NYKOS

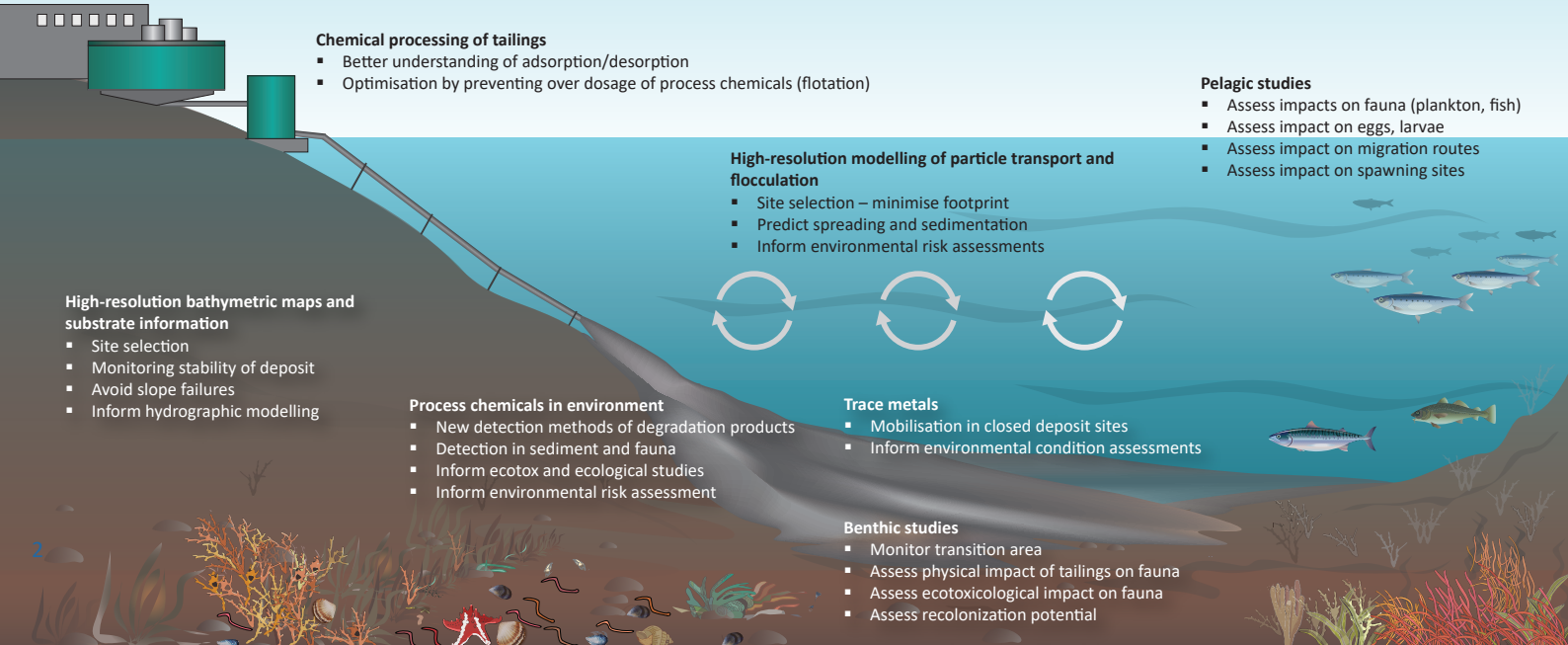
New knowlegde on Sea disposal

New knowledge on submarine tailing disposal in Norwegian fjords

Mining in Norway is currently in a phase of increased growth and subject to new environmental regulations. Many mines are particularly challenged by waste management, as they often produce large quantities of mineral tailings from processing. To overcome problems associated with deposition of mineral waste produced, many mines place their tailings at the seafloor of fjords as submarine tailings disposal (STDs).

The main objective of KPN NYKOS is to increase the knowledge base around the impact of STDs on the marine environment and facilitate the development of new environmentally sound criteria and monitoring technologies to allow for a more sustainable mining industry in Norway.

