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Environmental impacts of cutting deposits in the Frigg area

Report RF – 2002/030

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Distribution restriction: Confidential (open from 07 February 2004)

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Scope

This report summarises the findings from all investigations performed so far on cuttings deposits in the Frigg area. The following issues have been considered:

- Area description with field data
- The relationship between discharge data and actual mapping of the cuttings piles
- The level of different contaminants
- The effects of the cuttings on the benthic community
- The best solutions for cutting deposits in the Frigg area

Contents

Stavanger, 18. March 2013

Stig Westerlund, project leader

1 Approach

This report summarises the cuttings pile issue of the TotalFinaElf (TFE) operated installations in the Frigg area and their environmental impact. The work has been done to assess the environmental impacts of the cuttings deposits in general and as part of field decommissioning. The summary is based on several studies carried out during 1997-2001. For more details on specific issues presented in this summary report, please refer to the relevant report. The major reports addressed are:

1. Kjeilen, G., Cripps, S. J. and Jacobsen, T. G., 2001. Survey of information on cuttings piles in the Norwegian sector. Report RF-2000/151 (OLF)
2. SINTEF draft report, 2001. Deterioration of Reinforced Concrete Platforms in the North Sea-the Frigg Field. STF 22 F01604.
3. Westerlund, S. and Cripps, S. J. 1999. Trace metals and hydrocarbons in the cuttings piles at Frøy and CDP1 platforms. Report RF-1999/237.
4. Westerlund, S. and S. D. Olsen., 2000. Environmental investigation of cuttings deposits in the Frigg area Report RF-2000/219
5. Westerlund, S., 1998. Determination of trace metals and hydrocarbons in sediment under the Frigg DP2 platform. Report RF-1998/236.
6. Westerlund. S and G. Kjeilen. 2001. Environmental impacts of cuttings and mud discharged into the CDP1 concrete structure. Report RF – 2001/197.
7. Mannvik, H.-P. 2000. Chemical and biological survey of the cutting piles at Frigg, Øst Frigg, Nordøst Frigg, Lille Frigg and Frøy fields, June 2000. Akvaplan-Niva rapport APN-411.1997
8. Frigg Field Cessation Plan, TFE.

2 Cuttings piles

Cuttings piles are formed when cuttings and muds, generated when wells are drilled, are discharged to the sea and accumulate around the drilling location. Cuttings are material from the bedrock milled during the drilling and consist mostly of sedimentary rock material like sandstone, shale or limestone.

The size and composition of cuttings piles depend on an array of factors, such as the discharged volumes, type of discharges, discharge point, discharge period, water depth, influence of currents and waves etc. Historically, mud of different types has been discharged during drilling. Some of these muds contain compounds of environmental concern. The issue of drill cuttings piles in relation to field decommissioning is mainly concerned with potential environmental impacts from the presence of such piles.

A large cuttings pile in the North Sea is estimated and sometimes measured to have volumes of 20,000 – 45,000m^3, and thickness exceeding 20m. The cuttings piles in the Frigg area are considered to be small. None of the Frigg area piles exceeding 0.5 m at the thickest part, and volumes are estimated to be less than 500 m^3. A more relevant term for the cuttings piles in this area is **cutting deposits.**

Facts about drilling muds:

During drilling operations, drilling fluids (muds) are used in order to lubricate, to transport cuttings and as a weighting agent. The mud is a mixture of various solids, liquids and an array of different chemicals, of which barite is normally the main component. Most of the chemicals (>90%) are regarded as environmentally harmless.

A wide selection of drilling muds is used. The main categories are based on the nature of the main fluid of the mud which may be either oil based (OBM) (diesel, mineral oil), based on synthetic fluids (PBM) (e.g. esters, ethers, olefines etc.); or water based mud (WBM). The oil-based muds are generally the most environmentally harmful ones, and these are no longer permitted to be discharged at sea. The process of replacing oil-based muds with more environmentally friendly alternatives has been, and is, an ongoing process during the last two decades.

3 Introduction to the Frigg area

The Frigg area is located at the border between Norwegian and UK territories in the middle of the North Sea, west of Haugesund (Figure 1). The water depth in the area is about 100m, and the area is characterised by varying current directions due to amongst others inflow of Atlantic Water and flow of Norwegian Coastal Water in the opposite direction. Bottom currents in the area typically are around 10-15 cm/s. During severe storms, re-suspension and dispersion of bottom sediments due to waves may take place.

