Sustainable use and Future of Submarine Tailings Placements in the Norwegian Extractive Industry[11]

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ABSTRACT

The Norwegian mainland is mineral-rich and many of the mineral resources are situated close to the very long, ice-free coastline and fjords. EU's Mineral Waste Directive (2006/21/EC) was implemented on May 1st, 2008, and will be put into effect in 2012. Strict control will be applied to handling mineral waste from industries, in addition to financial guarantees in case of accidents and long-term monitoring. The closeness of mineral resources to the coast or in narrow valleys near vulnerable water bodies implies special waste-management considerations. Water-covered tailings deposits in lakes or so-called Submarine Tailings Placement of inert tailings are often considered. These waste-management techniques are not controlled by the 2006/21/EC, but by the Water Framework Directive (2000/60/EC), and possibly only allowed as so-called Heavily Modified Water Bodies (HMWB). We focus on the sustainable use of this type of HMWB, and whether they still comply with Norwegian law.

Additional Key Words: Submarine Tailings Placements, fjord, Water Framework Directive, Mineral Waste Directive.

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INTRODUCTION

Norway has many geological resources and many potential and active mining sites are located close to the coast or in narrow, glacially eroded valleys. This poses special challenges when it comes to all types of waste management. In this paper we will evaluate how and whether Submarine Tailings Placements should be used under the new directives from the EU.

THE EU MINERAL WASTE DIRECTIVE AND THE WATER FRAMEWORK DIRECTIVE

The new Mineral Waste Directive (2006/21/EC) was implemented on the 1st of May 2008, and will be put into effect on the same date in 2012. The directive will control waste management on dry land, possibly including tailings impoundments with a water cover ("man made lakes"). However, it does not control waste placements into rivers, lakes or fjords. Those environmental realms are to be managed by the Water Framework Directive (2000/60/EC, "WFD"), which comes into effect 2015.

The WFD is both a novel and ambitious approach to the environmental protection of European water bodies in that good ecological and chemical status of water bodies are a primary concern. Only very small deviations from the natural state are to be allowed under the WFD auspices, and the critical level of contaminants is defined by the aquatic ecosystem. This implies taking into account ecological effects. Consequently, the physical smothering of benthic ecosystems is of concern and poses a challenge for all types of extractive industries that deposit their rock-derived waste in rivers, lakes and fjords. The only way to continue depositing in such a manner is through the application for classification of the deposit as a "Heavily Modified Water Body" (HMWB) on the basis of the hydro-morphological changes, where there are demands for a "good ecologic *potential*", rather than "moderate ecological *state*" of the water body. Thus, the HMWB's do have to be rehabilitated after use, bringing the area of the water-body back to the "moderate ecological state".

WHAT ARE SUBMARINE TAILINGS PLACEMENTS AND HOW COULD THE TECHNIQUE BE PERFORMED IN FJORDS?

Submarine Tailings Placements (STP), also termed Submarine Tailings Deposits (STD) (Moody, 2000, Coumans, 2002, Ellis et al., 1995) and DSTP (Deep Submarine Tailings Placements – depth of discharge > 100 m), entails that the mineral wastes ("tailings") from mining process are disposed by pipeline on the seafloor. For the purposes of this paper, we will use the term "STP".

There are three main reasons for why STPs are performed. One reason is economical, in that it is, by far, less expensive to deposit tailings into a water-body rather than build tailing-dams on land that need maintenance for many years (Coumans, 2002). A second reason is scarcity of available land areas. Land deposits also impose an esthetical problem. A third, and controversial one, is using STP to reduce Acid Mine Drainage (AMD) for tailings containing sulfide ores. AMD is related to the reaction between sulfide, water and oxygen. These react to produce sulfuric acid in the tailings and subsequent leaching of heavy metals into the environment. The AMD of the tailings is reduced by permanent water-cover (Pedersen et al., 1991; Arnesen and Iversen, 1993). In the oceans, sulfate-reducing bacteria immobilize metals in the tailings (Perry, 1995), thus enhancing sequestration processes. The cover of the sulfate-rich seawater also acts as a buffer for any remaining sulfides in the tailings. Disadvantages of STP exist, however, and include the smothering of benthic ecosystems, toxic metal leaching reactions, and the permanence of the deposit (i.e. once placed, it is practically not recoverable- Poling, 1995). In addition, there may be severe damage inflicted on surrounding ecosystems by massive undersea landslides or pipe lines fractures. Consequently, decisions regarding STP implementation should be based on careful environmental assessment studies.

