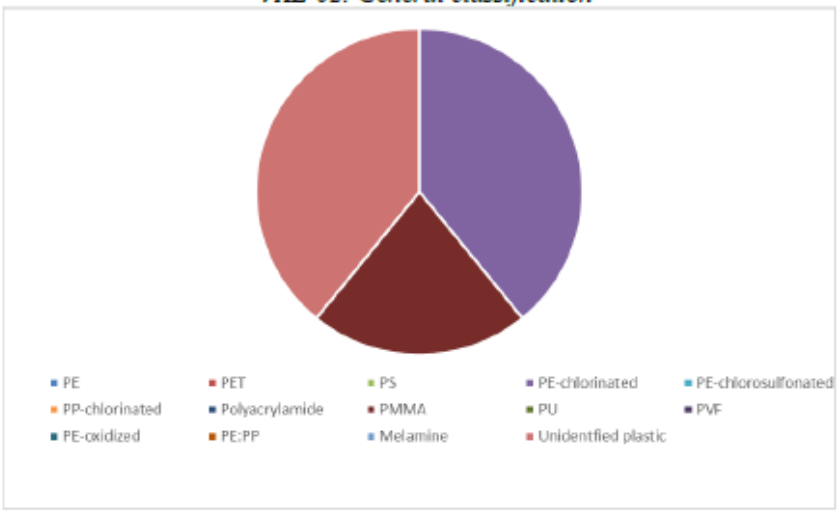
GYDA-21: General classification

In this sample, no plastic polymer particles were found. The analysed particles were classified as unknown (score < 0.6) (97 %) or rubber (3 %).

A17 **VAL-02**



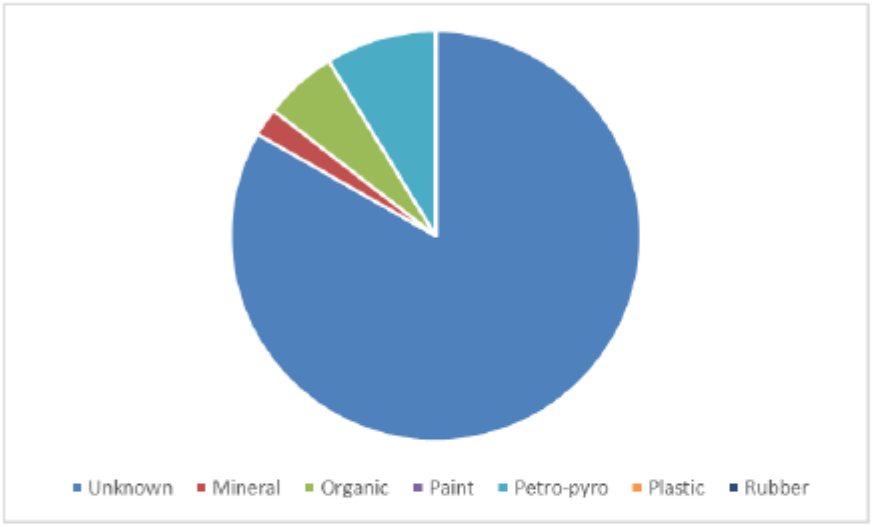
VAL-02: General classification



VAL-02: Polymer composition

Particles categorized as unknown (score < 0.6) (66 %) and organic (20 %) were most abundant. PE-chlorinated and "other" plastic (containing polymer and plasticizer) was the most abundant plastic polymers in the sample. There was also a relatively high number of rubber particles compared to other samples. As for GYDA-21, a substantial amount (almost 50 %) of the unknown particles were classified as "POLY(2,5-DIMETHYL-1,4-PHENYLENE-3,3'-DIOXO-5,5'-BIINDOL-2,2'-DIYL) 2/40" by the FT-IR library, but reported as unknown due to low match scores.

A18 VAL-04



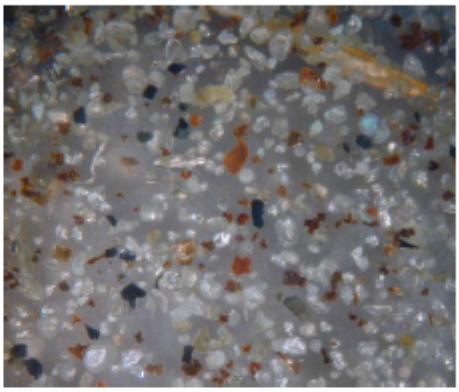
VAL-04: General classification

As seen by the figure above, no plastic polymer particles were quantified in the sediment sample from station VAL-04. A relatively large amount of petro-pyro particles were identified, compared to mineral, organic and rubber particles. Almost 50 % of the unknown particles were classified as "POLY(2,5-DIMETHYL-1,4-PHENYLENE-3,3'-DIOXO-5,5'-BIINDOL-2,2'-DIYL) 2/40" by the FT-IR library, but reported as unknown due to low match scores, similarly to Gyda-21, Val-02 and Val-05, Val-15, Ula-06.

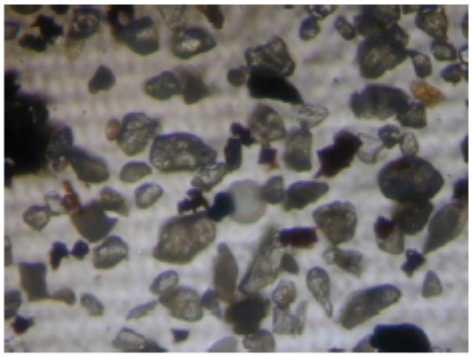
A19 **VAL-05**

Pictures from visual microscopy:

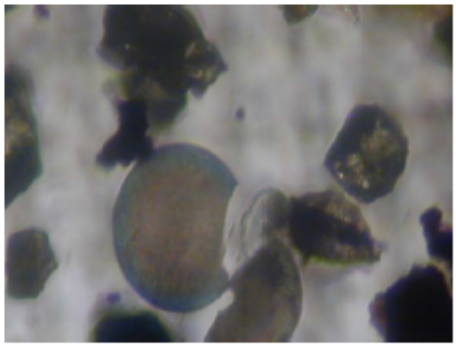
Overview



Heterogeneous particle distribution

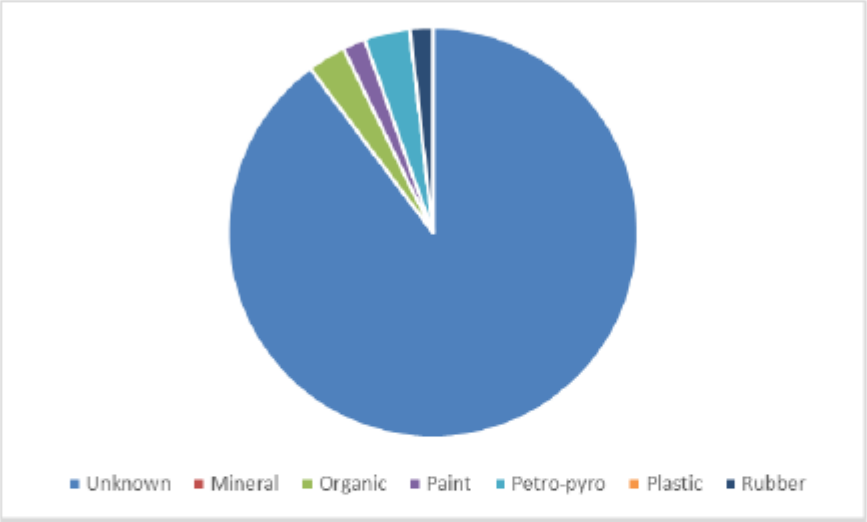


Several grey/black particles – charcoal?



Example of granule with sharp edges

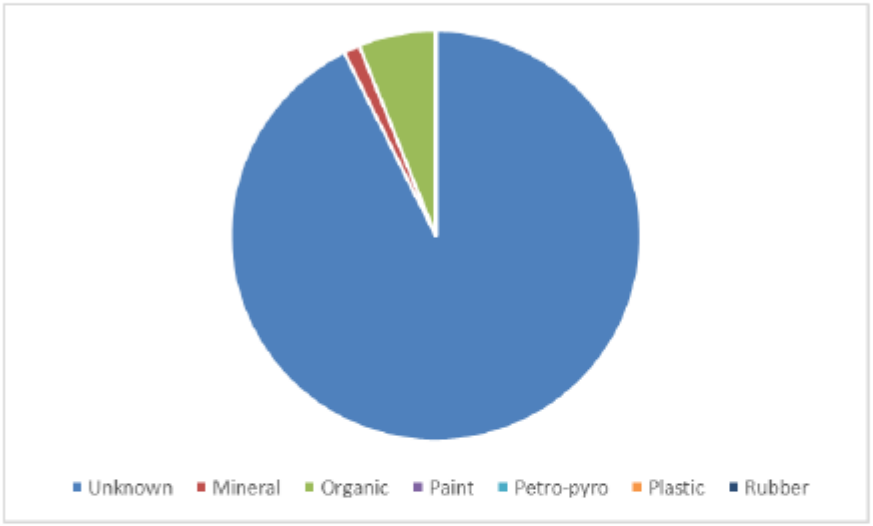
Relatively heterogeneous composition overall, but also a substantial amount of white/clear granules of approximately the same size (100-300 µm). 90 % of the particles were classified as unknown (match score < 0.6). Approximately 40 % of the unknown particles were classified as "POLY(2,5-DIMETHYL-1,4-PHENYLENE-3,3'-DIOXO-5,5'-BIINDOL-2,2'-DIYL) 2/40" by the FT-IR library, which indicates that these particles could have the same origin, as the particles were white/clear granules of approximately the same size and with similar FTIR spectra.



VAL-05: General classification

No microplastic polymers were identified at sufficient quality, but rubber and paint were present (see figure on next page).

A20 **VAL-15**

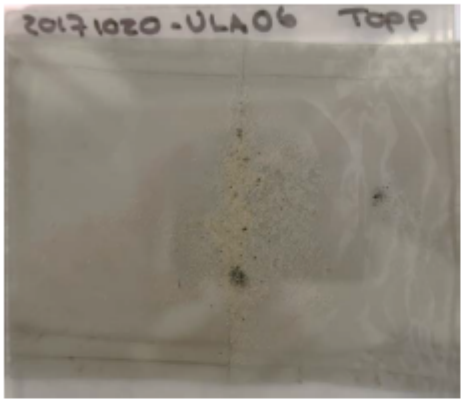


VAL-15: General classification

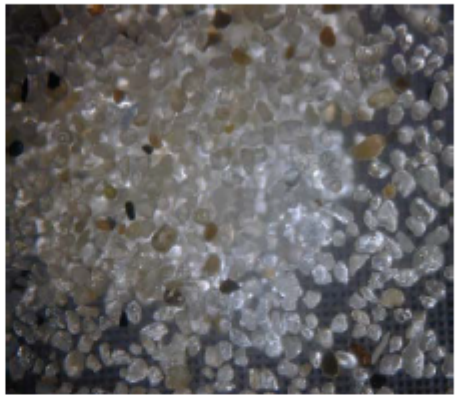
Over 90 %: unknown particles due to match scores < 0.6 with the reference library. Also in this sample, a substantial amount of the unknown particles. Also in this sample, a substantial amount of the unknown particles (32 %) were suggested to be classified as "POLY(2,5-DIMETHYL-1,4-PHENYLENE-3,3'-DIOXO-5,5'-BIINDOL-2,2'-DIYL) 2/40" by the FT-IR library.