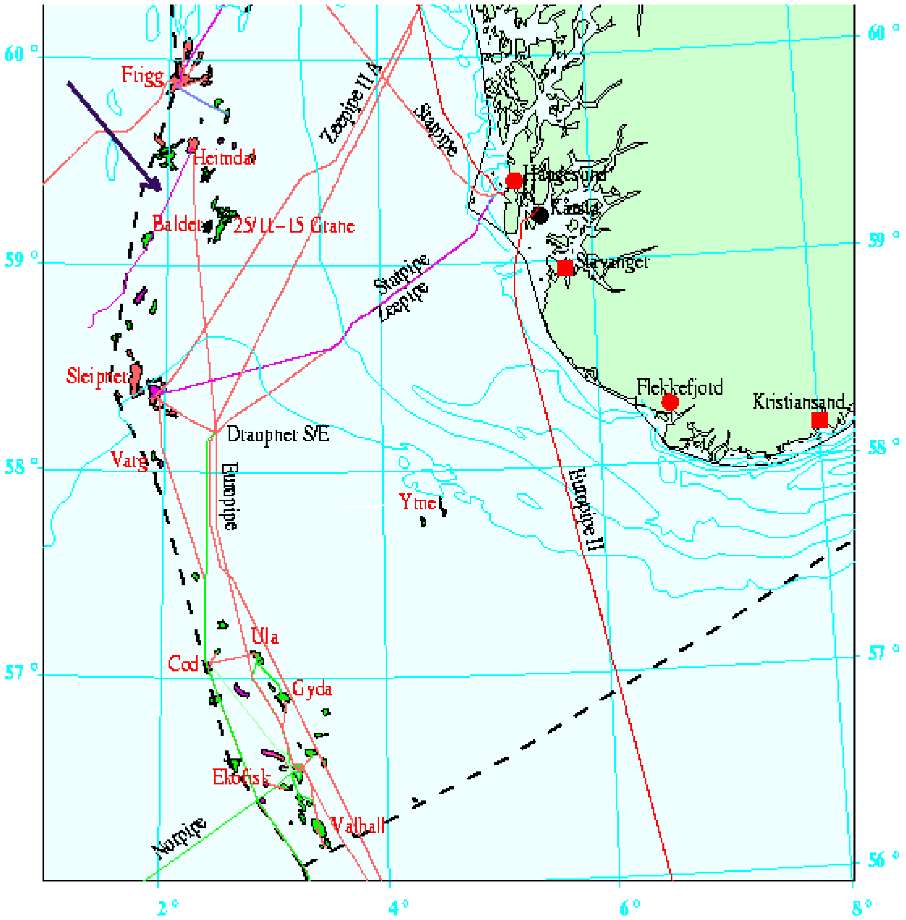


Figure 1: map of the North Sea showing the location of the Frigg field. The arrow shows the prevailing current direction for the bottom currents in the area.

3.1 Facts about Frigg fields and installations

The Frigg area (Figure 2) comprises several fields. The TFE operated fields discussed in this report include Frigg, Northeast-Frigg, Lille-Frigg, East-Frigg and Frøy.

The main field, Frigg, is shared between Norway and UK, the Norwegian share being 60.82%. The installations of the Frigg field are presented in figure 3. The other fields included are all Norwegian. Details of the fields are presented in table 1.

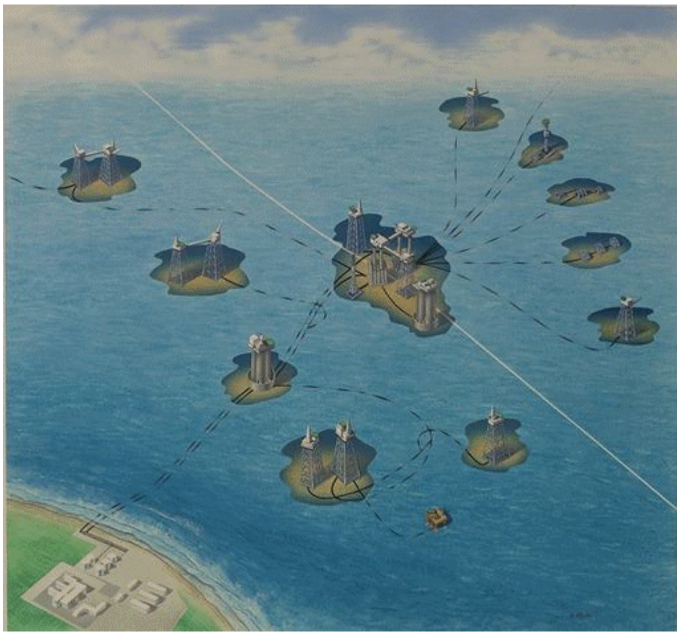


Figure 2: Illustration of the Frigg area. The line represents the Norway-UK border.

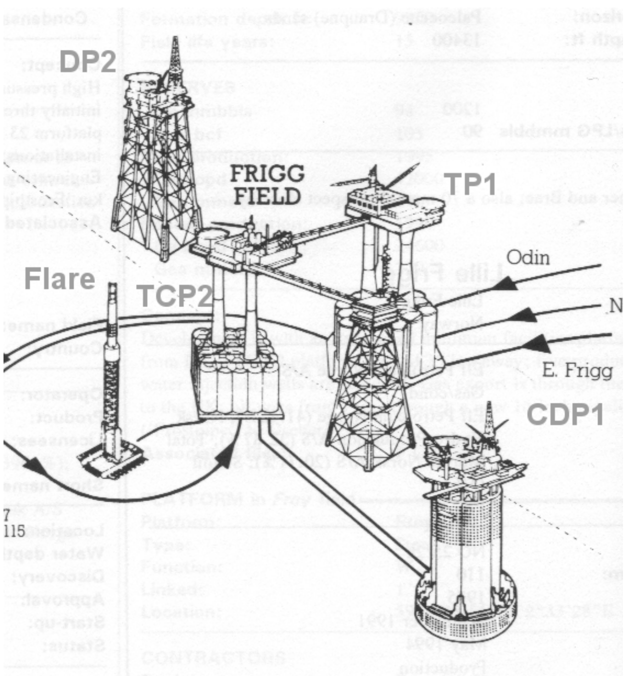


Figure 3: Illustration of the installations in the Frigg field. The installations at the Frigg field are partly located in the British sector and in the Norwegian sector.

Table 1. Frigg area field details.

