Project information

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Fate and Impact of MIne Tailings on marine Arctic ecosystems – FIMITA
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Summary of Results

WP 1 - Post-depositional processes in STDs: Folldal verk A/S opened the Ulveryggen copper mine that operated with flotation facilities between 1972-78 beside Repparfjorden, which extracted copper ore from the Ulveryggen mineralised zone. 3.1 million tonnes averaging 0.66% Cu grade was mined during those years (Nussir, 2017). Approximately 1 million m^3 of mine tailings was deposited during that time (Christensen et al., 2011). Information on where the deposit is situated and its physical form became available within this study.

The bathymetry of the inner part of the fjord delineates a few prominent features. Firstly, the wide threshold, a moraine ridge, which divides the inner and outer part of the fjord is obvious. Secondly, a series of cone-like shapes can be seen protruding off the seafloor along the western side of the southern inlet, forming an irregular ridge shape. The series of cones most probably represents openings in the pipeline every 100 meters over a 600 meter length, resulting in a ridge of tailings material. Each cone is most likely a result of tailings that have been released from a singular outlet point on the tailings pipeline. These cones can reach up to approximately 10 meters above the natural sea bottom. Analytical results of surface sediments show that these cones are not covered by much natural sediments. This means that the deposited tailings have a high likelihood of spreading either through sediment slides along the cone sides or by water currents. The spreading will continue to mix tailings with surface sediments in the inner inlet of the fjord and continue to affect these also in the long-term future.

Sampling the inner fjord sediments proved to be challenging. This is partly due to the deposit material consisting of small-grained particles of similar grain-size. In many parts of the inlet, a hard horizon at a depth of approximately 20 cm below the sediment surface stopped the sampling equipment from penetrating the sediment column further. This horizon turned out to be schist-like material, which consists mainly of iron oxide. This hard pan shows signs of being precipitated during the time of deposition of mine tailings (1972-1978), which would indicate a net sedimentation rate of 20 cm top sediments in approximately four decades.

In addition to grain- size analysis an attempt has been made to quantify the shape of the different type of particles. This was done based on 2D scanning electron images of sediment particles in polished sections of the size fractions 180-62 µm, 62-25 µm, and 25-10 µm.

Particular emphasis was placed on particle roundness, which relates to the relative rounding of corners and edges, and is

independent of form. The particles are subrounded, showing considerable wear, to rounded, with original faces almost completely destroyed. A preliminary analysis of the results does not seem to reveal any clear, statistically significant or systematic difference between tailings and natural material with respect to roundness.

Judging from the analytical results, the mine tailings are, in relation to the natural materials lying under and on top of the tailings, clearly enriched in the elements Au, Ba, Bi, Cr, Cu, Hf, Ni, Re and Zr. On the other hand the tailings are depleted on other elements: Be, Cd, Cs, In, Li, Nb, P, Pb, Rb, S, Sc, V and Zn. Therefore, there seems to be a clear chemical signature of the deposited material, and the horizons where it occurs within the cores can be established.

The Ulveryggen mine tailings deposited in the 1970's, differ considerably in concentration for many chemical elements, when comparing to the fabricated tailings produced by NTNU in 2015 from the same deposit. There could be several reasons for this: I) the samples collected to produce the fabricated tailings differ substantially from the ore used in the 1970's, II) the flotation process is different, or III) chemical changes have taken place during the 40 years the deposited material has been under water. The flotation process seems to include some differences, as the copper concentration in the tailings emitted in the 1970's were considerably higher (typical value ca. 470 ppm Cu (Paulsen et al., 1977) than analyses of the fabricated tailings produced in 2015 (ca. 200 ppm Cu). A few elements show similar concentrations in fabricated Ulveryggen tailings and the existing deposit in Repparfjorden; Au, Cd, Co, (Cu), Hf, In, Li, Nb, Sc, Zr and Zn, while the concentrations of Ag, Ba, Ca, Hg, K, Re and Th match natural sediments within the sampled cores.