No plastic polymers were identified in this sample, hence no figure showing the polymer composition.

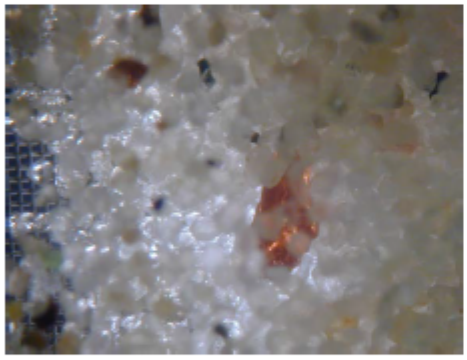
A21 **ULA-06**



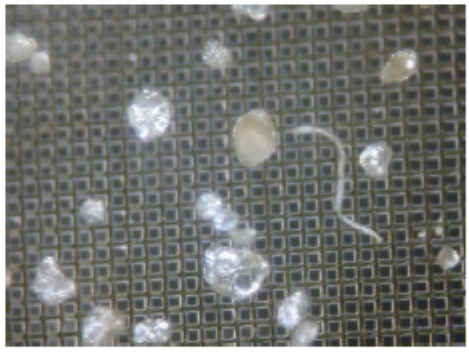
Overview



Homogenous distribution of white/clear granules

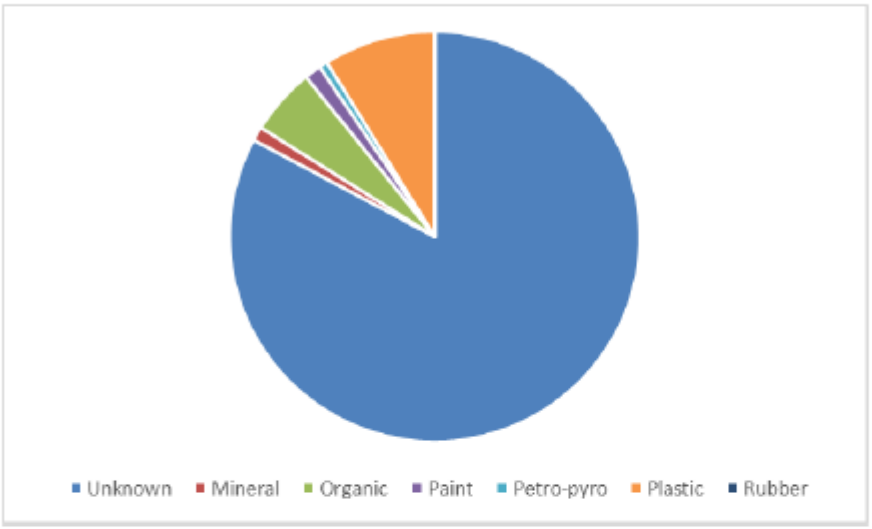


Mostly white/clear granules

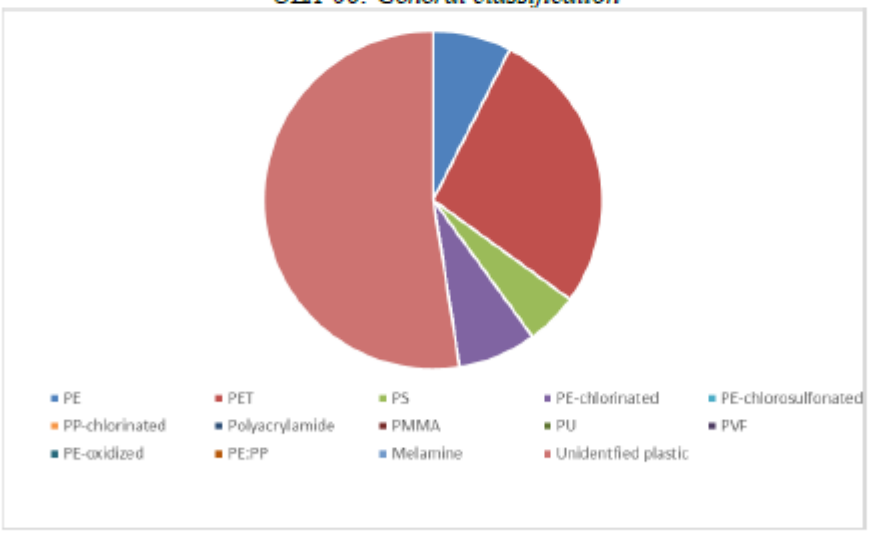


White fibre

Relatively homogenous composition of white/clear granules of approximately the same size (100-300 µm). Most of the particles were identified as unknowns (match score < 0.6 with reference spectra in the library database) (83 %), as shown on the next page. The second most abundant particle category was plastic (9 %) belonging to diverse categories, with PET being the most frequent type of identifiable polymer. The category "other" plastic included different additives, where one of them was the polymer "POLY(2,5-DIMETHYL-1,4-PHENYLENE-3,3'-DIOXO-5,5'-BIINDOL-2,2'-DIYL) 2/40" – which often was detected in several of the samples, but with too low match scores to be categorized as plastic. According to the FT-IR-library, over 50 % of the remaining "unknown" particles were in fact this polymer. As such, the reported minimum microplastic concentration for this sample is probably underestimated.



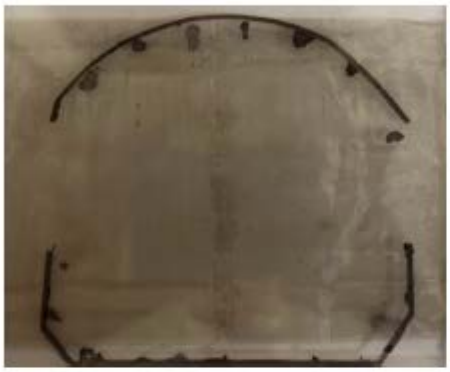
ULA-06: General classification



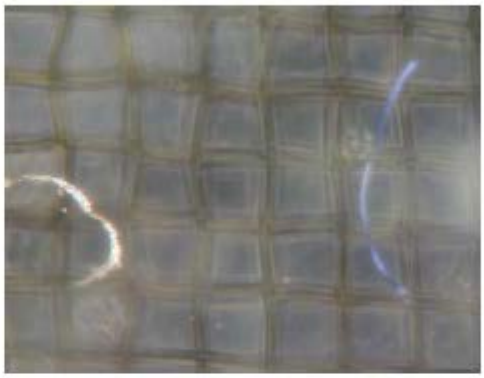
ULA-06: Polymer composition

A22 SNB-16R

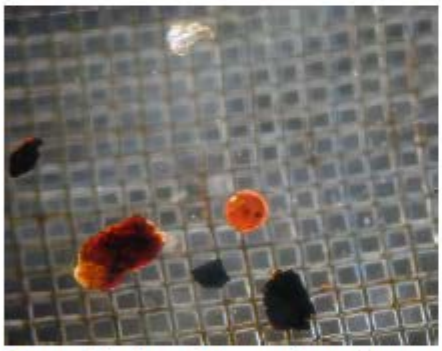
Pictures from visual microscopy:



Overview



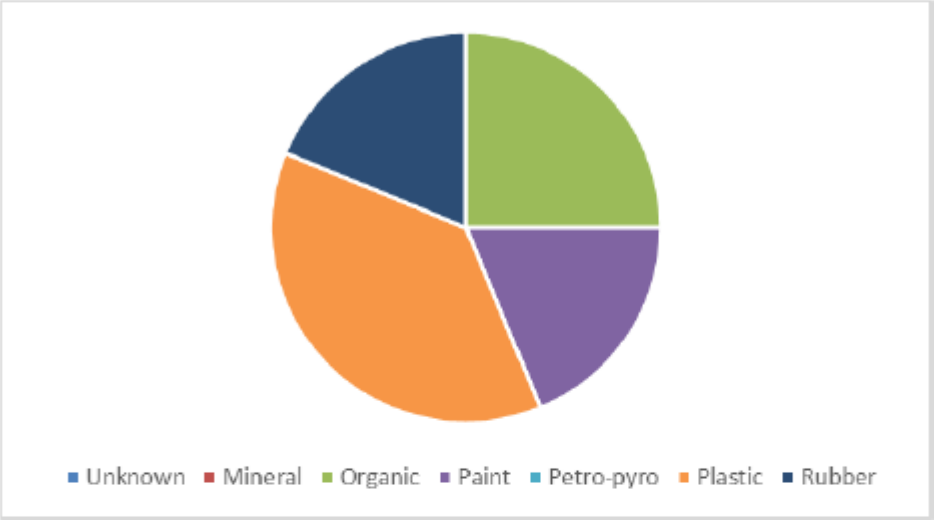
White and blue fibre



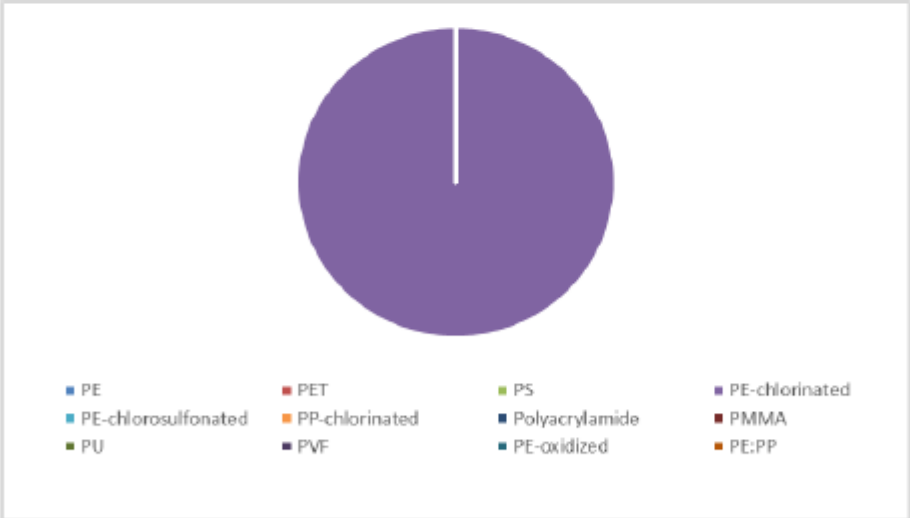
Some black, clear and red/orange granules, one spherical.

White fibre

Fibres: organic (cellulose). Particles: mix of organic (25 %), rubber (19 %) and plastic (38 %). Most common plastic polymer identified: PE-chlorinated.