Frigg	**Depth: 102-105m Installations: Steel platforms: DP2 (drilling platform), QP (quarter platform), FP (flare platform) Concrete platforms: TCP2 (treatment and compression platform), TP1 (treatment platfrom), CDP1 (concrete drilling platform) Production start-up: September 1977 Production end: Still in production Product: Gas Wells drilled: CDP1: 24 DP2: 28 Drilling fluids: Mainly WBM muds used and discharged, OBM used drilling sections of 1 well (236 m^3), 116 m^3 discharged. Associated installations: Both Frøy, Lille-Frigg, Northeast-Frigg and East-Frigg have been tied in to the main Frigg field.**
East-Frigg	**Depth: 100m Installations: 2 subsea templates, alpha and beta, connected to central manifold station (CMS) Production start-up: August 1988 Production end: December 1997 Product: Gas Wells drilled: 3 and 2 at the two templates (A and B) Drilling fluids: Mainly WBM muds used and discharged, OBM used for sections of 2 wells at PSA, (107 m^3) OBM not discharged Associated installations: East-Frigg has been remotely operated from Frigg QP, with the gas being piped to the Frigg TCP-2 platform 18km away for processing.**
Northeast-Frigg	**Depth: 100m Installations: 1 subsea template/manifold Production start-up: December 1983 Production end: May 1993 Product: Gas Wells drilled: 6 Drilling fluids: Only WBM muds used and discharged Associated installations: An articulate column (field control station) was installed nearby, but primary control was from Frigg TCP-2 platform. The gas was piped to the TCP-2 platform about 20km away for processing.**
Lille-Frigg	**Depth: 110m Installations: 3 subsea manifolds Production start-up: May 1994 Production end: April 1999 Products: Gas and condensate Wells drilled: 3 (1 single well at each subsea unit) Drilling fluids: Only WBM muds used and discharged Associated installations: The subsea unit was controlled from QP 23km away. The gas produced was also piped to TCP-2 for processing, while the condensate was piped to Oseberg and then to the Sture terminal.**
Frøy	**Depth: 117m Installations: 1 steel unmanned minimum facilities platform Production start-up: May 1995 Production end: 2000 Product: Oil and gas Wells drilled: 10 (planned; 5 injection and 4 production) Drilling fluids: Mainly WBM used and discharged. Some PBM (linear alpha olefines) used and discharged (1254 m^3). Associated installations: Platform controlled from TCP-2, 33km away. The gas produced was piped to TCP-2 for processing, while the condensate/oil was piped to Oseberg and then to the Sture terminal. The gas was piped to St. Fergus, Scotland.**

3.1.1 Installation specific cuttings discharges and piles

Drilling activity and discharges have taken place at some but not all the Frigg area installations. The installations at which drilling have occurred are summarised in Table 2.

Table 2: Summary of drilling and discharge data in the Frigg area. C = Cuttings, M = Mud. The number of years in column 4 represent the time from drilling stopped until the pile was mapped.

Installation	Discharge (C) m^3	Discharge (M) m^3	Years
Frigg DP2	6931	64504	23
Frigg CDP1*	5600	52000	21
Frøy	5462	41350	5
East-Frigg PSA	1055	7093	13
East-Frigg PSB	664	4346	13
Lille-Frigg C1**	833	9311	8
Lille-Frigg C2**	833	9311	8
Lille-Frigg C3**	833	9311	8
Northeast-Frigg	1566	19056	18

* Discharged into concrete column of structure
** Data from one template only is given, the other two are predicted from the same, given similar well lengths, fluid systems and number of wells

The CDP1 installation differs from the others in that cuttings have been deposited inside the main column of the structure together with ballast rock. The cuttings layer sits inside the column at about 35m above the seabed, and is covered by another 10m of gravel top filling. The cuttings pile issue of the CDP1 is very different from the rest of the sites, as the environmental impacts are more related to structure collapse than the cuttings. As shown below, the environmental conditions around the CDP1 structure is representative of sites with no discharges of cuttings.

4 Purpose and content of cuttings piles surveys

The cutting deposits in the Frigg area have been sampled at three occasions during the period 1998-2000. The surveys have been carried out to assist in making environmental impact assessments of the cuttings deposits. Physical, chemical and biological characterisations of the cuttings piles has been conducted. During the last survey, recent OLF Guidelines for cuttings pile characterisation was applied.

Key elements of the surveys include:

- Mapping (physical extent)
- Metal quantification (including the elements Cr, Ni, Cu, Zn, As, Ag, Cd, Pb and Hg)
- Quantification of organic substances (the most relevant being THC, PAH, B(a)P and PCB; see 'Facts about characterisation parameters')

Facts about characterisation parameters:

A number of physical, chemical and biological parameters have been used to fully address the potential impacts of the cuttings deposits. Physical parameters give information more related to the expected physical behaviour of the material on the seabed, and how it is expected to react to disturbance.

The focus of the chemical parameters has been to identify and quantify elements of environmental concern. The metals of most concern include mercury, cadmium and lead. Other compounds of special focus include the organic parameters; Total hydrocarbons (THC), Poly aromatic hydrocarbons (PAH), Benzo-a-pyrene (B(a)P) and also poly-chlorinated biphenyls (PCB). The THC level indicates the oil content of the sample, while the PAH and more specifically B(a)P parameters more directly relates to the actual toxicity and hence environmental impact of the sample. PCBs are of concern because of their recalcitrant and carcinogenic nature. They are not natural constituents of drilling muds or cuttings. If present in cuttings piles they must have been introduced by other means.

Biological parameters are restricted to macrofauna community indexes that say something about the “state of health” for biological life at the pile and its surroundings. Various indexes exist that in general provide the same type of information.

5 Results: Mapping

Different approaches to cuttings pile mapping has been used at different locations. For large cuttings piles, mapping using ROV techniques where the bottom topography is plotted is efficient, showing the cutting pile as a deviation from the normal bottom contour.

