Kjemisk og biologisk tilstand i sjøbunnen mer enn 20 år etter etablering av deponier for sulfidholdig gruveavgang i Jøssingfjorden og Dyngadjupet

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New knowledge on submarine tailings disposal (NYKOS) BIA-project ES532333

Some background information

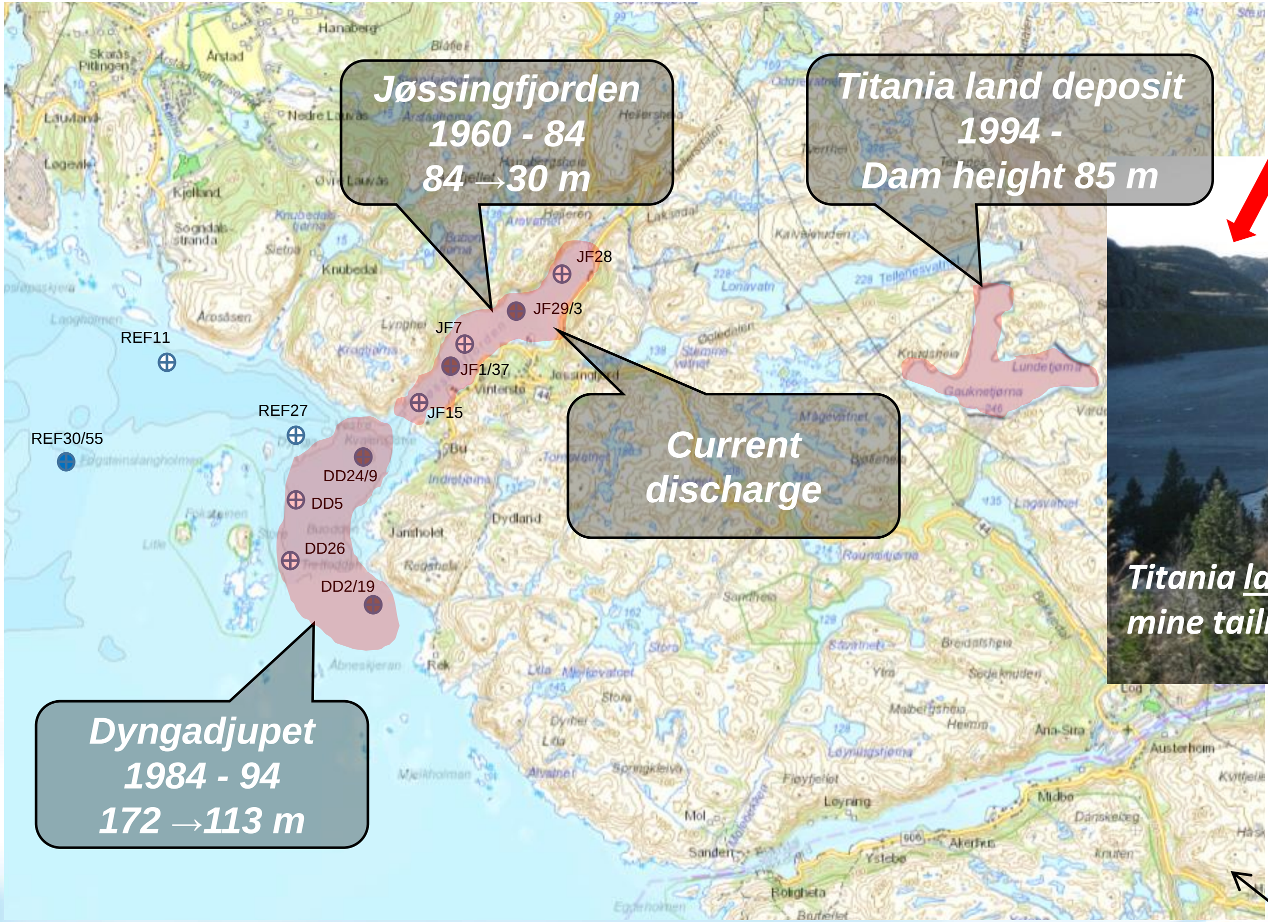
- Titania AS
  - exploits world's largest ilmenite ore
  - 7% of global production of ilmenite ($FeTiO_3$)
  - 3 million tons of tailings/year
  - 2% sulfide minerals
  - 800 tons Ni
  - 400 tons Cu
  - 160 tons Co
  - remnants of production chemicals