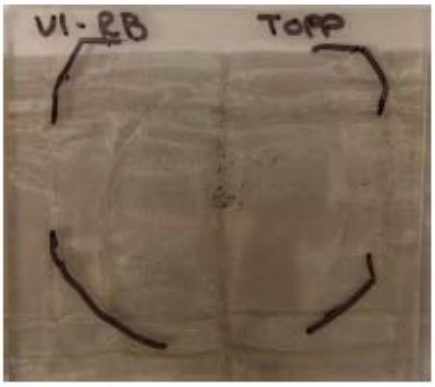


SNB-16R: General classification

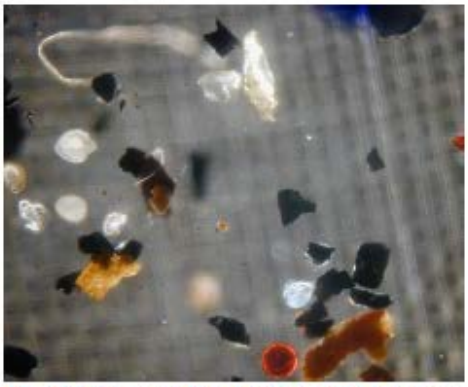


SNB-16R: Polymer composition

A23 **VI-RB**



Overview

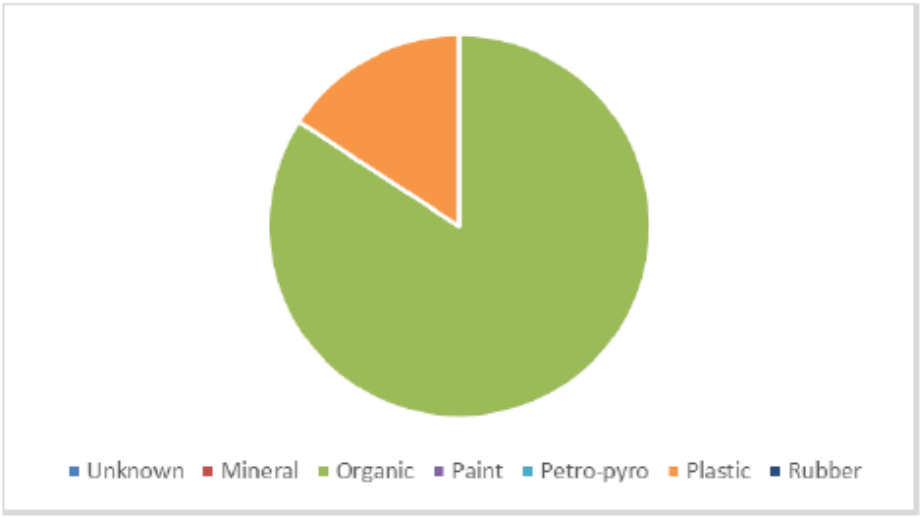


Heterogeneous distribution of particles – one spherical, red granule

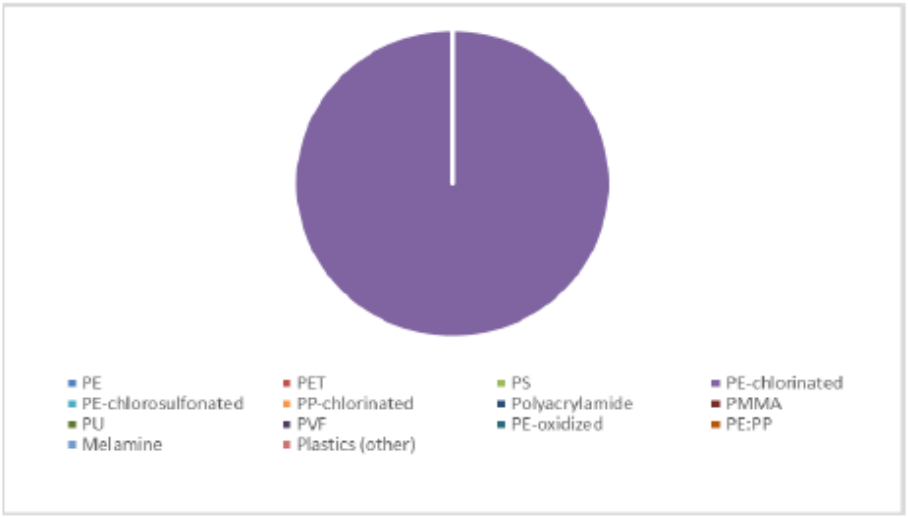
Heterogeneous distribution of particles

Clear layer

Mostly organic particles (25 %) and PE-chlorinated microplastics (38 %).

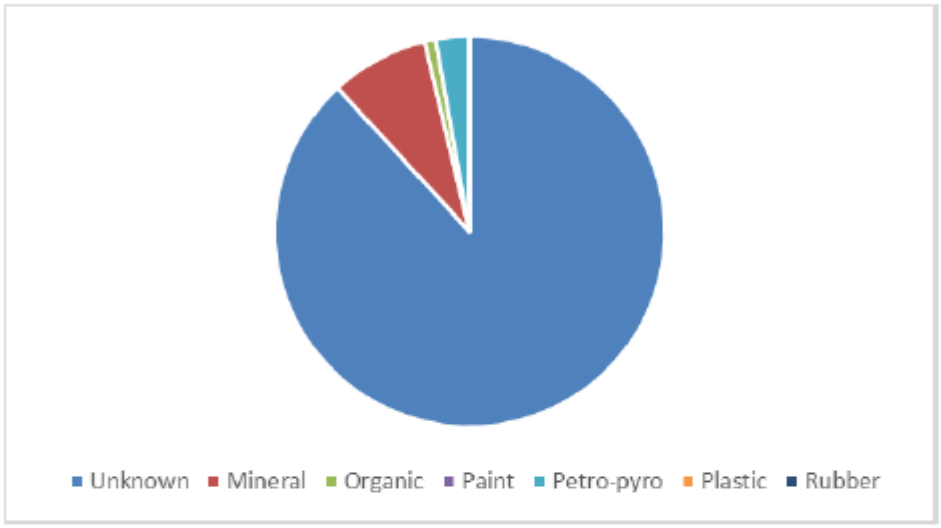


General classification



Polymer composition

A24 STC-06R

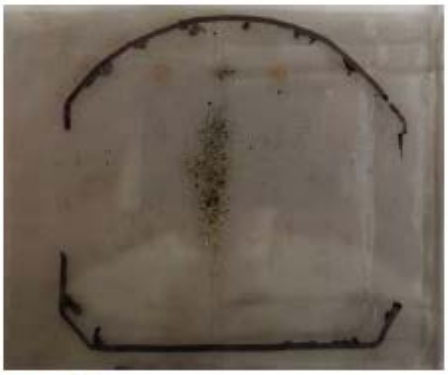


STC-06R: General classification

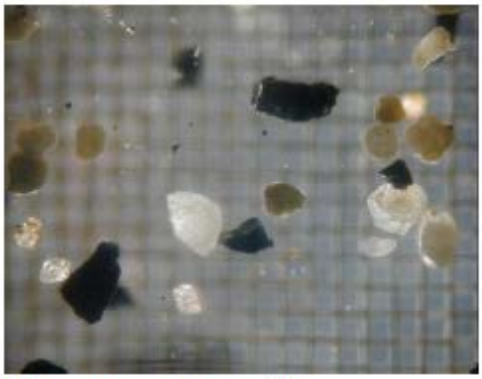
There were no microplastic particles identified in this sample. Mostly unknown (88 %) and mineral particles (8 %). Some petro-pyro (3 %).

A25 **KV-14**

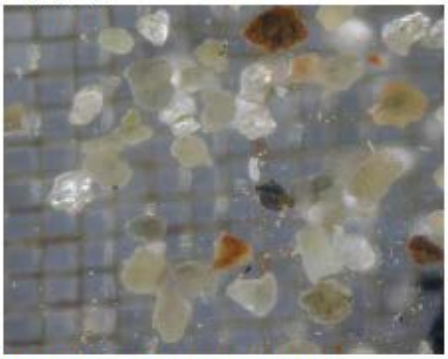
Pictures from visual microscopy:



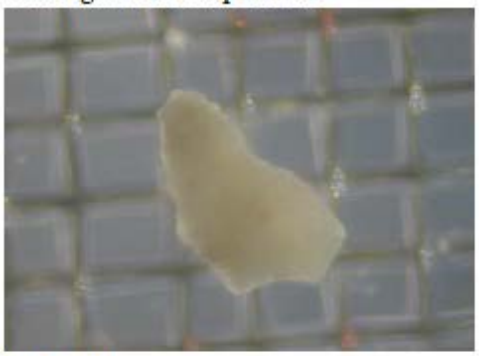
Overview



Heterogeneous composition

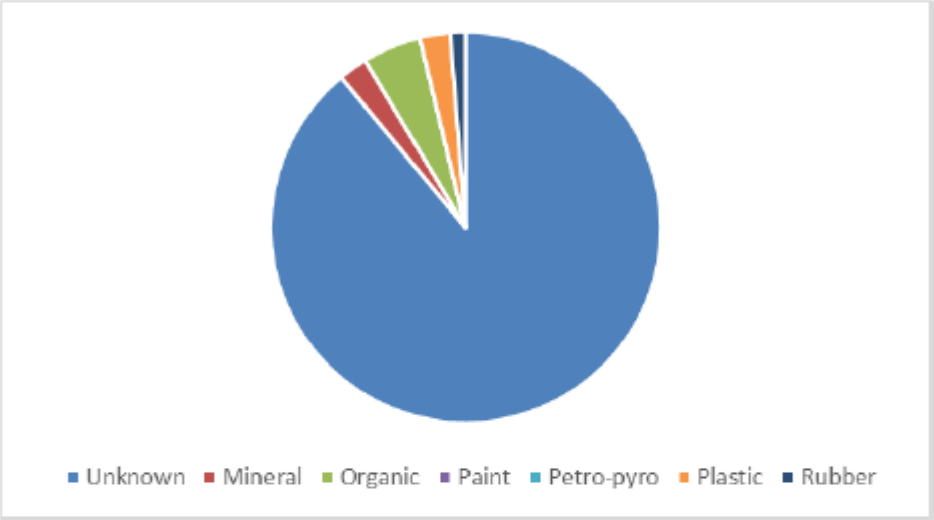


Mostly white and clear granules

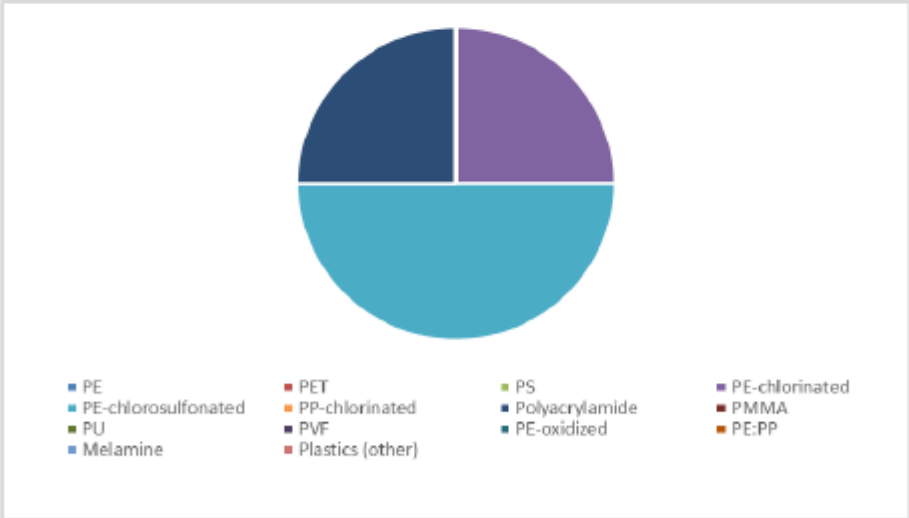


White layer

Most common: unknown particles (89 %). Most abundant plastic polymer: PE-chlorosulfonated, but also PE-chlorinated and polyacrylamide was quantified.