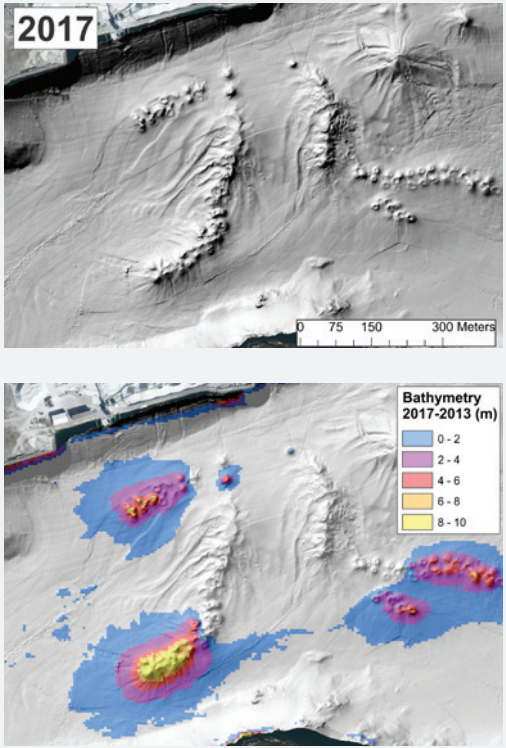
Per Helge Høgaas, Project manager, NYKOS project



Seafloor geology and tailings

The dispersal, distribution and stability of submarine tailings are ultimately linked to the natural processes operating on the seafloor. Optimal selection of the disposal site as well as the assessment of long-term fate of tailings require therefore detailed seafloor geological maps (marine base maps) that integrate substrate information with bathymetric data. Geological mapping and acquisition of full spatial coverage acoustic datasets should be undertaken during both planning and operational phases of submarine disposal. The main results include:

- New seafloor maps for disposal sites in Bøkfjorden, Stjersundet, Ranfjorden and Frænfjorden.
- Dispersal of tailings is linked to fjord specific processes and particle transport of >10 km can occur.
- In fjords that have experienced discharges of contaminants, uncontaminated STPs on top of affected seafloor sediments can confine contamination.
- Geological and acoustic methods are well suited for monitoring volume changes and lateral spreading of STPs.
- Marine base maps, including detailed bathymetry, geological seabed maps and results of sub-bottom profiling, are needed for planning and monitoring of STPs.
- Process-mineralogy analysis

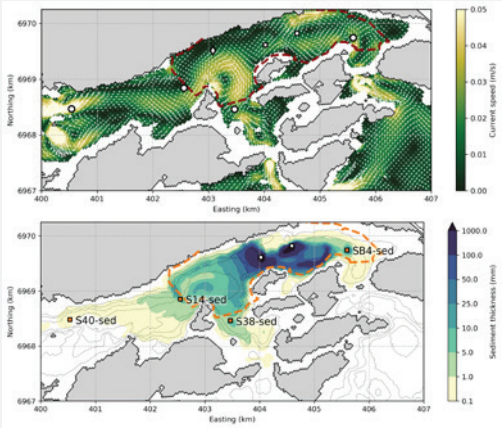


First panel shows a shaded relief image of the seafloor at the disposal site in Frænfjorden in 2017 with three chains of cone-like features marking positions of discharge pipes that have been extended into in the fjord. Second panel shows bathymetric difference between the 2013 and 2017 data visualized on the 2017 shaded relief image.

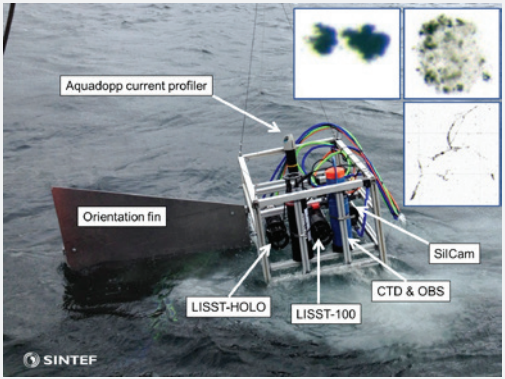
Modelling and measuring spreading of tailings particles

Mine tailings contain micrometer-sized particles, which can be spread with currents in the ocean. The particles will also tend to stick together in salt water, potentially forming large, complex flocs, which will sink at a different speed from the original particles. We have developed and deployed new particle imaging systems to directly observe mine tailings flocs in the ocean. Numerical models that can simulate the spreading and flocculation of tailings particles has also been developed.

- Direct observations of very large complex flocs incorporating tailings (up to cm scale).
- Floc sizes and concentrations determined using automated image analysis software.
- Numerical models can be used to predict the spreading and sedimentation of tailings particles.
- Model simulations combined with knowledge on biological impacts of tailings can be used to determine environmental risk
- Model simulations can be used to minimize environmental footprint through optimization of the discharge.



Results from numerical model simulations. Top: ocean currents in Frænfjorden showing eddy structures at 20 m depth (month average). Bottom: sedimentation rates from a tailings scharge.