Element	Concentration ($\mu g\ g^{-1}$ d.w.)
Nickel	270
Copper	140
Cobolt	55
Chromium	49
Zinc	15
Lead	<0.20
Cadmium	<0.05
Mercury	0.013

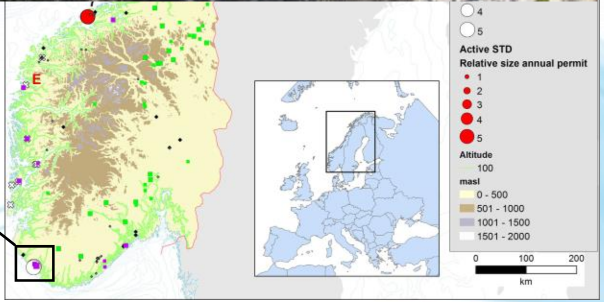
Tailings are crushed rock – why bother?

- Benthic habitats are strongly affected by hypersedimentation of any material
- Mine tailings disposed of in sea deposits are *allochtonous* materials
- May differ from *autochtonous* materials with regard to:
  - Particle size (often very small)
  - Particle shape (freshly grinded, sharp edges, needles)
  - Organic, degradable material
  - Reactive minerals, e.g. sulphides
  - Remnant chemicals added in flotation and flocculation processes
- These are some of the issues addressed in NYKOS WP4: "Effects of mine tailings and associated chemicals on marine, benthic ecosystems". WP4 Task 6: "Sulphide tailings"

STDs and land deposition since 1960



Titania land deposit for mine tailings, SW Norway



NIVA

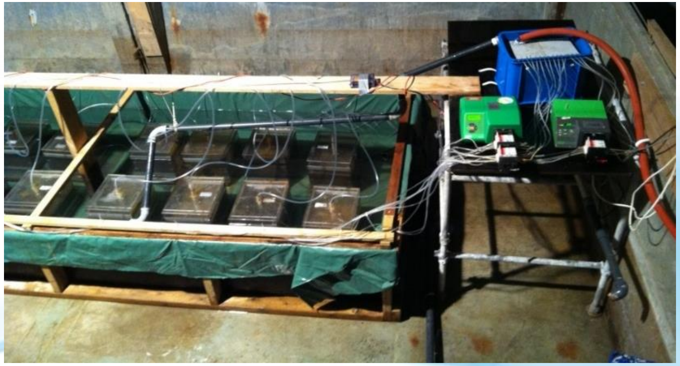
Sampling and measurements

Field survey 17.-19.11.2015:

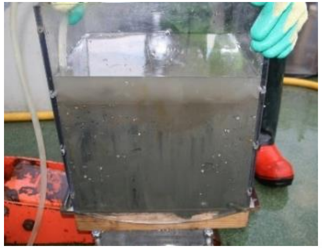
- Grab sampling for macrofauna
- Collection of boxcores

Box-core subsampling and measurements:

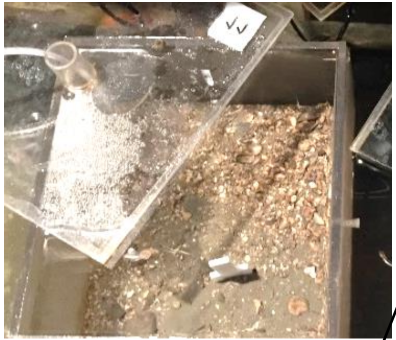
- metal analyses in sediments and pore water
- uptake of metals on DGT-probes
- sediment to water fluxes of trace metals (& O_2 and nutrient species)
- microelectrode profiles of O_2 and pH