KV-14: General classification

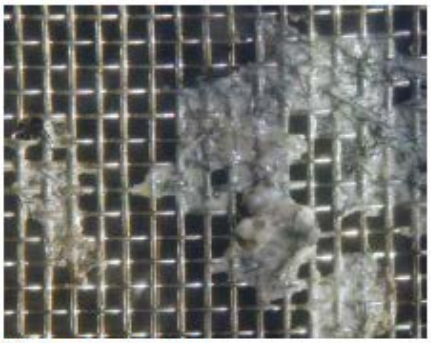


KV-14: Polymer composition

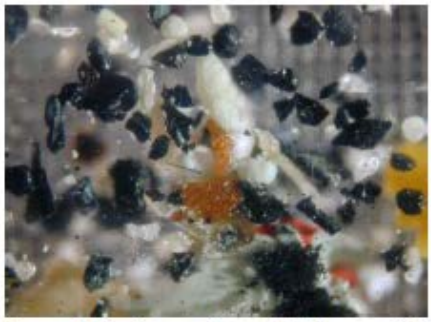
A26 **KV-02**

Pictures from visual microscopy:

Overview

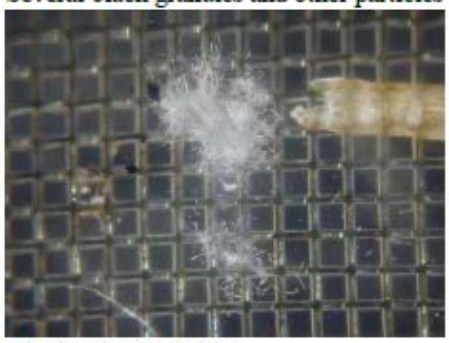


Unknown structure



Several black granules and other particles

White layer



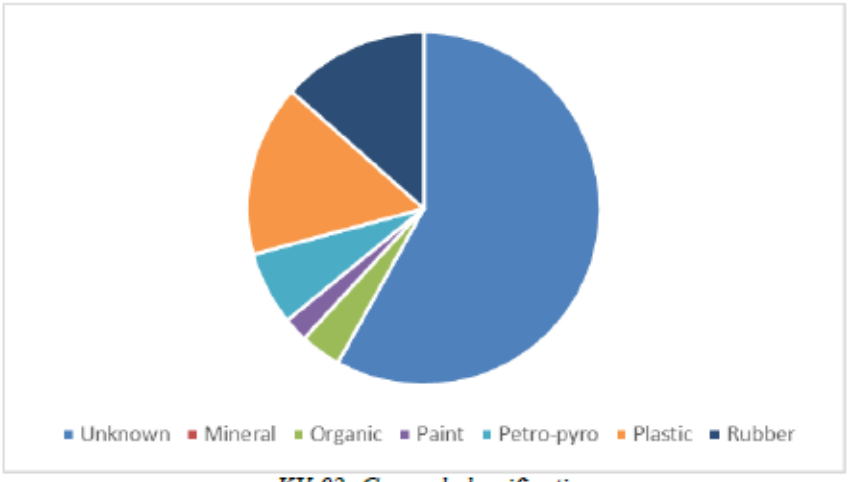
Cluster of white fibres

Yellow/white foam

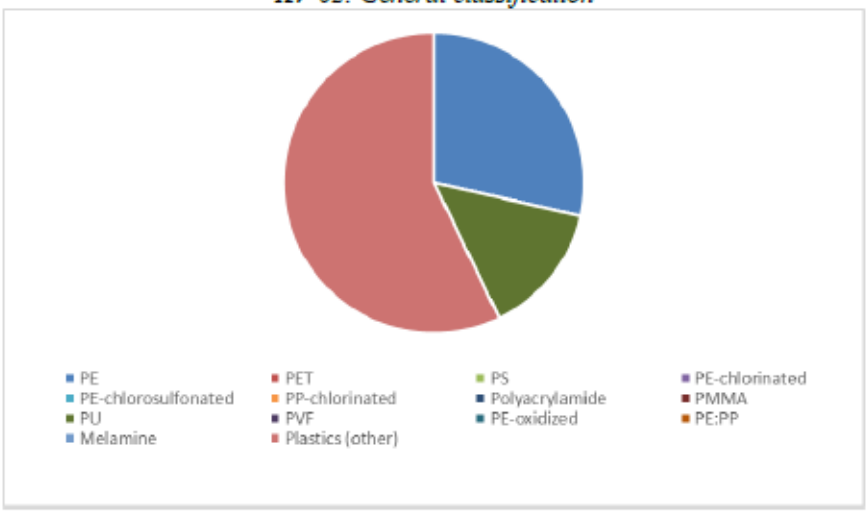
This sample contained several particles not found in any other of the sediment samples, as shown in the photos above. The uppermost right pictures shows several black fibres clustered together with something that looks like glue or slime. Layers of different colours (white, blue and red) were also found, as well as clusters of white fibres and a

foam-looking particle. In agreement with other samples, a heterogeneous composition of granules was identified.

FT-IR results showed that fibres were organic, and most particles were unknown (58 %), plastics (16 %) or rubber (14 %). Compared to other samples, the content of rubber particles was high in this one. The foam-looking particle (see above the picture at the bottom right) was plastic (polyether urethane, PU). The most frequently detected plastic polymer belonging to "other plastics" (additive containing polymers and "POLY(2,5-DIMETHYL-1,4-PHENYLENE-3,3'-DIOXO-5,5'-BIINDOL-2,2'-DIYL) 2/40"), followed by PE.

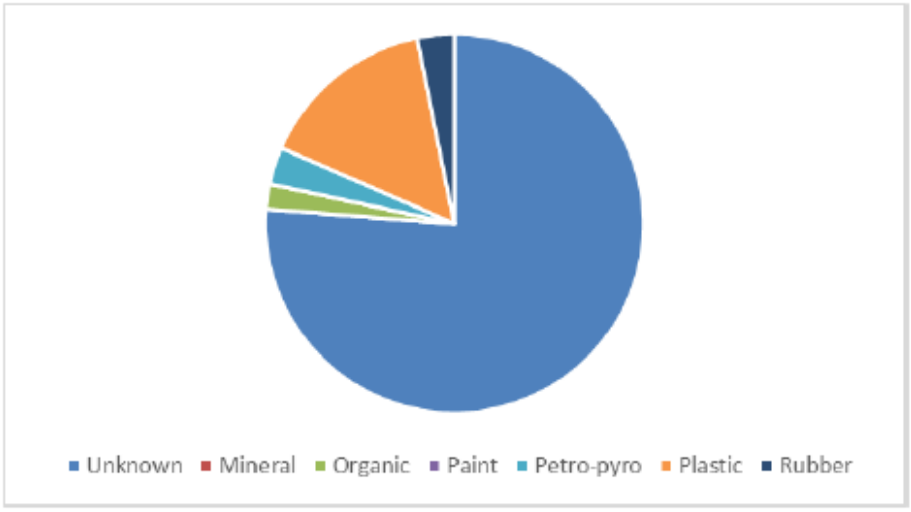


KV-02: General classification

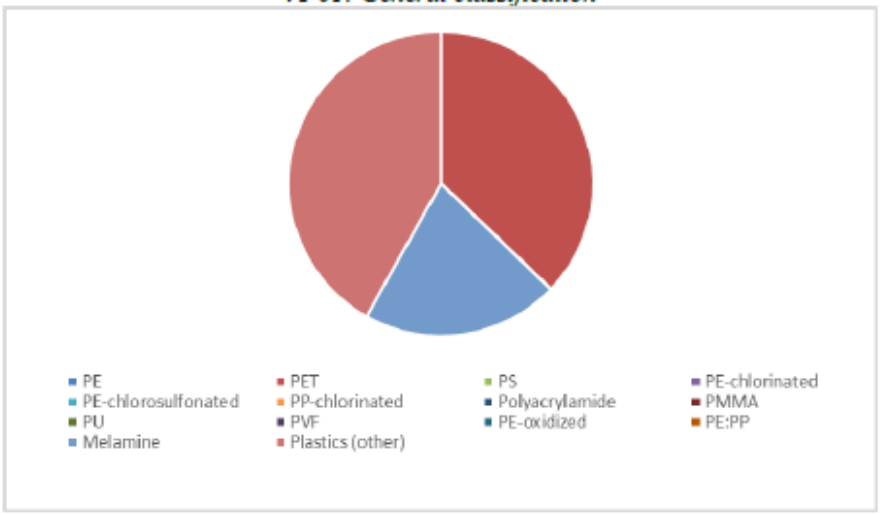


KV-02: Polymer composition

A27 VI-01



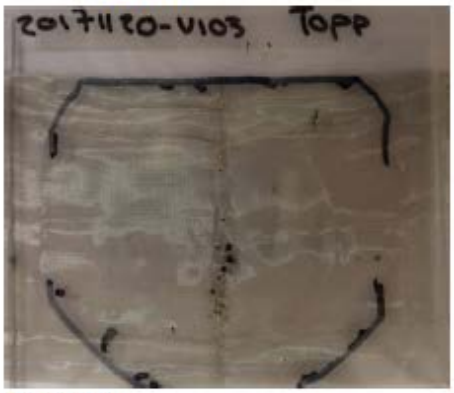
VI-01: General classification



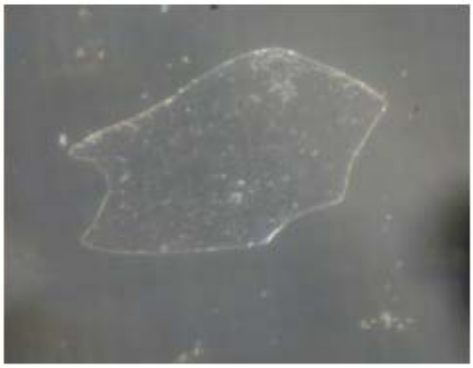
VI-01: Polymer composition

Heterogenous composition. Plastic polymers (15 %): mostly additives ("other plastics") and PET.