Mapping of the cutting deposits at Frigg was made by core sampling in the area where cuttings were expected. The lateral extent of the pile, and the thickness of pile material was estimated from the cores taken. A map of the Frøy cuttings deposits is shown in Figure 5.

The mapped pile/deposits volumes of the Frigg area installations are presented in Table 3. The remaining volumes are compared to total discharge volumes of cuttings + muds (WW) and total volume of cuttings and muds discharged after taking the water content of the mud into account (DW). The total discharge volumes are also illustrated in Figure 6.

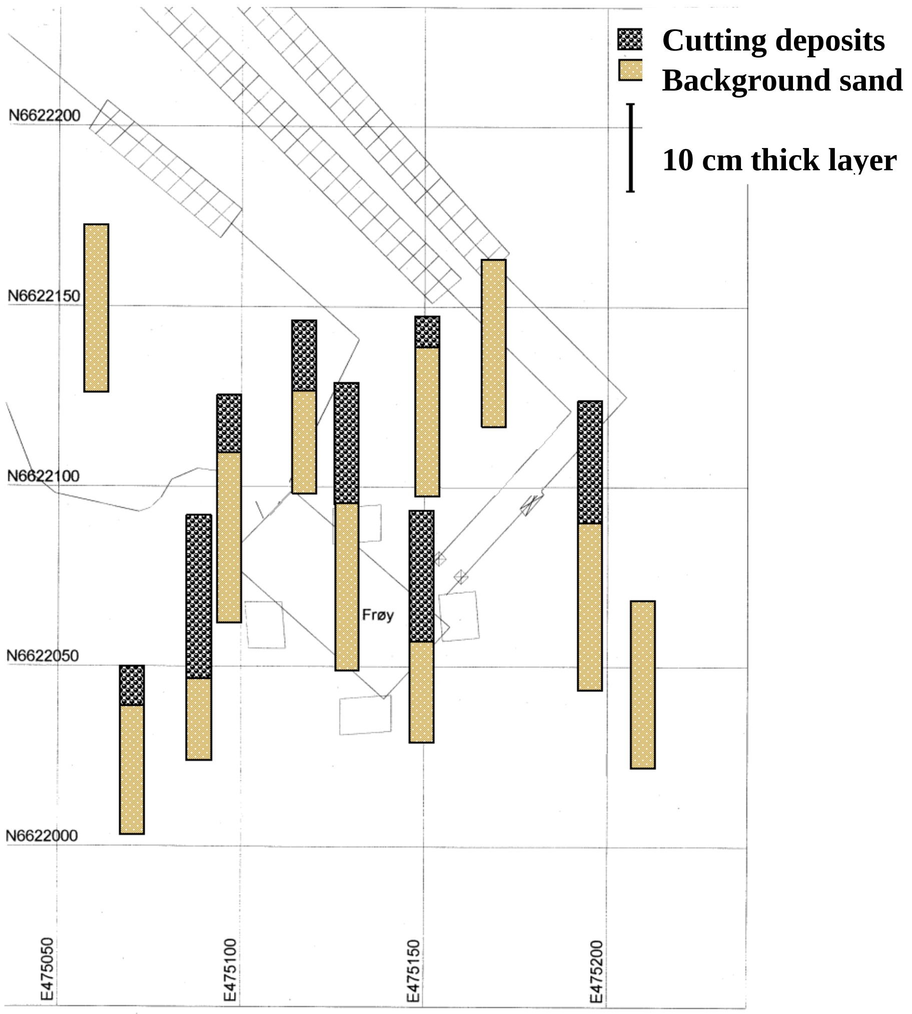


Figure 4. Picture generated from the mapping of the Frøy cuttings pile. This cuttings pile is the largest in the Frigg area. The thickest cuttings layers are found to the southwest of the platform, where the drilling was located.

Comparison of the discharge data and the mapping of the cuttings deposit show that only 1-5 % of the volume discharged (i.e. all cuttings and dry mud) are found in the cuttings piles (see Figure 5 and Table 3).

Table 3: Cutting deposits found at the base of respective installations in the Frigg area. The volumes are also shown in relation to the discharge data where mud is assumed to contain 10 % dry material.

	Cutting deposits found on sea-bottom			
	Mapped (m^3)	%of C	% of C and M	THC t/pile
Northeast Frigg	208	9.3	5.0	0.023
East Frigg PSA	49	4.1	2.6	0.106
East Frigg PSB	15	2.0	1.3	0.015
Frøy WHP	467	6.7	4.2	8.73
Frigg DP2	298	3.1	1.8	0.22
Lille Frigg C1*	12	1.4	0.7	0.004
Lille Frigg C2*	12	1.4	0.7	N.I.
Lille Frigg C3	12	1.4	0.7	N.I.
CDP1	0			
Total Frigg area	1073			9.1