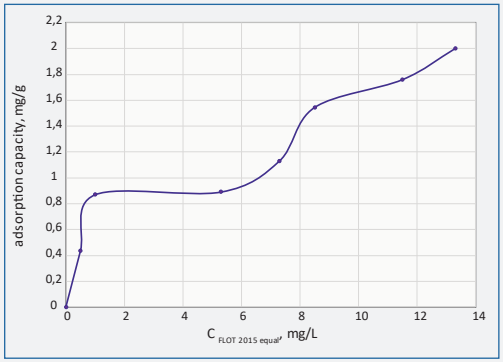


Floc imaging and supporting instruments being deployed in Frænfjorden.

Chemistry in the processing plant

The physiochemical properties of the tailings are governed by the preceding comminution and separation processes, but they are not necessarily optimized for the reactions that take place in a system where the tailings are disposed to the marine environment and fresh process water meets seawater. We focus on the considerable potential for improving properties of the tailings through novel approaches to study on adsorption/desorption characteristics of chemicals in order to prevent over dosage or recycle them prior to submarine tailings disposal. The rapid, simple and low-cost UV-spectrophotometric methods for quantitative analysis of the flotation collectors are developed and validated.

- Desorption of the flotation collectors is highly affected by seawater washing time and the initial concentration of chemicals.
- Less than 4% of the adsorbed flotation collector has been desorbed when the initial concentration is equal to the industrial dosage and monolayer adsorption has been established.
- At concentration levels higher than those required for efficient flotation multilayer adsorption is present and significant desorption will occur.
- The results suggest that exposure to seawater could accelerate the chemical degradation or decomposition of the flotation collectors within a timeframe of 18-24 hours.



Adsorption behaviour of FLOT 2015 on the calcite-silicates mineral system

UV-spectrophotometric tests of samples

Process chemicals and their transformation products

Mine tailings usually contain a variety of chemicals employed to separate the minerals. In NYKOS it has been developed an analytical methodology based on chromatography coupled to high resolution mass spectrometry to identify the presence of these chemicals at the low levels usually found in environmental samples. The methodology allows resolving the complexity of the analysis of technical products (that regularly consists of complex mixtures of chemicals) and track their fat and behavior in the fjord.

- Process chemicals from the flotation technical product FLOT2015 have been identified in sediments, water and biota from Frænfjorden.
- The main chemicals found are esterquat-type structures that break-down in water and form a mixture of degradation products.
- The main degradation products of the technical product FLOT2015 are fatty acids and methyltriethanolammonium (MTOA).
- An equilibrium between the chemicals adsorbed to the particles and the water surrounding them is stablished in a way that allows the chemicals getting dissolved and mobilized.
- The concentration of the transformation product MTOA in mussels exposed to the tailings shows a decreasing trend along the distance from the tailings' discharge point.

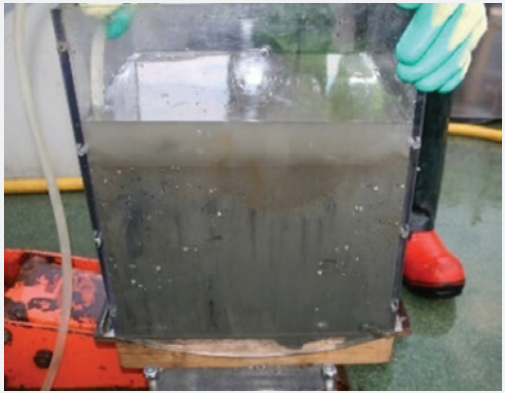
Sediment samples from Frænfjorden (left) where taken using a Gemini corer (right). Photo: E. Ramirez-Llodra (NIVA).

Sea cucumbers sampled in Frænfjorden being prepared for analysis of process chemicals. Photo: C. Escudero (NIVA).

Trace metal mobilization at old sea deposit sites

After tailings disposal is ended, the deposition sites are rapidly recolonized by a number of different species indicating the status of biological conditions. However, the biological condition does not necessarily respond to the potential presence of contaminants such as flotation chemicals or trace metals. NYKOS has investigated the mobilization of metals from ilmenite tailings deposited on a seabed site more than 20 years ago. The study was done in undisturbed sediment cores transferred to a soft bottom mesocosm.