A28 **VI-03**

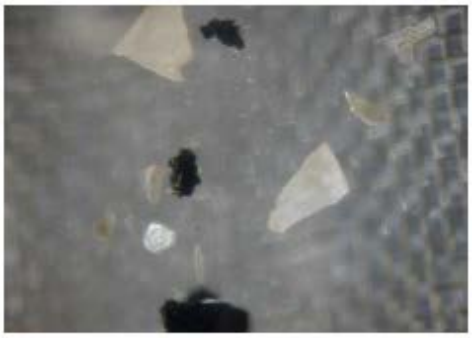


Overview



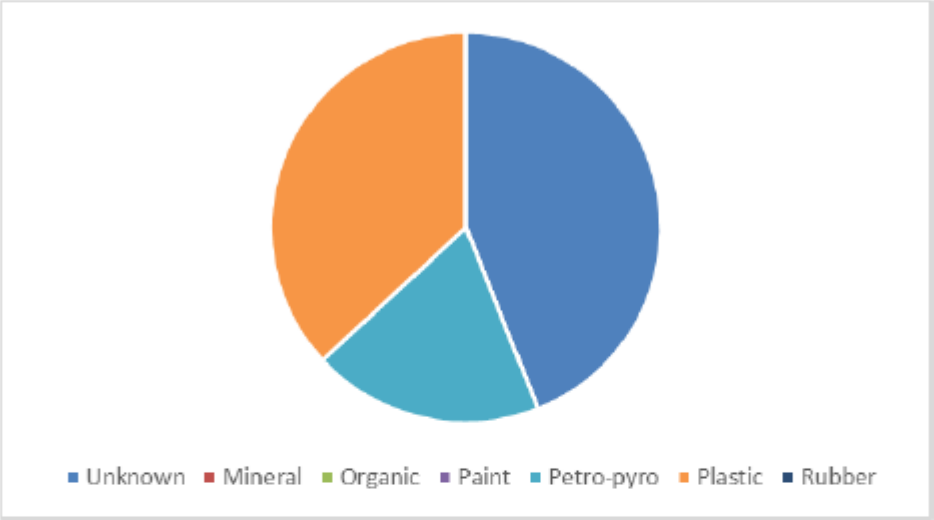
Clear layer

Heterogeneous composition of particles. A substantial amount of white layers

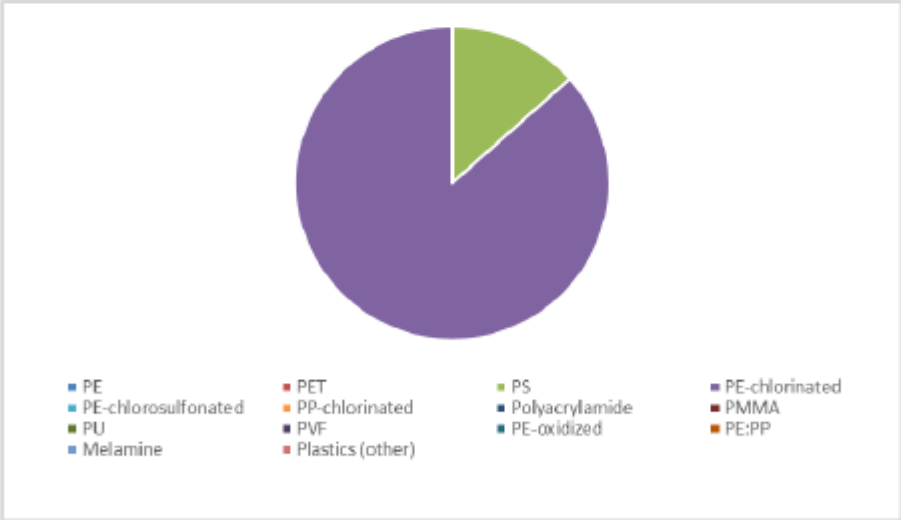


White layers, black and clear granules

Plastic (37 %) and petro-pyro (19 %) contributed to a substantial amount of the identified particles. The most abundant plastic polymer was PE-chlorinated and PS, as shown in the figure below.



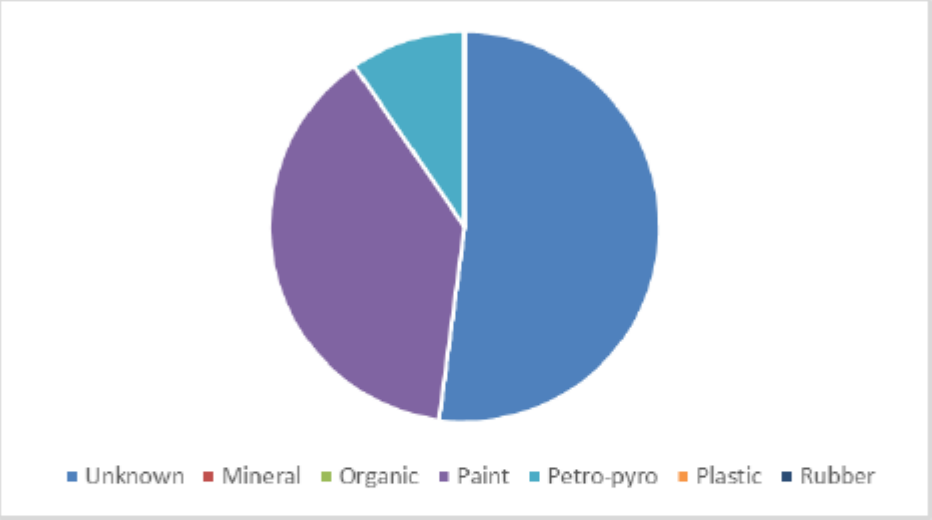
VI-03: General classification



VI-03: Polymer composition

A29 **VI-30**

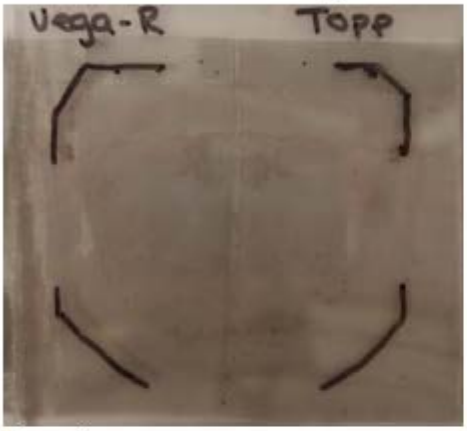
Mostly unknown particles (52 %), as well as paint (phenoxy and epoxy resin, 38 %) and petro-pyro (10 %).



VI-30: General classification

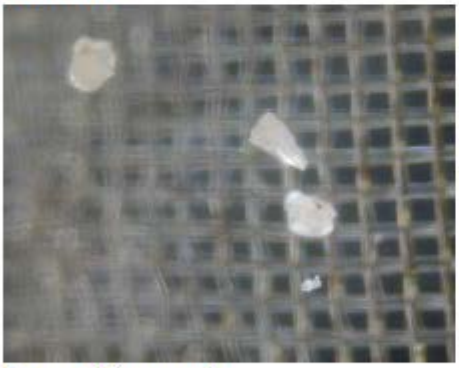
A30 **Vega-R**

Pictures from visual microscopy:

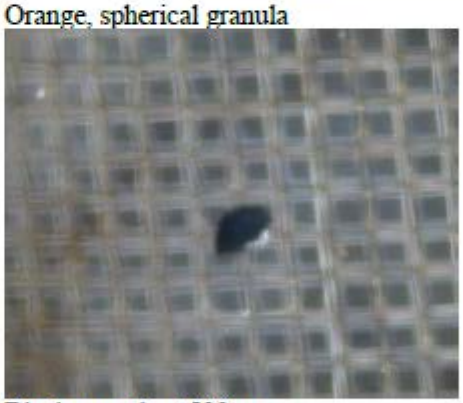


Overview

Orange, spherical granula

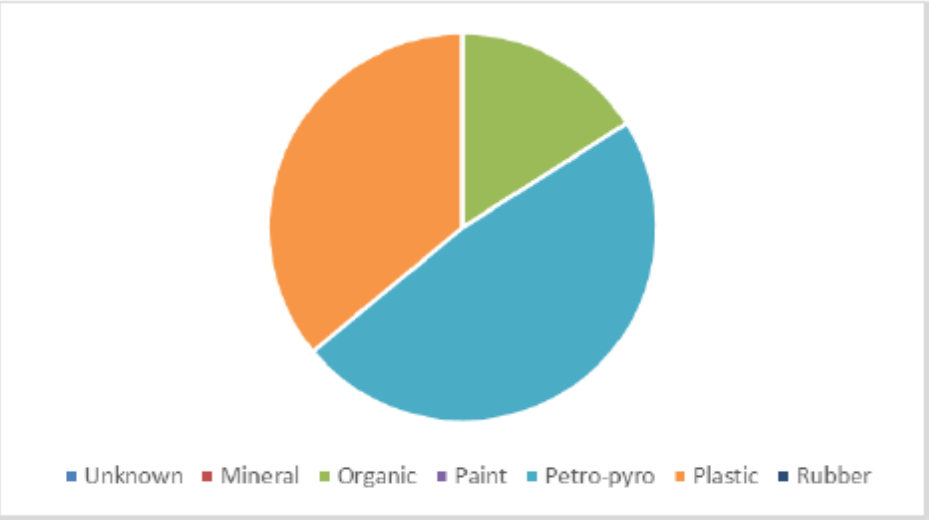


Some white granules

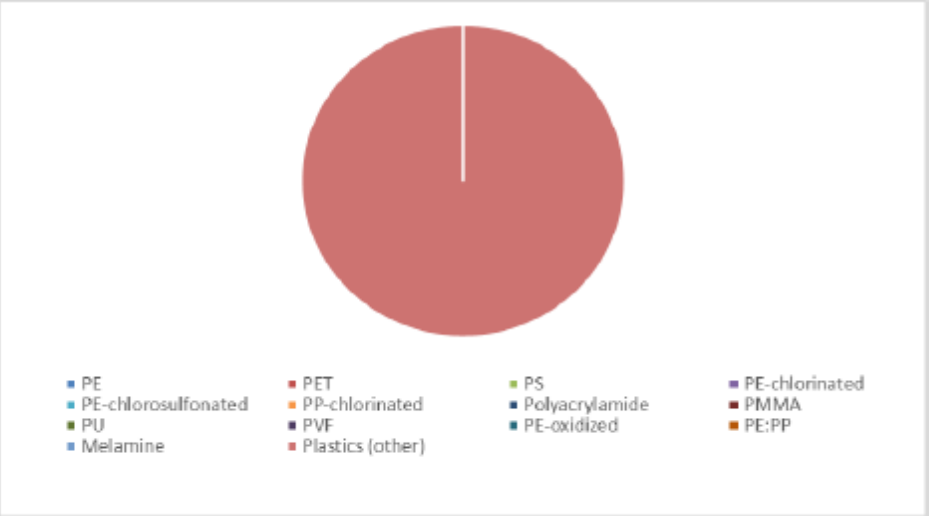


Black granule < 500 µm

According to FT-IR results, black granules as seen in the picture above were petro-pyro particles (48 %). In addition, plastic particles (PET) contributed to approximately 36 % of the overall composition of identified particles.