Caution should therefore be taken when using chemical results from the fabricated tailings in further analysis. The chemical result for the fabricated tailings from Ulveryggen and Nussir deposits show very different concentrations for most elements, making chemical predictions for a future deposit difficult.

A new study was added to the project after the fieldwork in 2015.The focus of this study was to evaluate deposited mine tailings from Repparfjorden as well as the newly processed mine tailings, in terms of metal availability, potential mobilization of metals with changes in pH, and the possibility of extracting more Cu from the new tailings. Acid and base extraction experiments provided desorption curves of mine tailing suspensions as a function of pH (0.5-12.7), and showed that Cu was more easily desorbed in the historic mine tailings. Substantial desorption (>40%) for both historic and new mine tailings occurred at pH values below 3 and above 12. These results combined with metal speciation, showing that the binding of Cu in the sediment changes around pH values 3 and 10, indicate potential for extraction of more Cu from the new mine tailings. Electrodialysis, based on applying an electric field of low intensity to extract metals from polluted soils/sediments, was designed for acidic and alkaline extraction, and in both cases more Cu was extracted than in the pure acid/base extractions, while maintaining low mobilization of other metals. Electrodialysis can hence be designed to target extraction of Cu while limiting the mobilization of other metals (Pedersen et al. 2017).

WP 2 - Recolonization and recovery of benthic ecosystems: The aim of the study performed in this WP was to investigate long-term recovery processes and short-term colonization of mine tailings in an Arctic fjord. The benthic community was sampled at various distances from the old deposit, and in a reference area in June 2015. In a colonization experiment, experimental trays filled with defaunated sediment and fresh tailings on the top was placed at the seabed and subject to colonization for 15 months.

It is yet too early to fully conclude on the benthic recovery at the old deposit. Notably, the Cu-concentrations in the sediments were still high. On the other hand, there did not seem to be clear disturbance effects on the fauna with regard to diversity or species composition.

In the colonization experiment, a major finding was that trays treated with mine tailings (nominal layer thicknesses of 6, 10 and 14.5 mm) showed a lower colonization than the controls, evidenced by lower species number, lower abundance and lower biomass. This effect can be due to toxic effects and/or effects of particle properties like grain size, angularity, or a low organic content. As the tailings were considerable finer than the control-sediment, this factor has most likely contributed to the observed differences. Generally, coarser sediments are more heterogenous and may offer more niches, which again may increase the species richness. The finding with lower colonization on sediments treated with mine tailings therefore accords well with this pattern. At the same time, Cu-concentrations were high in the boxes with the largest doses, which possible may have inhibited colonization.

WP 3 - Effects of sedimentation of fresh mine tailings on hard-bottom species:

In 2015-2016 a laboratory experiment, where *Acesta excavata, Primnoa reseadeformis* and *Geodia atlantica* were exposed to suspended solids and different temperatures, was carried out. The study showed that exposure to sediment does not affect the oxygen consumption and metabolism in *A. excavata*. However, elevated levels of NH_3 during incubations and a reduced conditions index indicates that the bivalves uses stored energy to maintain metabolism during times of sediment exposure. This is probably not sustainable in the long run (laboratory study was limited to 40 days). It is therefore possible that long-term effects on populations of this species may occur in areas with continuous discharge of particulate material (Scanes et al. in prep.). *P. reseadeformis* and *G. atlantica*, which were exposed in the same experiment, showed very

similar responses as A. excavate.

