Summary of KPN NYKOS information day, Tromsø, November 27th, 2018.

Background.

The main objective of the research project NYKOS is to develop new knowledge on submarine disposal of mine tailings. This includes impact on marine ecosystems in fjord environments, acceptance criteria, risk assessments, dispersal and sedimentation of mine tailings in fjords and development of new methods for monitoring and analytical tools. To match the objectives, 6 work packages where established and manned by scientific personnel from 5 research institutes (NIVA, NTNU, SINTEF, NGU and UiT). Additionally Post.Doc and Master students has been involved in the studies. An important task related to dissemination of results is publication in peer-review articles and information to the public by open and transparent meetings. The focus is new and useful knowledge. The end-users of the results are the environmental authorities, the mineral industry, politicians, NGOs and the scientific community. The information day in Tromsø was a part of the dissemination of preliminary results.

NYKOS was initiated in 2014 and terminates 1st May 2019. NYKOS is 80 % financed by the Norwegian Research Council and the remaining 20% from Norwegian mining industry.

Scientific presentations.

The KPN NYKOS information day was planned as an event to allow key personal in the NYKOS, EMWA and DiTail research programmes to present highlights from the three programs where all have one objective in common – to illuminate scientific results and research plans related to environmental impact of sea disposal of mine tailings in fjords and coastal water.

NYKOS (Developing new knowledge on submarine tailings disposal). The aim of the NYKOS project is "*to increase the understanding of how best to dispose of mine tailings in the marine environment, how to monitor the deposits through time, what ecosystem impacts do they have and how to ensure that fjord systems recover as quickly as possible after a mine closes down*".

EMWA (Environmental Waste Management). EMWA is a competence cluster focusing on research and education related to petroleum-and mineral- industry in cold environment. One of the research prioritizes is the study of effects of environmental pollution and the identification of actions that are required for preventing/minimizing the influence of potential environmental pollution. In this respect, as pointed out by the industry, it is important to pay attention to the Best Available Technique (BAT) and Life Cycle Assessments (LCA). Improved knowledge within relevant fields for new and expanding industrial activities in cold climates will be essential to develop EWMA to a key research and knowledge centre in the High north. EMWA terminated in 2017.

DITAIL (Disposal of mine tailings in Norwegian fjords and impacts on key ecosystem species) aims at study impacts of marine mine tailing disposal on pelagic ecosystem components in

Norwegian fjords: the copepod *C. finmarchicus*, a key species in the planktonic food web, and early live stages of cod Atlantic cod, a fish species of commercial interest. Tailing particles, metals and processing chemicals and their impact on the pelagic ecosystem will be studied. Additionally, the plan is to develop biological models to predict to what extent mine disposal sites will have an effect on biological populations as well as developing physical models predicting tailings dispersal in fjords. DiTail was initiated recently.

The NYKOS information day in Tromsø 27th November contained all together 11 scientific presentation; 7 presentations from NYKOS, 1 from EMWA, DiTail and UiT and 1 from Sibelco/Norwegian Mineral Industry.

Presentations (highlights).

Sea disposal sites which have been closed for some decades offer excellent opportunities to study the mobility of metals and chemicals used in the processing of the ore as well as recruitment of benthic organisms at the surface or in the tailings deposits. One such site is the Titania As, which are one of the largest ilmenite mines in the world. From 1960 to 1984 the tailings were disposed in a fjord basin (Jøssingfjorden), which originally was 84 m deep and had a sill depth of 30 m. The fjord basin was gradually filled up with tailings to sill depth and in 1984 the disposal site was moved to another marine basin (Dyngadjupet) outside Jøssingfjorden. Dyngadjupet was originally 172 m deep and in 1984 the depth was 113 m. In 1989 NGOs protested against the sea disposal and a political decision was made to terminate the sea disposal and build a land disposal site. At present the future of waste management at Titania is discussed; land disposal or sea disposal.

NIVA has studied the chemical and biological status of the abandoned sea deposits in Jøssingfjorden and Dyngadjupet. The tailings are enriched in nickel, copper and cobolt. Analyses of pore water also showed elevated levels of the same metals, indicating some mobilization from the tailings. The metals in the surface of the deposits and in pore water showed as expected lower levels in the surface compared to deeper down in the sediment cores. The leakage of metals from the sea deposits to-day represents about 5% of the leakage from the land disposal site, based on flux measurements. The status of the benthic fauna of the sea disposal sites is classified as good or very good according to the Norwegian classification system.