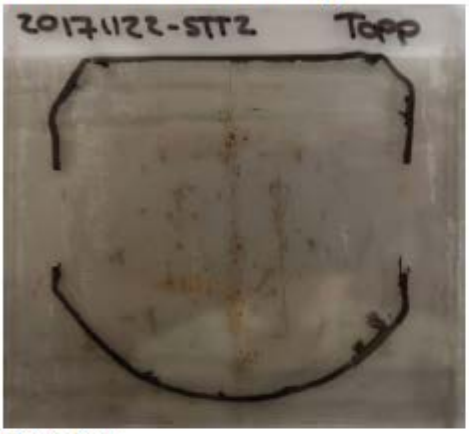
Vega-R: General classification



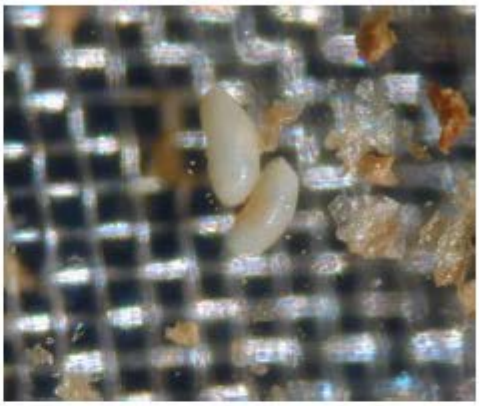
Vega-R: Polymer composition

A31 STT-2

Pictures from visual microscopy:

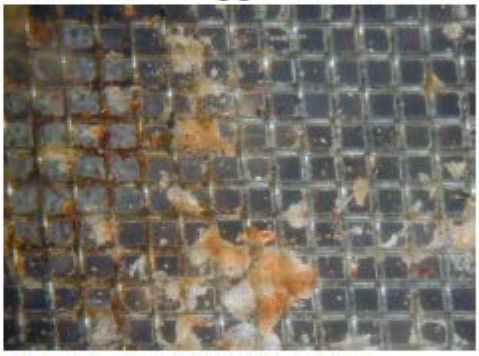


Overview



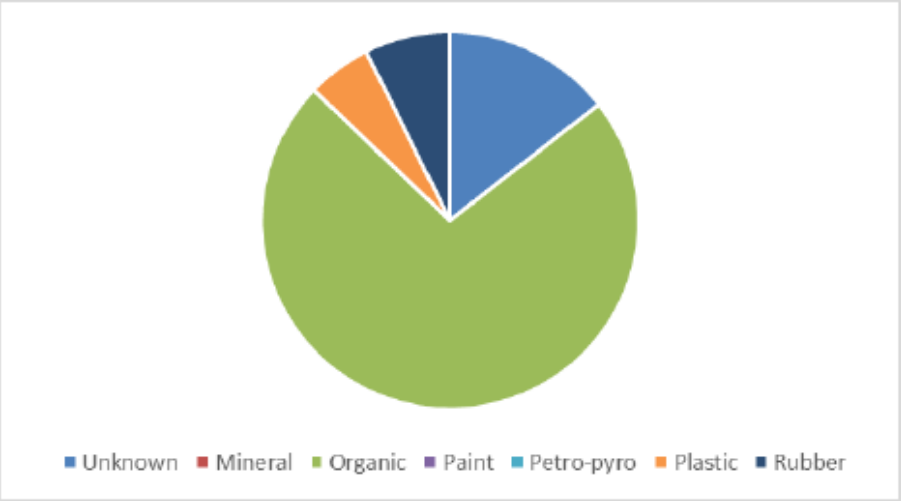
White, bean-looking granules

White fibre

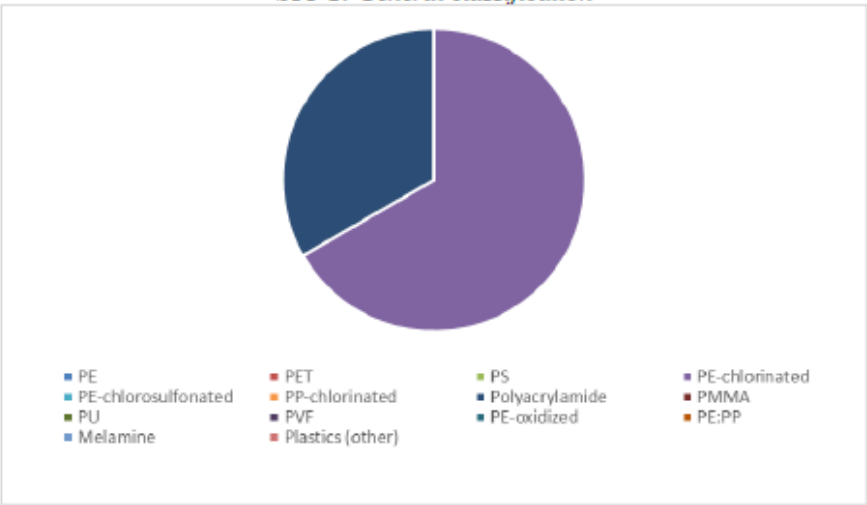


Area with rust and $ZnCl_2$-crystals

Relatively large amount of organic particles (73 %) compared to other samples. PE-chlorinated and polyacrylamide was the plastic polymers quantified (6 %). In addition, rubber was found (7 %).



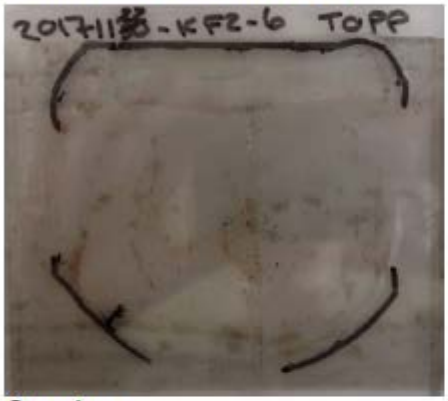
STT-2: General classification



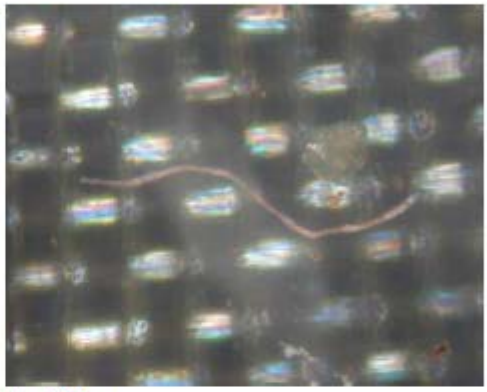
STT-2: Polymer composition

A32 **KF2-6**

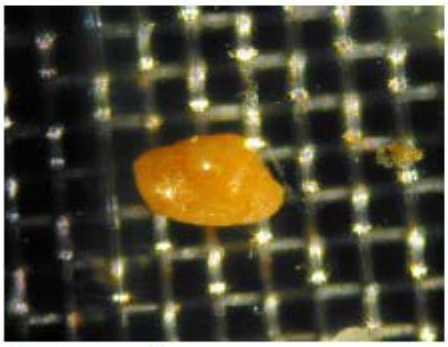
Pictures from visual microscopy:



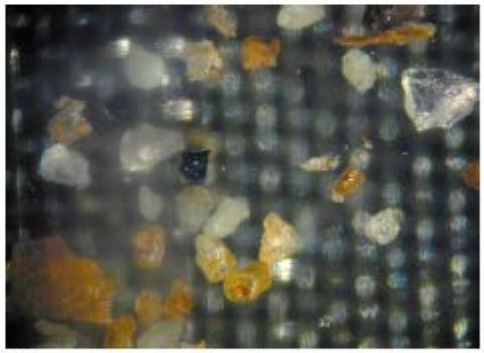
Overview



Red fibre

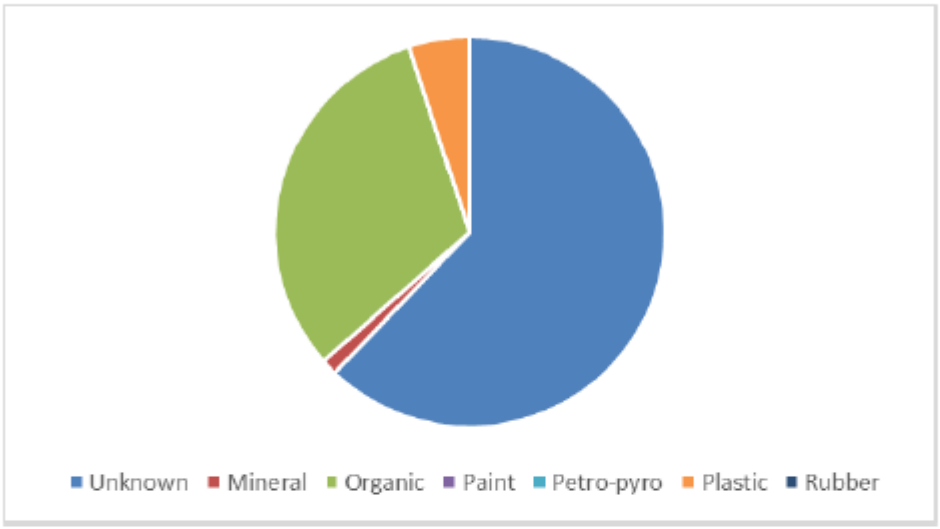


Orange granule

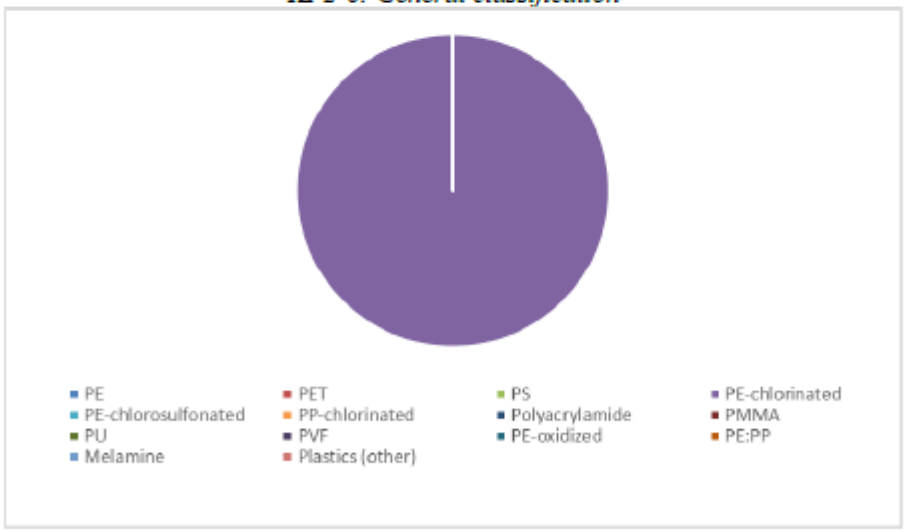


Clear, white, black and orange granules

Mostly unknown (62 %) and organic (32 %) particles. Plastic polymer (5 %): all PE-chlorinated.