Metal pollutants in marine ecosystems are broadly acknowledged as deleterious, however, very little toxicity data exist for deep-water corals and in particular the species found in the cold-water coral reefs and coral gardens characteristic of Norwegian fjords, from Rogaland to Finnmark. We addressed this gap by performing acute copper toxicity test on 3 foundation species growing on rocky substrate from 100-600 m depth, namely the scleractinian *Lophelia pertusa*, the bivalve *A. excavata* and the demosponge *Phakellia ventilabrum*. In the experiment, a variable response to copper exposure was detected. The deep-water bivalve appeared to be the most sensitive of the species tested with mortality observed already at a copper concentration of 100 μmol l-1. In the sponge *P. ventilabrum* no mortality was detected even when exposed to copper concentrations at 1000 μmol l-1. In the coral *L. pertusa* a 100% mortality was detected when exposed to 1000 μmol l-1 while no mortality was detected at 100 μmol l-1. Sub-lethal stress responses (on respiration and cellular integrity) were detected when exposed to much lower concentrations for all three species. Increased lysosomal destabilisation and reduced respiration rates were observed for *A. excavata* at 1 μmol l-1, for L. pertusa at 10 μmol l-1 and for *P. ventilabrum* at 100 μmol l-1. Visual examination of the organisms indicated that contraction of the shell and retraction of the tentacles were the first signs of stress in the bivalves and corals.

This study has provided important baseline information, enabling comparison of the acute sensitivity of the deep-water species *A. excavate*, *L. pertusa* and *P. ventilabrum* to copper pollution. To accurately predict the effects of copper pollution from anthropogenic sources on deep water ecosystems, however, additional experiments are needed. The observations of sub-leathal stress responses at concentrations as low as 1 μmol l-1 stresses the need for new experiment exposing the organism to low doses of copper for extended periods of time (14-60 days). Furthermore, new experiments should also monitor the recovery of cellular integrity and respiration rates and assess delayed mortality.

WP 4 - Assessment by the local population of ecosystem service effects from STDs:

In 2015 the debates on mining in Kvalsund and Kirkenes were mapped using literature study of media, reports and government documents. The main statements in the two cases were identified as a basis for Q-studies. Q-methodology is a method used to identify the different opinions, or perceptions, on a topic in a population of stakeholders. The first step is to map the debate on a topic, in this case the mining operations in Finnmark. The core elements in the debate are identified and short statements representing the debate are selected for the Q-sort. These statements are called "Q-statements". The Q-statements are presented to stakeholders who have to sort the statements (do a Q-sort) according to how much they emphasise that statements and if they agree or disagree. The Q-sorts of the different stakeholders are analysed to identify the main perceptions and agreements/disagreements between the different perceptions on the topic studied. Fieldwork was conducted in Kirkenes (in 2015) and in Kvalsund, Hammerfest and Tromsø in 2016 (focus on the Nussir project), where 13 local informed stakeholders sorted the 43 Q statements identified for the Sydvaranger and Nussir mining operations. The stakeholders also commented on the statements. This gave the basis for both a Q-analysis and qualitative data that can inform the results. In 2017 final stakeholder interviews, to cover in particular Sami stakeholders that were identified through the interviews in 2016, were conducted. Results from all field activities have been compiled and are currently being analysed.

Master and PhD-students involved in the project

One Master student (Anne Mette Tholstrup Simonsen) and one Post. Doc. (Elliot Scanes) have been involved in the project

For the Management

FIMITA has produced new knowledge about effects of subsea mine tailing deposition on marine habitats and their ecosystems. As such sub-sea tailing deposits are present already in Northern-Norway and new ones are planned, knowledge about environmental impacts of mine tailings is highly demanded by environmental managers, NGOs and the public. It is also important for environmental managers to know how ecosystem services and local communities are affected by mining activities, and this has also be investigated in FIMITA.

Some important results:

- Chemical analyses of old mine tailings show that tailings are, in relation to the natural materials lying under and on top, clearly enriched with the elements Au, Ba, Bi, Cr, Cu, Hf, Ni, Re and Zr. On the other hand, the tailings are depleted of the elements: Be, Cd, Cs, In, Li, Nb, P, Pb, Rb, S, Sc, V and Zn.
- Binding of Cu in the sediment changes around pH values 3 and 10, and this indicate potential for extraction of

more Cu from the new mine tailings. Electrodialysis, based on applying an electric field of low intensity to extract metals from sediments, was designed for acidic and alkaline extraction, and in both cases more Cu was extracted than in the pure acid/base extractions, while maintaining low mobilisation of other metals. Electrodialysis can hence be designed to target extraction of Cu while limiting the mobilisation of other metals.