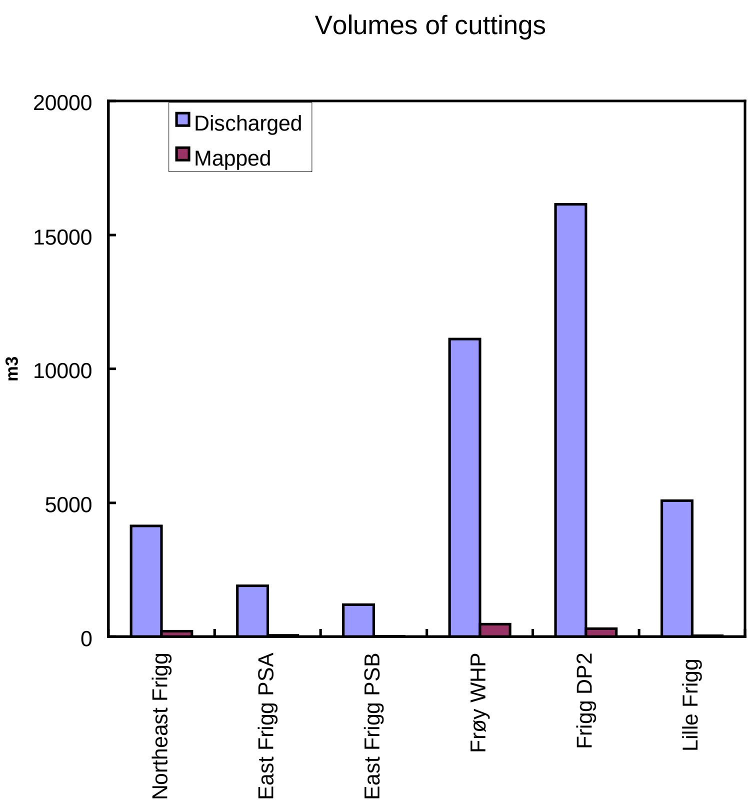


Figure 5. Illustration of discharged cuttings and mud (dry volume) in relation to remaining cuttings found in the mapped piles.

5.1 Cuttings deposits at the seafloor

The cuttings deposits found in the Frigg area are from the North-Sea perspective, considered to be small. All deposits are mainly located beneath steal structures giving the forces of erosion free access to erode the deposits. With a few exceptions, all mud discharges have been WBM muds. Small amounts of oil based mud have been used at DP 2 and East Frigg, while discharges only took place at DP 2. At Frøy, PBM mud (poly-alpha olefin) has been used and discharged. The mud composition is to some extent reflected in the composition and volume of the cutting deposits.

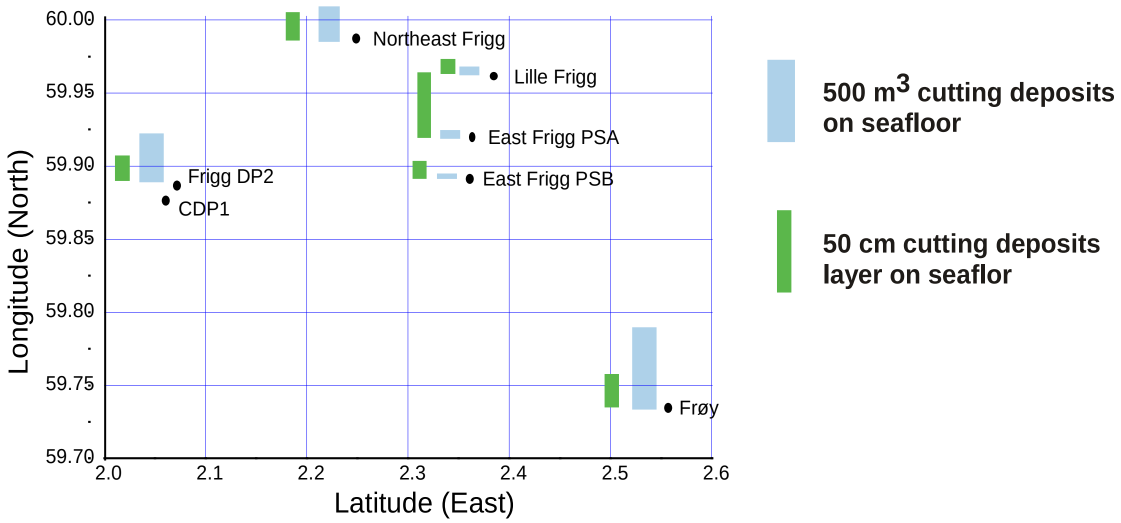


Figure 6: Illustrations of the cuttings volumes and maximum thicknesses of the cuttings found in the surveys.

The largest remaining volume of deposits is found at Frøy. Frøy also have the largest percentage of discharged volume remaining as a pile (Table 2). Another view of the cutting deposits at the Frigg area could be seen from the maximum thickness of the piles. It should be noticed that all cuttings at Frigg seem to be covered by a thin layer of new sediment, indicative of sedimentation or suspended material. This is also observed at the other small deposits and in the peripheral parts of the piles.

The thickness of the cutting deposits at the Frigg area must also be considered as thin. Although the East Frigg PSA is not the largest pile by volume, the thickest layer can be found here. The mapping of the East Frigg PSA pile shows that this relative thick layer covers a very small area of the sea-bottom.

5.2 Area covered by cuttings

Only small parts of the total North Sea area is explored and used for oil and gas production. The area covered by cuttings deposits may seem large. However, if we define the Frigg area as the total area covered by the grid of Figure 7, only a very small portion is actually covered by the deposits:

The cuttings deposits in the Frigg area (1073 m^3) covers 0.12 km^2 which is about 0.001% of the area covered by the grid presented in Figure 6. This is illustrated in Figure 7 below.

Figure 7. Illustration of the area covered by cuttings in the Frigg area. The black line shows the total area covered uy cuttings and the blue area represent the whole Frigg area (Fig 4).

5.3 Results: chemical parameters

A selection of metals and organic contaminants has been measured in the material collected from the cuttings piles.

Figure 8 and 9 summarises the metals and organic contaminant data of the components that can be considered a threat to the North Sea environment. The concentrations found within the cuttings deposits at each installation were found to be rather similar. The numbers presented in the figures are average concentrations of the contaminants based on a large set of samples from each site.

In the absence of an adequate classification system for the North Sea upon which the seriousness of the contaminant levels can be judged, a system which was developed for classification of Norwegian fjords and coastal waters has been used. This system is described further in 'Facts about SFT classification system of fjords and coastal waters'. Of all the compounds analysed at all Frigg area installations, none has been found at concentrations exceeding SFT class 2. Most components have been found at levels within SFT class 1.