A number of criteria are therefore necessary to make an STP a more sustainable alternative to a land deposit. The pros and cons of both options must always be considered, and the ecological status of the area before initiation must be evaluated in detail. In glacially eroded valleys and coasts, like those in Norway and on the northwest US coast and Greenland, land deposits may be difficult to place because of 1) limited land availability, 2) high rainfall and potential leaching problems and 3) the esthetical problems related to land-deposits. Consequently, within these areas, STP has been pursued as an alternative to land deposition with varying degrees of success.

Ellis (2008) attempted to define a contemporary best practice for STP. In order to ensure a successful STP, many criteria must be followed. A critical feature to the success of STP is the transport of the tailings through the vitally important surface euphotic (sun-lit) zone without influencing it. Many areas termed STP sites in the literature are shallow coastal deposits, and cannot be regarded as suitable STPs, since this critical feature is not present. In coastal placements, the tailings may be reworked by wave action and aerated, causing extensive acid mine drainage problems (e.g. Marinduque - Plumlee et al., 2000, Ellis 2008). In addition, the tailings are deposited in such a way that they settle through the euphotic zone during the placement process, influencing physical-chemical parameters such as turbidity, light level and pH.

The tailings must be placed onto the sea-bottom without reacting with the surface layers above the stable thermo- and/or halocline of the fjord. This process is usually done by depositing the tailing-slurry by placing the pipe-line discharge point below the halocline. Fine grained materials from the tailings, if placed correctly, will form a downward-directed turbid plume in the dark and denser bottom waters of the fjord. The fine material can also be controlled by adding flocculation agents to the tailings before depositing. Additionally, seawater should be mixed into the tailings to increase the density of the plume. To avoid the air-bubbles in the tailing pipeline, causing transport of small particles into the upper part of the water column, the pipeline should be de-aerated.

The choice of disposal-site should be selected to avoid major user-conflicts (important spawning grounds, commercial fishing grounds etc). The natural system should be known in detail. The seafloor should be made up of soft sediments and benthic community structures and genetic biodiversity should be well investigated. The area to be smothered should not be a genetic source population or spawning ground for the rest of the area. In order to prevent sediment erosion within, and transport from the proposed dumpsite, current regimes should be well investigated and predictable. The currents should not be too strong or too weak / absent, and the exchange rate of bottom and surface waters of the fjord should be well known. Failure to quantify current regimes/ flushing rates was a major cause behind the problems of the Black Angel Mine in Greenland (Loring and Asmund, 1989). The fjord turned over every winter and this ultimately caused an uncontrollable extention of tailings material along the seafloor, which resulted in heavy metal incorporation into marine organisms within the fjord (Eberling et al., 2002; Larsen et al., 2001).

The bathymetry of the dumpsite must be well known. New technology allows for very high-resolution mapping of the sea floor and the design of the deposit should reflect the basin bathymetry. A geological barrier such as a fjord sill created by glacial end-moraines at the end of the ice ages can effectively separate the deposits from the open sea (Odhiambo et al, 1996). In other areas where there are no such sills, tailings may reach the deep ocean (Ellis et al., 1995). While such small and frequent turbidity flows are commonplace and an essential feature of a successful STP ensuring the even and balanced distribution of sediments to the deeper parts of the deposition site (Hay et al., 1982), large mass-wasting event may be tsunamigenic and must be avoided. It is therefore important to monitor the evolution of the STP in the fjord, so the STP is created in such a way that large turbidity-flows and/ or mass movement events are prevented, and small flows are encouraged (Hay, 1982 Hay et al, 1982, 1983a 1983b; Ellis, 2008).