- Metal concentrations are maintained at high levels in the top layer due to vertical mixing driven by the activity of the benthic fauna (bioturbation).
- Tailings mixed into the oxic surface layer reacted with O2 to release copper, nickel and cobalt to the pore water and the overlying seawater.
- Cobalt behaves different from copper and nickel due to its redox sensitivity.
- Release of nickel from the sea deposit to the overlying water was large compared to reference locations in the sea (15:1), but small (1:20) compared to the release via drainage water from a land deposit with the same tailings.
- Because metal concentrations exceeded environmental classification standards (EQS) for copper and nickel, the observed “good” biological condition in accordance with the Norwegian guidelines (Vannforskriften) was modified to a an overall “moderate” ecological condition.



Box cores were sampled in Jøssingfjorden and transported to the benthic mesocosm at the marine research station at Solbergstarnd for subsampling and flux measurements.

Ecotoxicology

The mine tailings can have toxic effects in marine organisms through both the physical impact of the particles as well as the chemicals present on the tailings.

The NYKOS project was able to differentiate between chemical and particle effects (shape/ size) using a combination of sediment elutriate and whole sediment toxicity bioassays in a range of marine organisms. Furthermore, by using mussels exposed to the mine tailings within a fjord recipient, the impact of environmentally relevant concentrations of mine tailings with distance from the discharge point can be determined. The main results of this field investigation included:

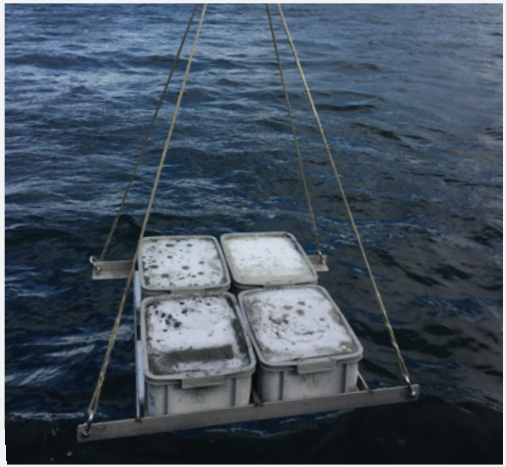
- The detection of process chemicals used by the mine, in the tissue of mussels position up to 2 km from the discharge outlet.
- A suite of biomarkers measured in the mussels indicated a clear stress response, which was correlated with chemical bioaccumulation and proximity to the discharge outlet.

Deployment of mussels in a fjord recipient to study environmentally relevant impacts of the tailings to mussel health and chemical bioaccumulation.

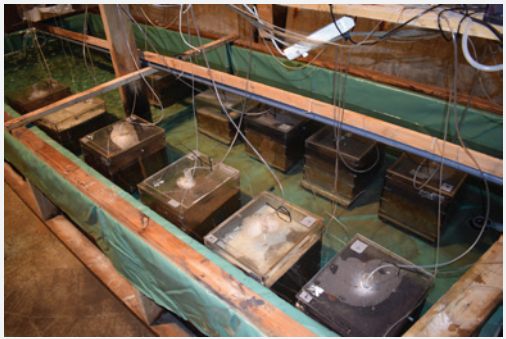
Effects of tailings on benthic fauna

The seafloor is the ecosystem compartment that is most affected by submarine disposal of mine tailings. NYKOS has investigated the effects of tailings on the fauna at the seafloor, through experimental studies, to better understand the role played by sedimentation rate at the border of the impact area, as well as the recovery potential of tailings-impacted sediments. The main results show:

- Significant effect of all tailings tested with a threshold of 2 cm.
- The abundance of epifauna (larger organisms on the seafloor) shows a stronger reduction close to the tailing outflow than the infauna (smaller animals living in the sediment).
- The infauna close to the tailings outflow is dominated by tolerant species, indicating a community shift.
- A recolonization experiment showed evidence of fast initial colonization of sediments capped with thin layers of tailings, but with a community differing slightly from sediments without tailings.
- Detritus feeders are more sensitive than carnivorous and omnivorous species, and non-mobile and tube-building species are more sensitive than mobile, free-living species.