Facts about SFT classification system of fjords and coastal waters:

The SFT classification system is used to classify fjords and coastal waters with respect to their contaminant level and hence the expected environmental impacts. The system is divided into 5 classes (1-5), of which the most contaminated class is denoted class 5. For each component included, class limits are defined based on the impact of the compound. The colour code of the classes is illustrated below, using Cu as an example. Each component will have similar limits based on their potential impacts.

The five classes are:

Class 1 - minor or uncontaminated coastal environments;
Class 2 - moderately polluted;
Class 3 - markedly polluted;
Class 4 - strongly polluted;
Class 5 - very strongly polluted environments.

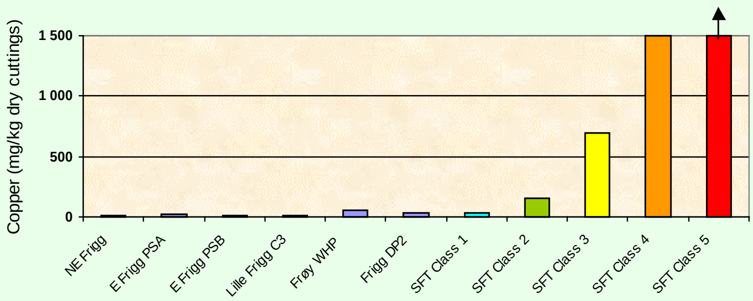


Illustration of the SFT Classification system for Cu in the different cutting deposits in the Frigg area. As can be seen the concentration limit for Cu in a moderately polluted area (green bar – SFT class 2) by far exceeds the actual levels measured in the cuttings deposits.

Table 4 summarises the data on metals and organic contaminants in the Frigg area that could be a threat to the North Sea environment. The concentrations found at each installation were found to be rather homogenous. The data shown represent average concentrations of the contaminants based on a significant number of measurements at each site.

Table 4: Average concentrations of contaminants found in the cutting deposits in the Frigg area. Blue colour indicates SFT Class1.

	NE Frigg mg/kg	E Frigg PSA mg/kg	E Frigg PSB mg/kg	Lille Frigg C3 mg/kg	Frøy WHP mg/kg	Frigg DP2 mg/kg
Cr	100	300	43	25	28	18
Ni	10	20	7	8	45	15
Cu	15	20	8	10	57	32
Zn	60	40	28	28	80	330
Cd	1	0.13	0.18	0.13	0.32	0.5
Pb	25	30	30	28	25	72
Hg	0.04	0.2	0.03	0.034	0.042	0.020
PAH	50	400	130	70	500	240

5.3.1 Metals

The metals that currently are in focus and of most concern are Hg and Cd. Over the last decade much effort has been made to minimise the anthropogenic (man-made) input of these metals. Metals levels of Hg, Cd and Pb are presented in Figure 8.

No metal concentration above SFT Class 2 was found in the cutting deposits in the Frigg area.