- In a recolonisation experiment, where frames with sediment and mine tailings were placed on the seafloor, a major finding was that trays treated with mine tailings (nominal layer thicknesses of 6, 10 and 14.5 mm, simulating the fringe of a deposit) showed a lower colonization than the controls, evidenced by lower species number, lower abundance and lower biomass. This effect can be due to toxic effects and/or effects of particle properties like grain size, angularity, or a low organic content.
- Exposure to suspended solids did not affect the oxygen consumption or cellular stress response in Acaesta excavate, Primnoa reseadeformis and Geodia atlantica. However, elevated levels of NH3 during incubations and a reduced conditions index indicates that the organisms uses stored energy to maintain metabolism during times of sediment exposure. This is probably not sustainable in the long run (laboratory study was limited to 40 days).
- Even low concentrations of Cu affected sub-lethal stress responses in the deep-water species Acaesta excavate, Lophelia pertusa and Phakellia ventilabrum.

Published Results/Planned Publications

From pilot-project: Ramirez-Llodra, E., Trannum, H.C., Evenset, A., Levin, L.L., Andersson, M., Finne, T.E., Hilario, A., Flem, B., Christensen, G., Schaaning, M., Vanreusel, A. 2015. Submarine and deep-sea mine tailing placements: a review of current practices, environmental issues, natural analogs and knowledge gaps in Norway and internationally. Mar. Poll. Bull. 97: 13-35.

Pedersen, K.B., Jensen, P.E., Ottosen, L.M., Evenset, A., Christensen, G.N., Frantzen, M., 2017. Metal speciation of historic and new copper mine tailings from Repparfjorden, Northern Norway, before and after acid, base and electrodialytic extraction. Miner. Eng. 107: 100 -111.

Trannum et al. in prep. Recolonisation and recovery of an Arctic benthic ecosystem subject to submarine tailings disposal.

Andersson et al. in prep. Metal speciation and mobilization from a sub-sea tailing deposit.

Scanes, E. et al. in prep. Chronic sediment exposure and acute temperature elevation cause physiological stress on the deep living bivalve Acesta excavata.

Scanes et al. Cellular stress responses in hard-bottom communities exposed to mine-tailings.

Falk-Andersson et al. in prep. Local populations assessment of impacts of sub-sea tailing deposition on ecosystem services – the Nussir and Sydvaranger cases.

Communicated Results

The project has been presented at a French - Norwegian seminar at the Fram Centre in October 2016. It has been presented to Troms Fylkeskommune in November 2016, as well as at 4 conferences:

Pedersen. Environmental Waste Management - Mine tailings in Repparfjorden – Availability of Metals. Arctic Froniters 2016 - Side events Forskningsløft i nord.

Pedersen. Submarine mine tailings disposal in Repparfjorden, northern Norway – long-term dispersion and availability of Cu. ARTEK event 2016 (Sisimiut, Grønland).

Pedersen. Metal speciation of historic and new copper mine tailings from Repparfjorden, Northern Norway, before and after acid, base and electrodialytic extraction. Sustainable Minerals '16 (Falmouth, England).

Pedersen 2016. Arctic Forum 2016, Kirkenes, Norway: Environmental Waste Management, November 2016

Interdisciplinary Cooperation

FIMITA is a truly multidisciplinary project. The research team has expertise within sediment geology, geochemistry, ecology, ecotoxicology, economics and planning studies. The results from the different scientific fields is currently being assessed together and will be included in interdisiplinary scientific articles.

Budget in accordance to results

The Fram Centre funding was essential for this project. The subject has not been covered by NFR programs (not before 2017), and therefore other funding was difficult to obtain. The funding from the Fram Centre has been used to obtain results within different rresearch disiplines and all together at least 6 articles in peer-reviewed journals will be written based on these results.

Could results from the project be subject for any commercial utilization

No

If Yes

No