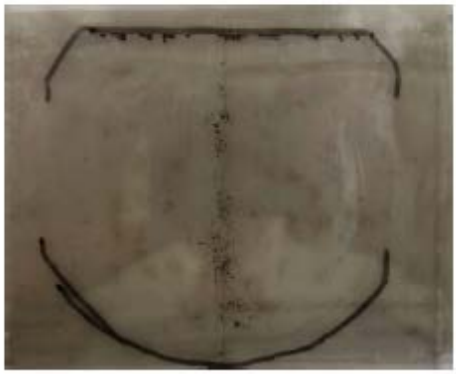


KF2-6: General classification



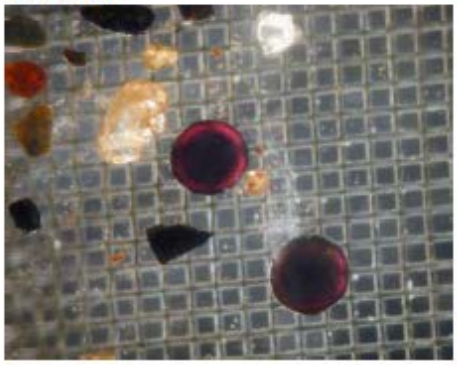
KF2-6: Polymer composition

A33 SC3-4

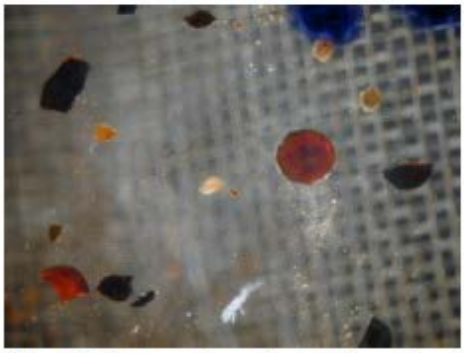


Overview

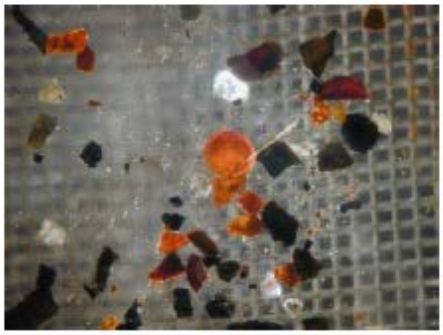
Red fibre



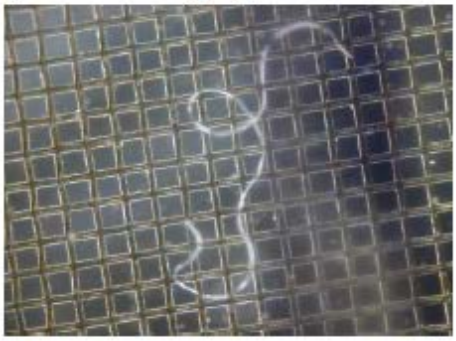
Spherical, purple granules



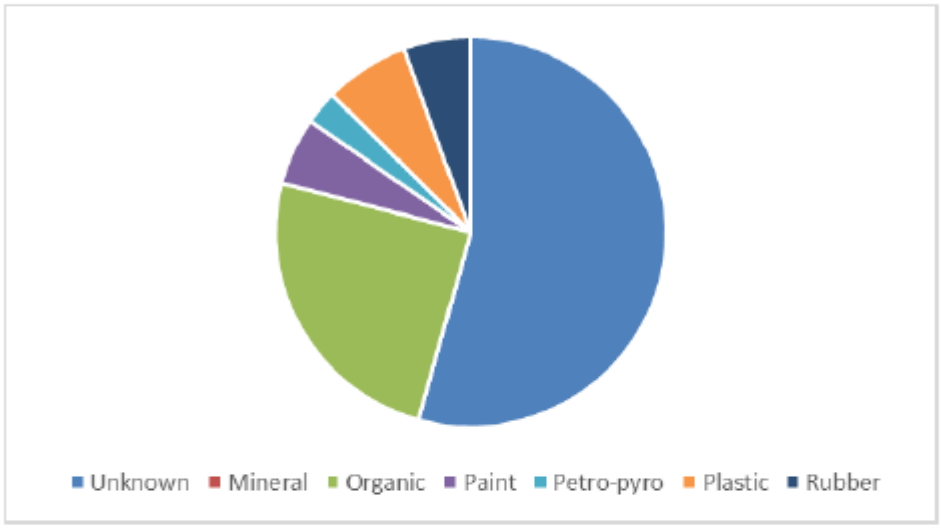
Spherical orange to red granule and red granule with sharp edges



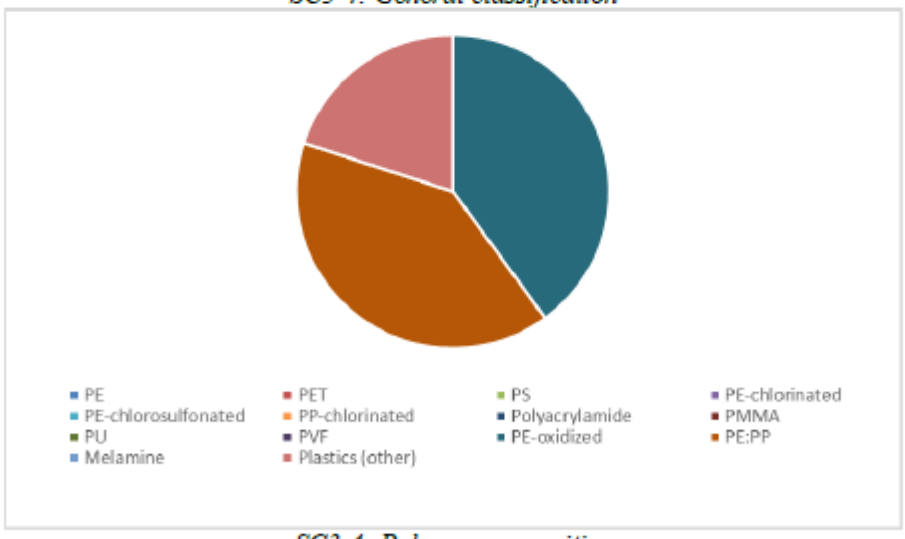
Heterogeneous composition of particles. NB! Orange, spherical granule



White fibre



SC3-4: General classification

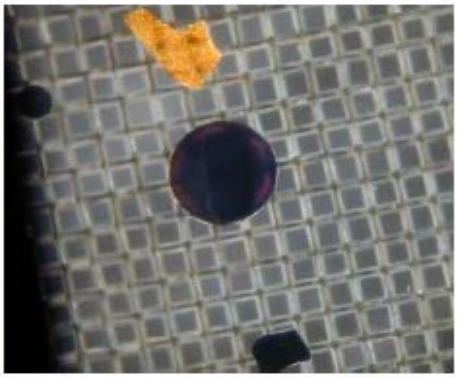


SC3-4: Polymer composition

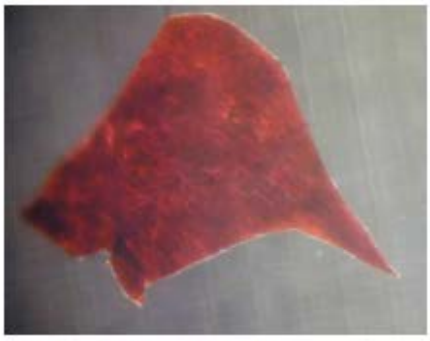
Heterogeneous composition. Mainly unknown particles (54 %). Most frequent plastic polymers (7 %): PE:PP, PE-oxidised and additives ("other plastic").

A34 **KRT-14**

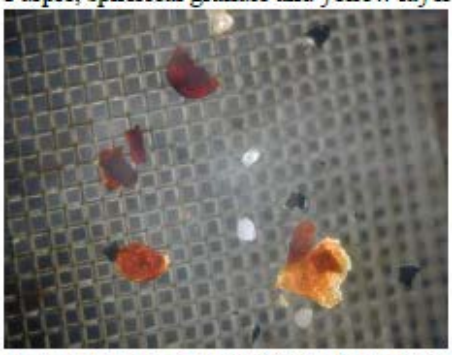
Overview



Purple, spherical granule and yellow layer

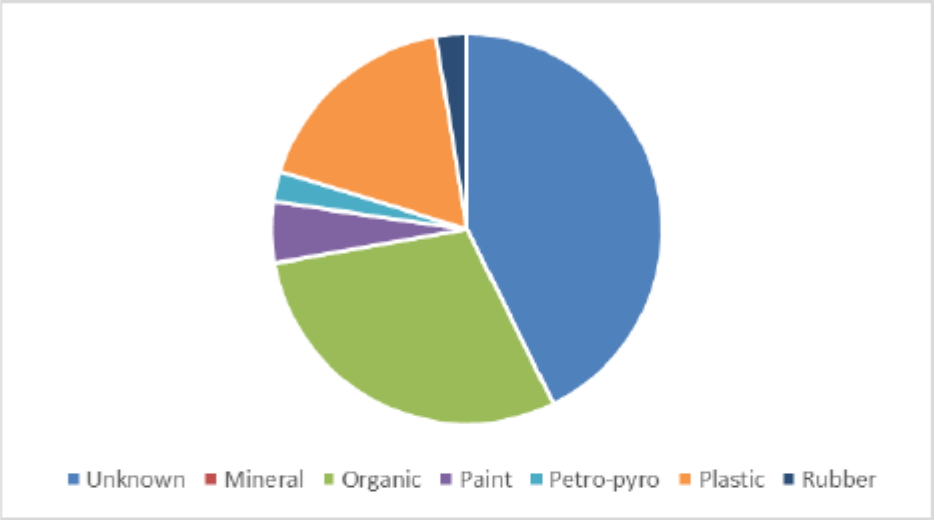


Red layer with sharp edges

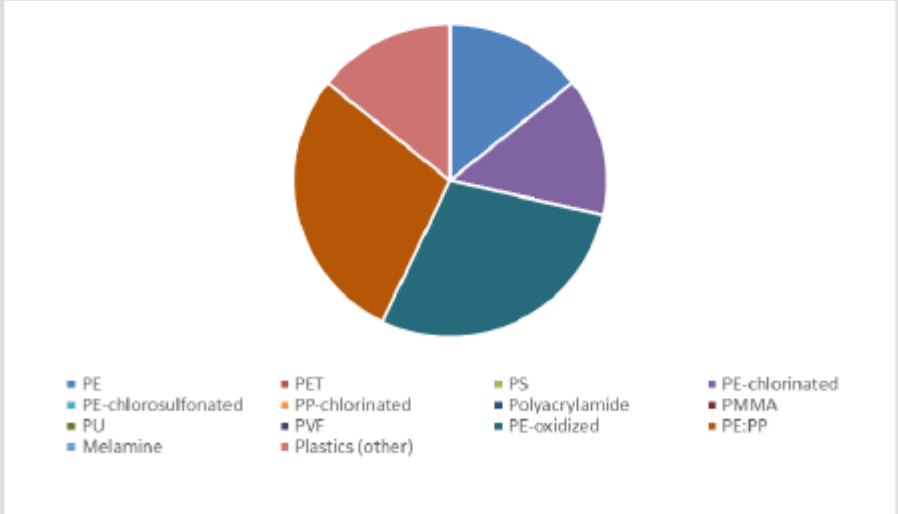


Heterogeneous composition of particles, some with sharp edges

As indicated by the pictures above, the chemical composition was heterogeneous (see figure on next page). Mostly unknown (43 %), organic (30 %) and plastic particles (18 %), as well as paint (5 %), rubber (3 %) and petro-pyro (3). The most abundant plastic particles were PE (oxidized and chlorinated), PE:PP and additives / others.