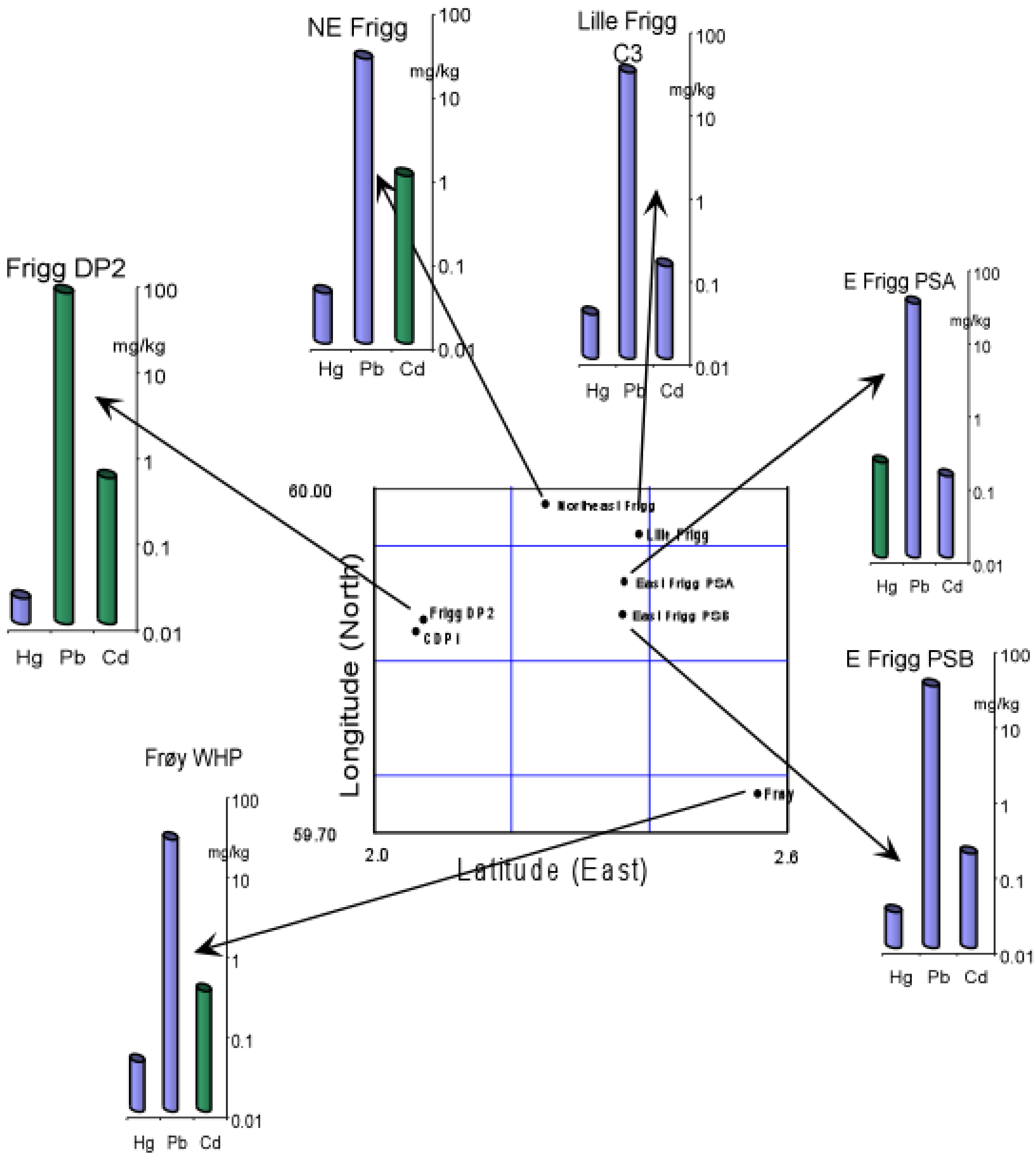


Figure 8: Bars showing (relative) levels of Hg, Pb and Cd. The blue bars indicate SFT Class 1 and the green bars indicate that the values measured fall within SFT Class 2.

5.3.2 Organic contaminants

Among organic contaminants, focus has recently been on PAH:s and PCB:s. For PAH, naphtalenes are the dominating PAH compound, while the level of more harmful and possibly carcinogenic PAH compounds (e.g. B(a)P) are generally low. The B(a)P exceed SFT Class 1 at Frøy and DP2, the sites where most drilling activity have taken place (the relationship between the organic parameters are addressed in the 'facts about characterisation parameters').

Measurements of PCB in the cutting deposits in the Frigg area showed only low levels, and no obvious PCB-contamination of the cutting could be found.

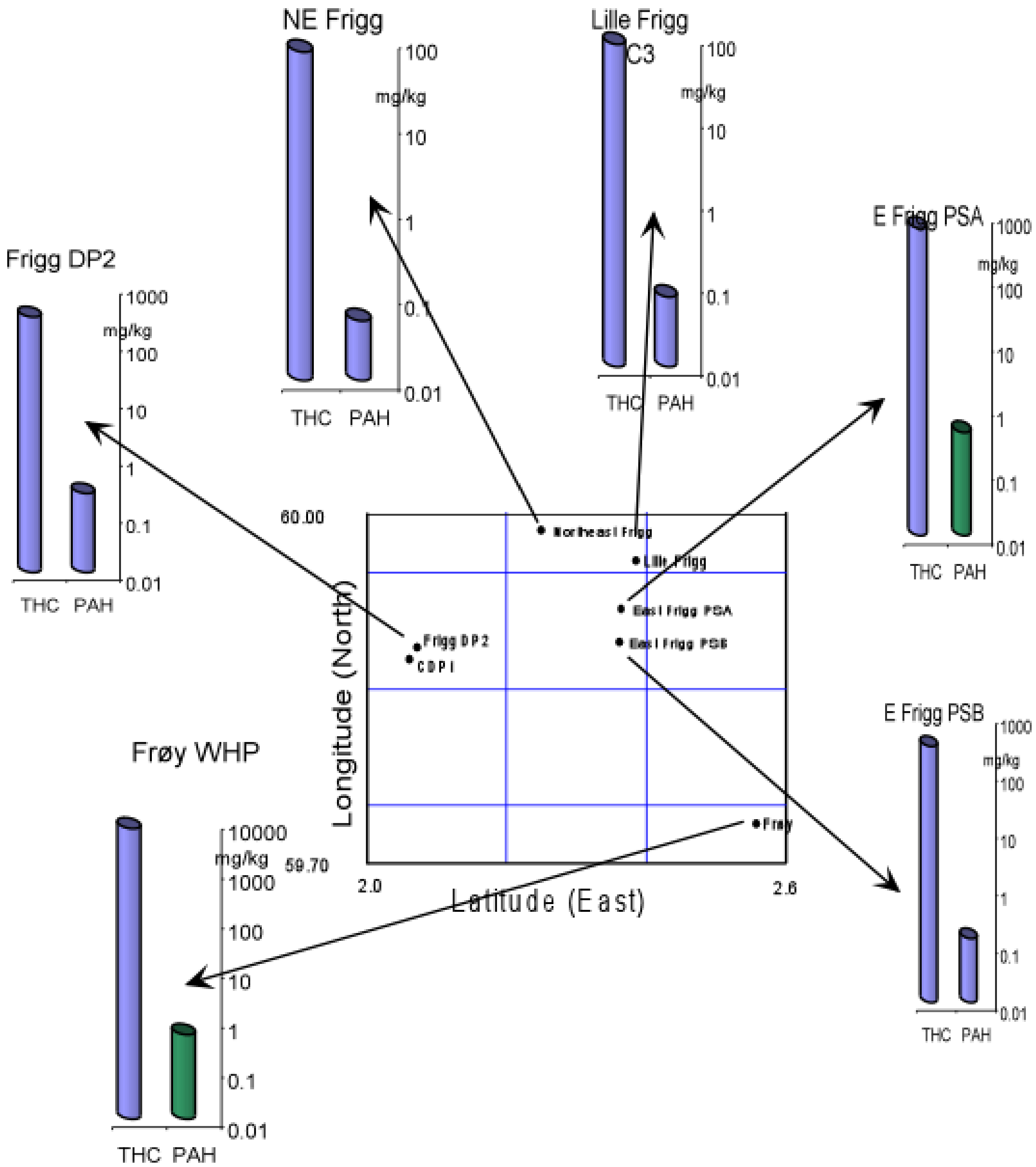
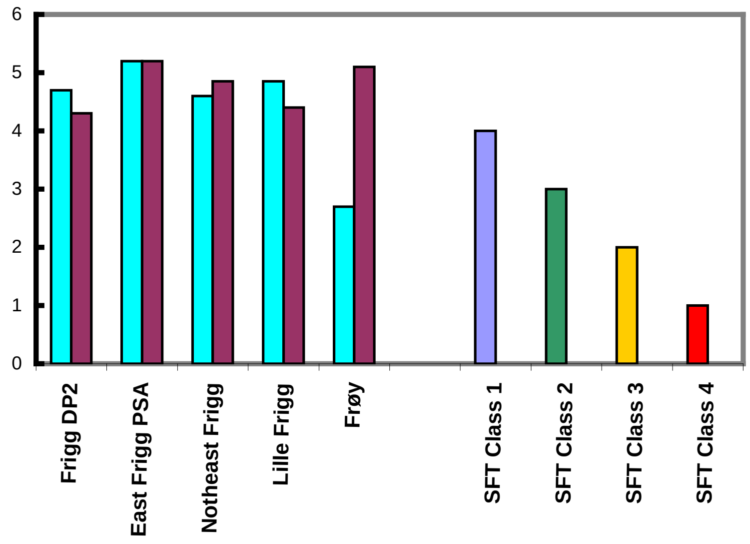