The Island Copper Mine is a well-known example of a claimed successful STP initiative (Ellis et al., 1995, Ellis, 2008), although the containment of tailings within the fjord has been disputed (Pedersen, 1984). The sulfide-bearing tailings were placed in an intermediate deep fjord (Rupert Inlet, British Columbia, Canada) and were the subject of many investigations. The benthic infaunal ecosystem was monitored over 29 years (as reviewed by Burd, 2002), and studies showed that 3 years after closure infaunal diversity in the deposit was as high as in far-field reference stations.

EXPERIENCES WITH STP IN NORWAY

The extractive industry has been permitted to create STP's in the fjords of Norway at several sites (Fig. 1A). As many potential mineral-resources exist along the coast (Fig. 1B) policy-makers should expect that the extraction industries will wish to use the Submarine Tailings Placement method in the future. Some STP's have been subject to major controversy (e.g. Jøssingfjord: Skei, 1975; Ibrekk et al., 1989; Aagaard & Bjørlykke, 2007), whereas others have operated for many years without much publicity. Studies have shown some recolonization of infauna in some of the tailings (Jaques et al., 1993, Nøland et al., 1995; Olsgard & Hasle, 1992;, Skaare, 2007), whereas other sites have not been studied. No studies of recolonization of mine deposits in fjords have indicated major lasting ecological impact.

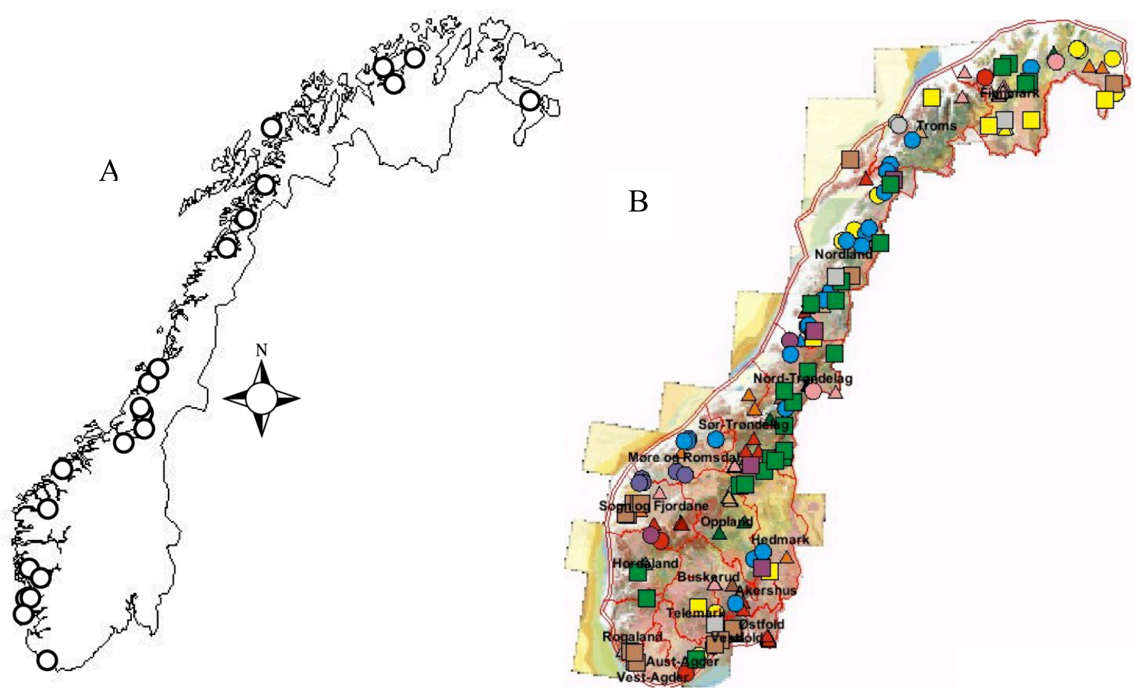

Figure 1: A: Location of major STPs in Norway. B: Location of well known mineral resources in Norway. Source http: www.NGU.no.