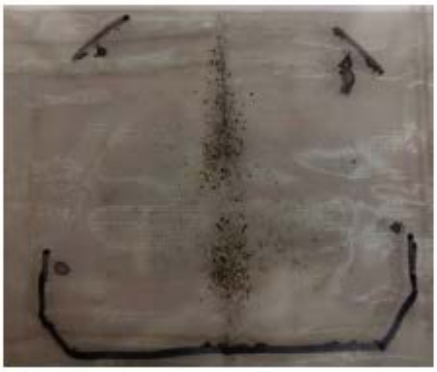


KRT-14: General classification

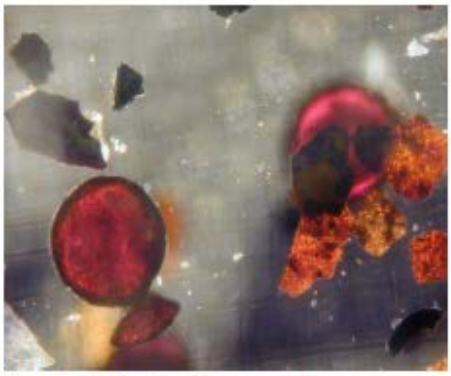


KRT-14: Polymer composition

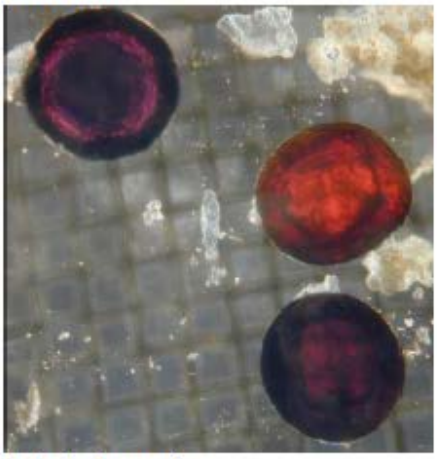
A35 **GRS-2**



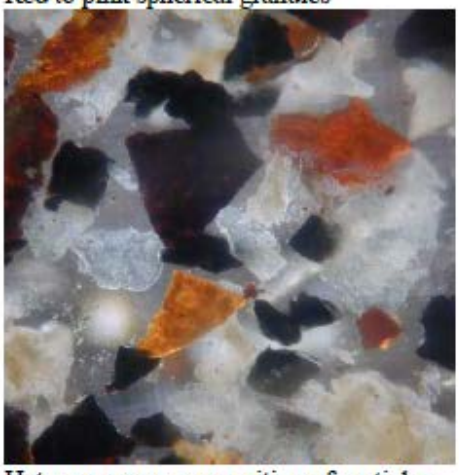
Overview



Red to pink spherical granules

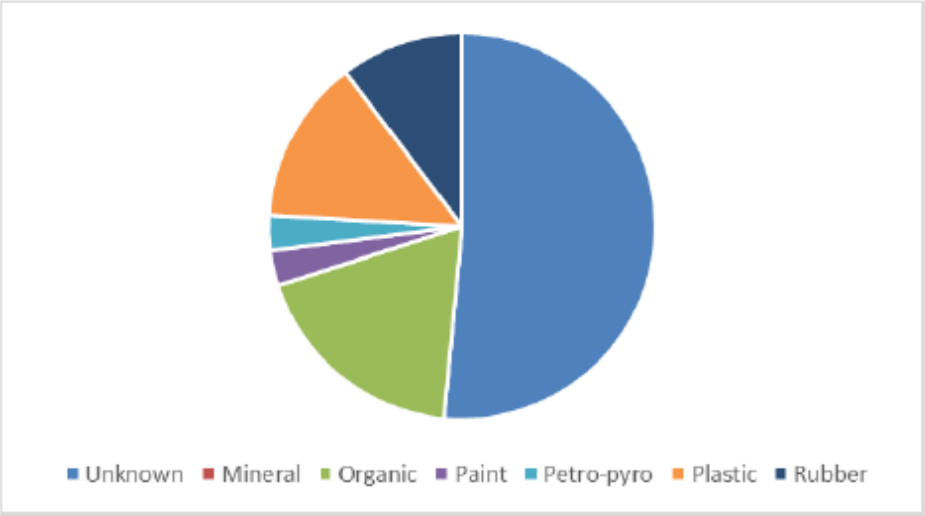


Spherical granules

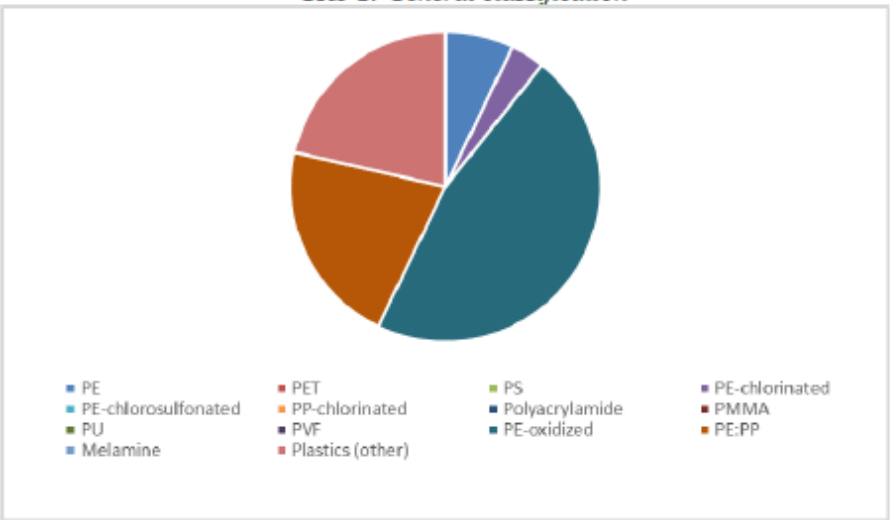


Heterogeneous composition of particles

The following categories of particles were found: unknown (52 %), organic (19 %), plastic (14 %), rubber (10 %), paint (3 %) and petro-pyro (3 %). Plastic polymers identified were mostly PE (oxidized and chlorinated), PE:PP and others (such as additives).



GRS-2: General classification



GRS-2: Polymer composition

A36 Summary Table, FT-IR results meeting quality checks

Tabell A 1 Percent composition of various plastic types in the sediment samples collected from the Norwegian Coastal Shelf

Station	PE	PP	PET	PS	PTFE	PE-chlorinated	PE-chlorosulfonated	PP-chlorinated	Polyacrylamide	PMMA	PU	PVF	PE-oxidized	PE:PP	PVC	Melamine	Plastics (other)
Reg-01	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	6,7%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Reg-02	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Reg-03	0,0%	0,0%	16,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Reg-04	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Reg-06	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	2,5%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Reg-07	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	1,1%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Reg-08	0,0%	0,0%	0,0%	5,4%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	6,1%
Reg-09	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	4,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Reg-11	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Reg-14	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	10,2%
EKO-12	0,6%	0,0%	0,0%	0,4%	0,0%	0,6%	0,0%	0,6%	0,0%	0,0%	0,0%	0,4%	0,0%	0,0%	0,0%	0,0%	0,0%
EKO-14	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	2,1%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	2,1%
EKO-21	0,0%	0,0%	0,0%	0,0%	0,0%	1,3%	1,3%	0,0%	14,5%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%

Station	PE	PP	PET	PS	PTFE	PE-chlorinated	PE-chlorosulfonated	PP-chlorinated	Polyacrylamide	PMMA	PU	PVF	PE-oxidized	PE:PP	PVC	Melamine	Plastics (other)
GYDA-18	0,0%	0,0%	0,0%	0,0%	0,0%	18,5%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
GYDA-21	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
VAL-02	0,0%	0,0%	0,0%	0,0%	0,0%	1,0%	0,0%	0,0%	0,0%	0,6%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	1,0%
VAL-04	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
VAL-05	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
VAL-15	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
ULA-06	0,7%	0,0%	2,4%	0,4%	0,0%	0,7%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	4,6%
Røg-12	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	8,7%
SNB-16R	0,0%	0,0%	0,0%	0,0%	0,0%	37,5%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
VI-RB	0,0%	0,0%	0,0%	0,0%	0,0%	15,8%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
STC-06R	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
KV-14	0,0%	0,0%	0,0%	0,0%	0,0%	0,6%	1,3%	0,0%	0,6%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
KV-02	4,5%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	2,2%	0,0%	0,0%	0,0%	0,0%	0,0%	9,0%
VI-01	0,0%	0,0%	5,7%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	3,2%	6,4%
VI-03	0,0%	0,0%	0,0%	5,0%	0,0%	31,9%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%

Station	PE	PP	PET	PS	PTFE	PE-chlorinated	PE-chlorosulfonated	PP-chlorinated	Polyacrylamide	PMMA	PU	PVF	PE-oxidized	PE:PP	PVC	Melamine	Plastics (other)
VI-30	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Vega-R	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	36,0%
STT-2	0,0%	0,0%	0,0%	0,0%	0,0%	3,7%	0,0%	0,0%	1,8%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
KF2-6	0,0%	0,0%	0,0%	0,0%	0,0%	5,1%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
SC3-4	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	2,8%	2,8%	0,0%	0,0%	1,4%
KRT-14	2,5%	0,0%	0,0%	0,0%	0,0%	2,5%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	5,1%	5,1%	0,0%	0,0%	2,5%
GRS-2	1,0%	0,0%	0,0%	0,0%	0,0%	0,5%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	6,4%	2,9%	0,0%	0,0%	2,9%

About DNV GL

DNV GL is a global quality assurance and risk management company. Driven by our purpose of safeguarding life, property and the environment, we enable our customers to advance the safety and sustainability of their business. We provide classification, technical assurance, software and independent expert advisory services to the maritime, oil & gas, power and renewables industries. We also provide certification, supply chain and data management services to customers across a wide range of industries. Operating in more than 100 countries, our experts are dedicated to helping customers make the world safer, smarter and greener.