Figure 9: Bars showing (relative) levels of THC and PAH. The blue bars indicate SFT Class 1 and the green bars indicate that the values measured fall within SFT Class 2. THC is not represented in the SFT classification system.

5.3.3 Benthos investigations

The results of the latest environmental investigations of the benthic fauna around the Frigg area installations and investigations in the Frigg area cuttings deposits are summarised in Figure 10.



Stations in cutting deposits **Stations > 100 m away from cutting deposits**

Figure 10: Illustration of the benthic fauna in the cuttings deposits and at locations away from the respective cuttings deposits. Data presented as Shannon diversity index.

The SFT classification system for fauna is opposite the system for pollutants.
A high number indicates a good environment

Figure 10 contains for comparison also fauna results from the regional surveys around the installations (stations 250 m from the installation). The disturbance on the fauna in the Frigg area is low compared to large oil production areas such as Statfjord and Ekofisk. In figure 10, the effects to the benthos are compared to an existing classification system, the Shannon-Wiener index, upon which the SFT classification system is based. Several alternative classification systems exist.

The figure show that similar effects to biota (no or slightly disturbed) are found in the cutting deposits at DP2, East Frigg, North East Frigg and Lille Frigg. The disturbance level around these is also comparable to the observations made around the TCP1 and TP1 platforms where no cuttings have been discharged at all.

The only cutting deposits from the Frigg area that seems to have some impact on the benthic fauna is the Frøy site. Here higher disturbance group is found in the cuttings pile from Frøy. The disturbance can also be seen at the 250 m station (from the platform central point). This may partly be explained by the fact that this is also the installation with the most recent discharges. In addition, Frøy has the highest THC levels due to the discharges of PBM muds containing linear alphaolefins.

6 Recommendations related to field decommissioning

Based on the findings of the pile characterisation work, recommendations for disposition of the cuttings deposits have been presented. Generally, alternatives evaluated for final disposal of the cutting deposits at the Frigg area installations have been:

1. Removal and onshore disposal
2. Leave in place

Based on the environmental assessment, indicating limited environmental impacts, it is recommended that the cuttings are left in place and disturbed as little as possible during removal of the structures. The same recommendation is also made regarding the cuttings encapsulated within the CDP1 structure. From the CDP1 assessment it was concluded that the most severe environmental impact will be the eventual structure collapse rather than the contents of the cuttings deposited.

7 Summary and conclusions

- None of the chemical constituents measured in the cuttings deposits at the Frigg area, was found to exceed SFT class II. This suggests that the cutting deposit in the Frigg area represents a moderately polluted material. The SFT classification system is not developed or adapted to North Sea seabed conditions, but still gives an indication of the relative status of pollutants in the material material.
- The benthic fauna in the cutting deposits is only slightly disturbed at most sites examined. Similar disturbances can be seen in areas with oil installation in general.
- Sedimentation of new material over the cutting deposits is observed to have covered up the cuttings at several locations. Observations suggests a tendency that when the cutting deposits are thin, the cuttings will be covered by the surrounding sand. However, it is feasible that erosion processes occurring during severe weather conditions might expose the cuttings again.
- No investigation of the content in the CDP1 has been carried out. However, the drilling activities at CDP1 were comparable to the activities of DP2, and there is therefore also reason to believe that the cuttings discharges and deposits are of a similar nature. The potential environmental impacts of the cuttings in the CDP1 are evaluated to be minor.
- Disturbance of the cuttings material is the main process by which the contaminants of the material may become available to the surroundings. Since the contaminant levels are rather modest, and the cuttings volumes are small this is not expected to have a significant environmental impact in the Frigg area.
- Processes likely to cause disturbance are first and foremost operations related to removal of structures. Erosion and resettling processes in the area may also be significant during periods of severe weather conditions. Other processes taking

place on and within the pile while otherwise undisturbed (e.g. biodegradation, leaching etc.), is considered to be of minor importance and is not expected to alter the pile composition significantly even on a long-term basis.