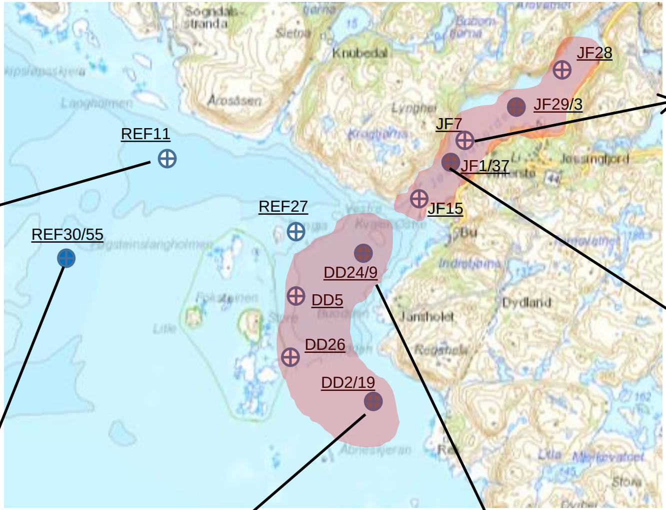


Seabed visual appearance

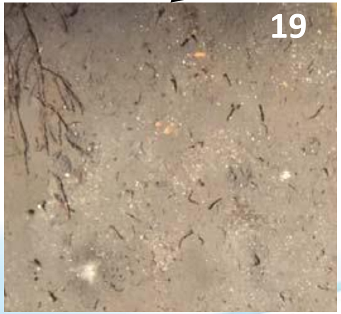


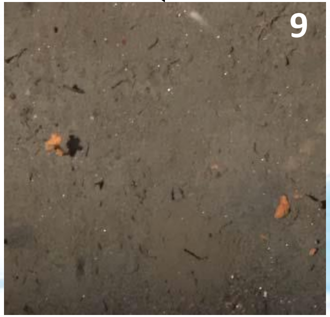
Reference stations





Dyngadjupet

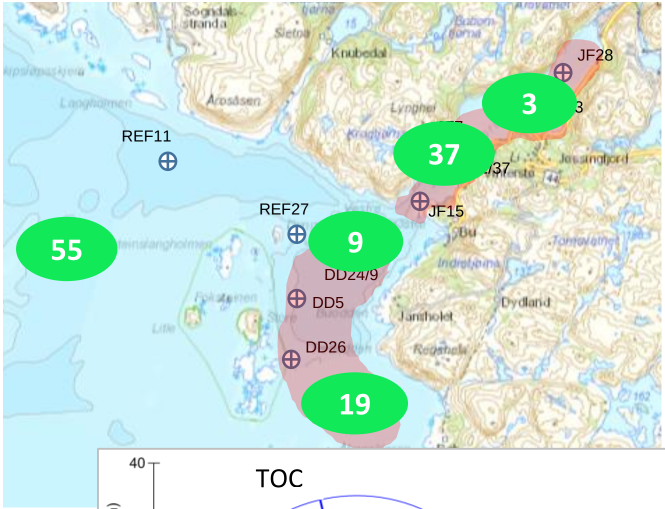


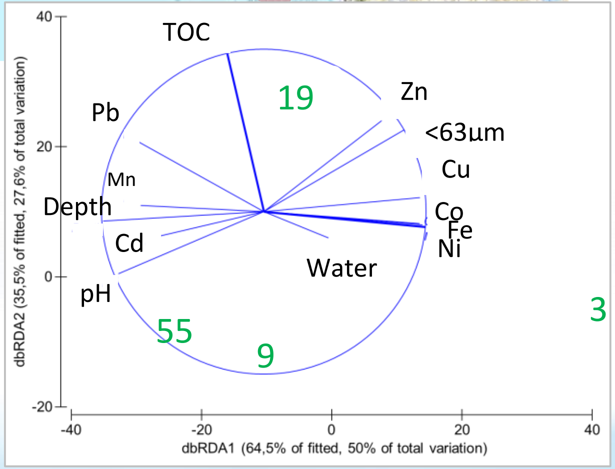


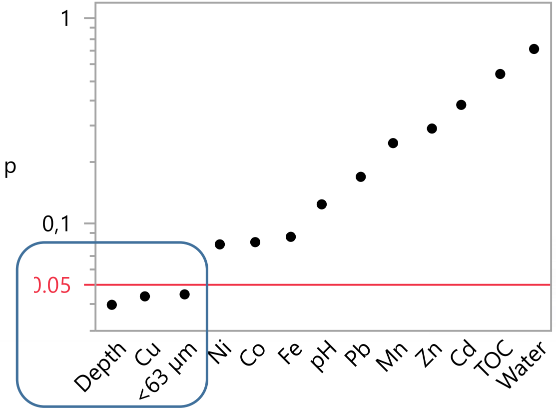
Jøssingfjorden

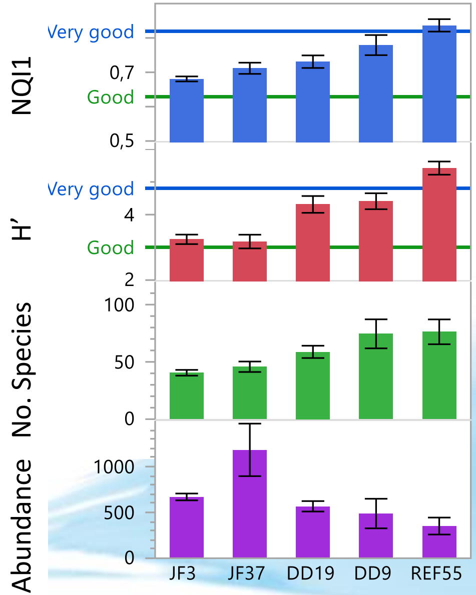
Macrofauna

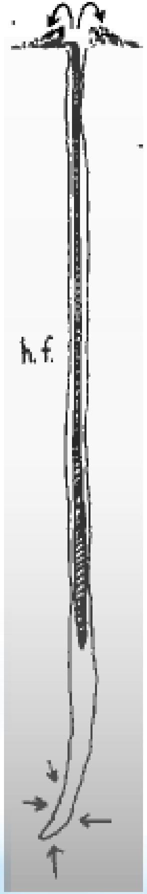
- 5 stations, 20 grab samples
- Sifted on 1 mm sieve
- ISO 16665:2014











Potential for bioturbation in Dyngadjupet by «the conveyor belt deposit-feeder *Heteromastus filiformis*»

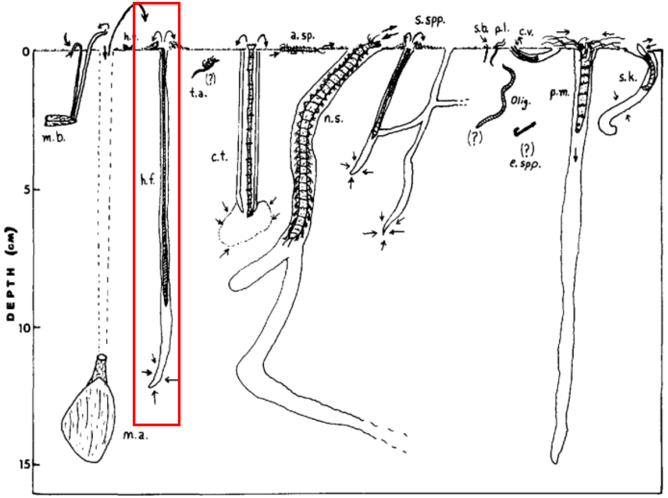