NIVA has also investigated the impact of flotation chemicals in Frænfjorden (maximum depth 70 m), where the processing plant Omya Hustadmarmor AS is situated. They discharge calcium carbonate along with processing chemicals to the fjord at about 20 m depth. Omya uses now Flot2015 in their flotation process and studies showed that this chemical undergoes hydrolytic degradation once discharged into the fjord. The products of the likely degradation route are considered as non-toxic and with low bioaccumulation potential. In overall, FLOT2015 can be considered as an evolution of the industrial tensioactives following a concept of “Benign by design”. This is a good example of how the mining industry now is

substituting processing chemicals known to cause environmental risk with other chemicals with less potential to harm the environment.

In addition to the chemical studies of flotation agents, a study was made of the bottom fauna of Frænfjorden. The conclusion was that the impact of the tailings was most prominent on epifauna (organisms living at the surface of the sediment) compared to infauna (organisms living down in the sediment).

NGU has carried out marine geological mapping of Frænfjorden and Stjernsundet (Sternøy); both areas impacted by sea disposal of mine tailings; the latter related to mining of nepheline syenite and the tailings are deposited near the surface of a bay. At Sibelco Nordic, Stjernøy no chemicals are used in the operation. Both sites have in common, low discharges of metals.

Use of coring and high resolution seismic have allowed detailed mappings of the sea bottoms and the tailing deposits. The sediment stratigraphic picture based on gravity coring visually demonstrates the interphase between natural sediments and the light coloured tailings (due to calcium carbonate) disposed by Omya in Frænfjorden. Shallow seismic investigation visualizes the shape of the tailing cones, the appearance of submarine slides related to tailing deposits as well as natural historical slides. This information is required when planning and operating sea disposal of mine tailings.

NGU/UiT has investigated natural sediments and tailings in Bøkfjorden and Ranfjorden in relation to a Master`s thesis. Both sites have in common that they are impacted by discharges from iron ores. Since 2014 the tailings from Rana Gruber tailings have been discharged at 125 m depth in Ranfjorden (previously at 30 m depth for the coarse fraction and 45 m for the fine fraction). The discharge from Sydvaranger Gruve is at 45 m depth (previously at 27 m depth).

The seabed mapping has been done with TOPAS light seismic (the same equipments as used in Frænfjorden and Stjernsundet). Additionally, multi-proxy analysis of core material and geochemistry and mineralogy. The seismic work clearly shows the traces of submarine slides (channels) from the slope where the tailings historically were building up. Due to the red colour of the tailings from Rana Gruber (due to iron minerals) the layer of tailings was easily recognized in the sediment cores (appear as a bench mark). Geochemical analyses of the core material also indicated high levels of lead and zinc occurring during the period when Bergverkselskapet Nord-Norge was operating a Zn/Pb mine (1928-1987).

The seismic investigations in Bøkfjorden also demonstrated the appearance of a major submarine channel eroded by slumps and turbidity flows carrying tailings out to Reinøy, some 5-6 km away from the discharge point of tailings.

NTNU is investigating the possibility to manipulate the tailings before it is disposed in the sea to reduce the environmental risk. Additionally, they are looking at the behaviour of

floatation chemicals in seawater and freshwater respectively, particularly differences in degradation.

Normally, seawater is added to the pulp before it is disposed in the sea and a question asked is to what extent mixing with seawater will mobilize the chemicals adsorbed to the surface of the mineral particles. Adsorption and desorption of collectors (amines and xanthates) show that amines are degraded much quicker in seawater than in freshwater. In fact, after 2 hours exposure to seawater the amine concentration is reduced by 50%.

It has been pointed out that the degradation products should be tested with respect to toxicity, as this has not been done before. The processes controlling degradation of chemicals used in the processing of ores should also be investigated.

SINTEF has developed a model and a measurement toolbox for quantifying the transport, fate and effect of mine tailings in the sea. This is an important task in the NYKOS project. Quantifying dispersal and sedimentation of tailing particles in the sea is necessary to estimate the area of potential impact and an important tool in monitoring. Use of in-situ imaging system to study particle size and shape of particles in a large size range (mikrons – centimeter) is essential. This is useful when assessing aggregation and flocculation of small particles which influences the sinking rate of tailing particles and natural particles and a combination of those in flocs.