ACCIDENTS

Accidents involving STP's may be very harmful to the ecosystems in the area surrounding the spillage-area. The two major concerns are breaking discarge pipes and large mass-wasting events (slides) within the tailings. If pipes break on shore, large amounts of tailings may be dispersed in the less dense surface waters. This may cause problems in the shallow water ecosystems in the euphotic zone. Thus, it is important to use the best available technology regarding pipe selection, keeping in mind the abrasive nature of the tailings. In addition, as few joints as possible should be used in the pipes, thus limiting the risk of failure. The off-shore oil-industries have developed promising equipment for these requirements. In addition, it is beneficial if the disposal site is close to the ore processing plant Remedial actions should be taken immediately (i.e. silt-curtains and other remedies) if a spill occurs.

It is important to avoid large mass-wasting events in the STP. Thus, an STP design should involve methods to stimulate small turbidity-flows to the deeper areas, mimicking a submarine delta. The bathymetry should be monitored so that the pipe line may be moved and redesigned if major steepening to the sides of the deposit delta occurs.

REHABILITATION DURING OPERATION AND AFTER CLOSURE

During active deposition of material to an STP, the benthic area in question is often transformed from a productive area into a submarine desert. The EU Water Framework Directive requires a "good ecological potential" during operation and a return to a "moderate ecological state" after termination. The benefits of an active rehabilitation programs at the end of an STP-program is therefore expected. During deposition, the smothering-rate is so extensive that there are few animals or plants that can live in or on top of the constantly changing sediment surface. Ellis (2008) stated that sedimentation rates < 20cm/yr prevented biodiversity loss of the seabed at the Island Copper Mine. Byrd (2002) showed that recolonization of animals with a pelagic larval stages occurred after just 3 years on this deposit. However, the sterility and low grade of organic material in the sediments may make the recovery process unnecessarily slow.

Before the STP is initiated, a thorough biodiversity study (taxonomic and genetic) is warranted and the recolonization processes of the tailing placements should be explored using hydrodynamically unbiased experimental sediment and tailings. In addition, studies should also be carried out to document the effect on ecosystem processes and recolonization rates of mixing tailings with microbially active sediments as a mediation strategy following STP shutdown. After a part of the deposit is completed to the expected level, rehabilitation should be initiated. Attempts could involve methods of refertilizing the sediments or providing sediment habitat for plants and animals by a thin sediment-capping of the deposit. Refertilization strategies may include the addition of organic matter to the seabed, artificial reef emplacements, and the transplantation of sessile plants and animal from source areas, as would be implemented in any land deposit after closure.

THE NEED FOR FURTHER RESEARCH

Often, the use of STP's are opposed by stakeholders on the basis of the "precautionary principle" (Raffensperger & Tickner, 1999), that is, there is not enough scientific research performed on the STP's to determine whether the technique will be detrimental to the ecosystem of an area. Thus, according to the argument, it is better *not* to do something if one does not know the consequences of one's actions. There is therefore a great need for research on existing STP's around the world and the dispersal of knowledge that does exist. Norway has many abandoned and existing STP's, in many types of fjords. Thus, there are great opportunities to examine the existing situation and experiment with novel and scientifically motivated rehabilitation-techniques in these areas.

CONCLUSION

STP's may be possible to operate under the EU Water Framework Directive, as a Heavily Modified Water Body. If the permit for a HMVB is given, the environmental criteria are more accommodating but not lax. There will, however, be requirements for rehabilitation of the water-body after closure, and thus, rehabilitation practices are needed and should be thoroughly tested.

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