Figure 2. Macrobenthos of Lowes Cove sampling stations monitored from August, 1981, through July, 1984. Abundant taxa are shown along with major modes of particle transport (arrows) associated with each. Vertical scale is accurate; horizontal scale is exaggerated. Fauna (left to right) are: *Macoma balthica*, *Mya arenaria*, *Hydrobia totteni*, *Heteromastus filiformis*, *Tharyx acutus*, *Clymenella torquata*, *Aglaophamus* sp., *Nereis succinea*, *Scoloplos* spp., *Streblospio benedicti*, *Polydora ligni*, various oligochaetes, *Corophium volutator*, *Eteone* spp., *Polycirrus medusa*, and *Saccoglossus kowalewskii*.

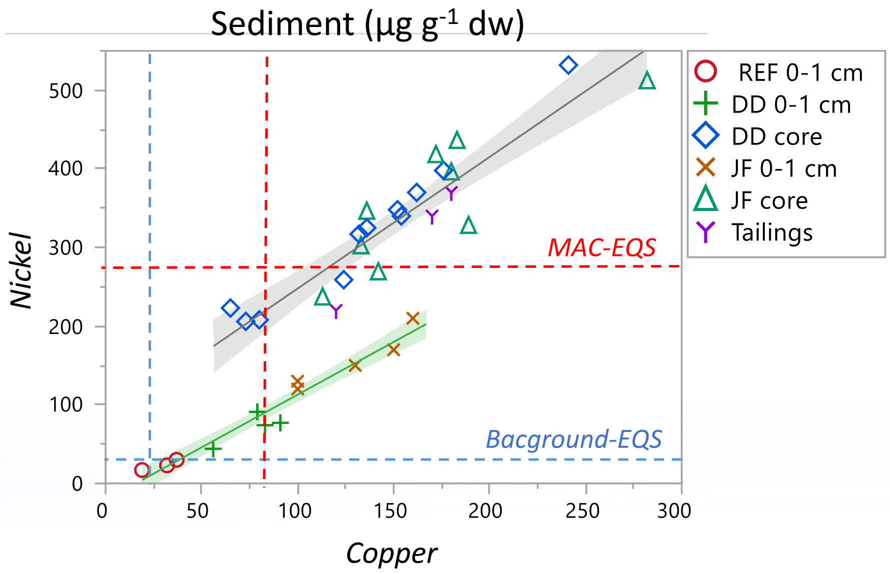
Table 4 Overview of ten most dominant taxa pr. station (average pr. 0,1 m^2) in Jøssingfjorden, 2015. Faunal group in parenthesis; A=Annelida, M=Mollusca, E=Echinodermata, P=Phoronida, C=Cnidaria, N=Nemertea.