The transport fate model DREAM was originally designed for use in the oil industry for produced water discharges and drilling waste but is now used to model mine tailings in the sea and flocculation. This model has been applied in Frænfjorden to estimate impacted water volumes and sediment areas.

UiT has investigated the copper ore in Kvalsund community with respect to geochemistry and mineralogy. About 1 mill tonnes of tailings were deposited in Repparfjorden during the period 1972 – 1978/1979 when Folldal Verk was in operation. Now Nussir AS are planning to re-open the copper mine and they have permission to discharge of 1-2 mill tonnes annually into Repparfjorden. The presentation demonstrates the need of a geochemical and mineralogical classification of the ore and the tailing waste. Furthermore, knowledge has been gained about the behaviour of sulfidic tailings in seawater compared to freshwater and the environmental implications.

EMWA was initiated as a 5 years research project in 2009 and received funding for an extended period of 3 years. The funding from the Norwegian Research Council amounted to 70% of the total costs. For looking at environmental impacts of discharge of mine tailings in fjords, Repparfjorden was used as a case history. Sediment cores were sampled as a background for assessment of environmental risks of previous copper tailings accumulated in the sediment from the active mining period during 1972 and 1978/79. A subsurface maximum of copper was detected in the sediment cores associated with previous mining. Availability of metals in the sediments was assessed by fractionation using varies chemicals.

Desorption experiments carried out in the lab indicated a small desorption of copper from the sediments containing tailings (0.01-0.2% during 21 days).

DiTail is a new research project on sea disposal of mine tailings, focusing on the impact on the pelagic ecosystem. This program is complementary to NYKOS which focuses on the benthic impact. Effects of mine tailings on sensitive key species of the fjord ecosystem will be studied. Effects on molecular levels will also be included as well as development of biological models to predict development, growth and reproduction. In addition to studies of biological effects the project will also investigate flocculation processes and develop models for physical dispersion of mine tailings in fjords.

Sibelco/ Norwegian Mineral Industry was giving an overview of the BREF – Best Available Techniques Reference Document Process for the Management of Waste from Extractive Industries (MWEI BREF) in Europe. The intention with the BREF was to raise awareness of "good practice" and promote their use. BAT Reference Document is based on the Extractive Waste Directive (Mineralavfallsdirektivet, nytt kapittel 17 i avfallsforskriften). The MWEI BREF is not a legally binding document and the document shall not propose emission levels. In 2013 it was decided to start a process of reviewing the BREF-document from 2009 and the Norwegian `s position was that sea tailings disposal techniques from Norway, and other countries, should contribute with sufficient documentation to decide on Best Available Techniques on this field. After a 5 year reviewing process the final draft is completed in 2018. Sea disposal is mentioned in ch.2 of the report where positive and negative effects are described and the report also refer to NYKOS as a knowledge base. Sea disposal is also mentioned in ch.5 (BAT conclusions). The TWG (technical working group being responsible for the reviewing process) acknowledges that progress has been made in improving the knowledge base on sea tailings disposal (STD) but, following the exchange of information, no consensus has been reached either on the inclusion or on the exclusion of BAT for STD in this document. The TWG encourages the technoscientific community to further expand the knowledge base on impacts and benefits of STD. Finally, the TWG acknowledges that Norway continues to acquire experience in this field and has shared experience to this extent.

Discussion.

The discussion at the end of the meeting was focusing on additional questions raised to the individual speakers. It was expressed a common agreement that issue of waste management should be knowledge based. This is independent on land disposal or sea disposal is selected as alternative. However, it is a challenge to decide when the knowledge base is satisfactory and the decision makers are comfortable with their decisions.

The discussion was very much engaged with knowledge gaps, particularly related to pelagic impact and fish. Zooplankton which migrate vertically in fjords to escape predation, and the potential impact of mine tailings at depth, is little known. Investigation of zooplankton (*Calanus finmarchicus*) in Frænfjorden has shown that mineral particles are ingested, but no signs of major effects.

In the discussion the knowledge about impact on marine ecosystems and on different life stages of organisms is important, particularly related to fish. Furthermore, use of molecular methods, which are a new tool for studying tailings in the marine environment and impact. To what extent behaviour of marine organisms is influenced by mineral particle in the marine environment is another new issue.