Recolonization experiment where sediments capped with thin layers of tailings are subject to colonization of benthic fauna. Photo H.C. Trannum



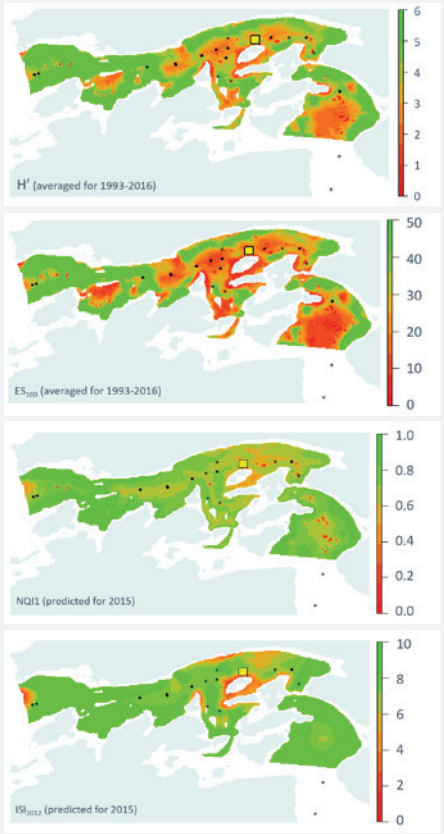
Mesocosm experiment where benthic fauna is exposed to mine tailings. Photo H.C. Trannum

Spatio-temporal modelling

The benthic fauna community has been monitored by DNV-GL and NIVA in Frænfjorden back to 1993. Supplied with NYKOS grab samples from 2015, this dataset represented an opportunity to investigate the spatiotemporal dynamics in benthic community assemblages in this fjord. In particular, we wanted to assess if species composition seemed to be affected by the discharge, and if this pattern changed through time.

- Most indices increased by distance to point source, indicating that both diversity and sensitive species might be negatively affected by the tailings.
- Also, the proportion of sensitive species in the sediments increased over time, indicating improved conditions in the area.

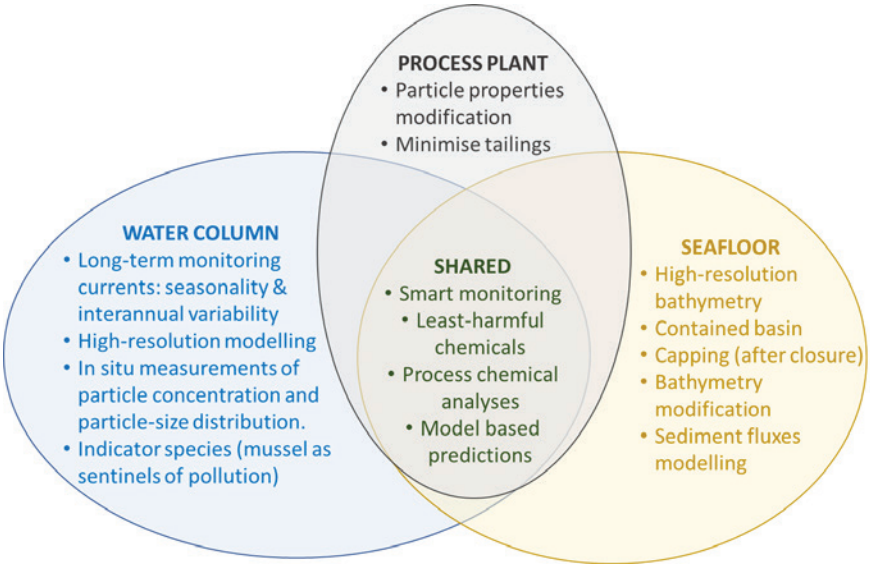
These results support the findings from the experimental study discussed above, which suggests that tolerant species are dominating the faunal community close to the tailings outflow, where sedimentation rates are high. Whereas more sensitive species are found further away, where the sedimentation rates are lower. Frænfjorden was here used as a case-study, because of its high number of benthic fauna samples and long time-series. The generality of the results is assumed to be relevant also for the other NYKOS fjords, but might also differ with tailing type, sedimentation rates, ocean current conditions, and other local environmental factors.



Map of fauna diversity (H' and ES100) and sensitivity (NQI1 and ISI2012), according to the predictive GLM models. The point source is shown as a yellow square. Black dots show the position of fauna stations visited in the period 1993-2015.

Best Available Techniques

Best Available Techniques (BATs) are the most effective techniques and methods available to the relevant industrial sector that achieve high level of protection of the environment. NYKOS highly recommends the development of such BATs for submarine tailing disposal in Norwegian fjords, based on current scientific knowledge of STDs and the response of the receiving systems. The processes that would benefit from clearly defined BATs address issues in the process plant, the water column and the seafloor, as well as shared processes/methods that can be applied to the discharging system and the two recipient systems.



Initial processes and methods proposed for consideration for BATs on submarine tailing disposal of mineral waste.

Research Partners

SINTEF · NIVA Norsk institutt for vannforskni · University of Tromsø · Norges Geologiske Undersøkelse NGU · NTNU

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