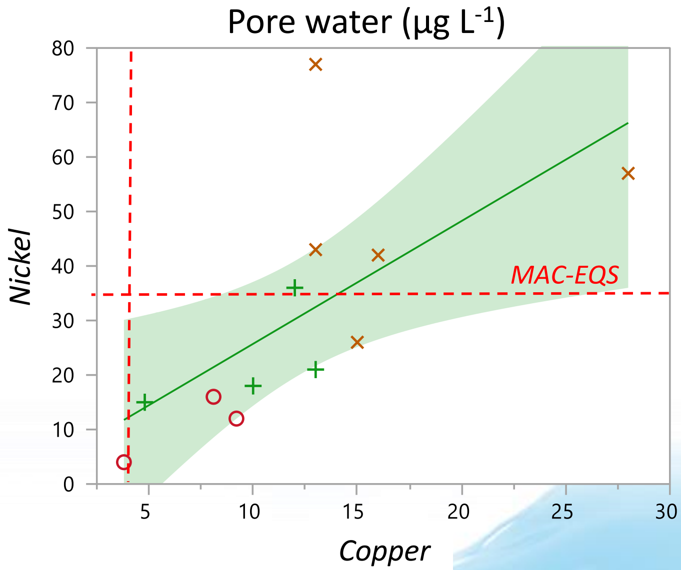
Taxon	St.3	Taxon	St.37	Taxon	St.9
Galathowenia oculata (A)	223	Phoronida indet (P)	325	*Galathowenia oculata* (A)	180
Kurtiella bidentate (M)	139	*Kurtiella bidentate* (M)	248	*Thyasira* sp. (M)	25
Amphiura filiformis (E)	105	*Amphiura filiformis* (E)	178	Phoronida indet (P)	19
Corbula gibba (M)	34	*Amphiura* sp. (E)	131	*Paramphinome jeffreysii* (A)	15
Ennucula tenuis (M)	25	*Galathowenia oculata* (A)	99	*Eclysippe vanelli* (A)	15
Pholoe baltica (A)	15	*Corbula gibba* (M)	38	*Spiophanes kroyeri* (A)	14
Pista lornensis (A)	12	*Edwardsia* sp. (C)	31	*Heteromastus filiformis* (A)	13
Thyasira sp. (M)	12	Nemertea indet (N)	30	*Trichobranchus roseus* (A)	12
Chaetozone setosa (M)	10	*Scoloplos armiger* (A)	23	Irregularia juv. (E)	11
Ophiuroidea juv. (E)	10	*Dosinia* sp. (M)	18	*Amythasides macroglossus* (A)	9

Taxon	St.19	Taxon	St.55
Heteromastus filiformis (A)	138	*Eclysippe vanelli* (A)	29
Thyasira sp. (M)	51	*Spiophanes kroyeri* (A)	22
Galathowenia oculata (A)	50	*Amythasides macroglossus* (A)	20
Diplocirrus glaucus (A)	47	*Thyasira* sp. (M)	20
Polycirrus sp. (A)	33	*Heteromastus filiformis* (A)	14
Pholoe baltica (A)	23	*Pholoe baltica* (A)	13
Eclysippe vanelli (A)	18	*Galathowenia oculata* (A)	13
Abyssoninoe hibernica (A)	18	*Notomastus latericeus* (A)	13
Notomastus latericeus (A)	15	*Yoldiella* sp. (M)	12
Spiophanes kroyeri (A)	11	*Polycirrus plumosus* (A)	9

Cu and Ni in sediment and pore water

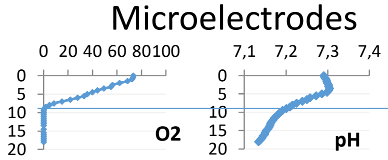
EQS-values from, Guideline M608, 2016, Norwegian Environment Agency
Harmonized with EU-legislation

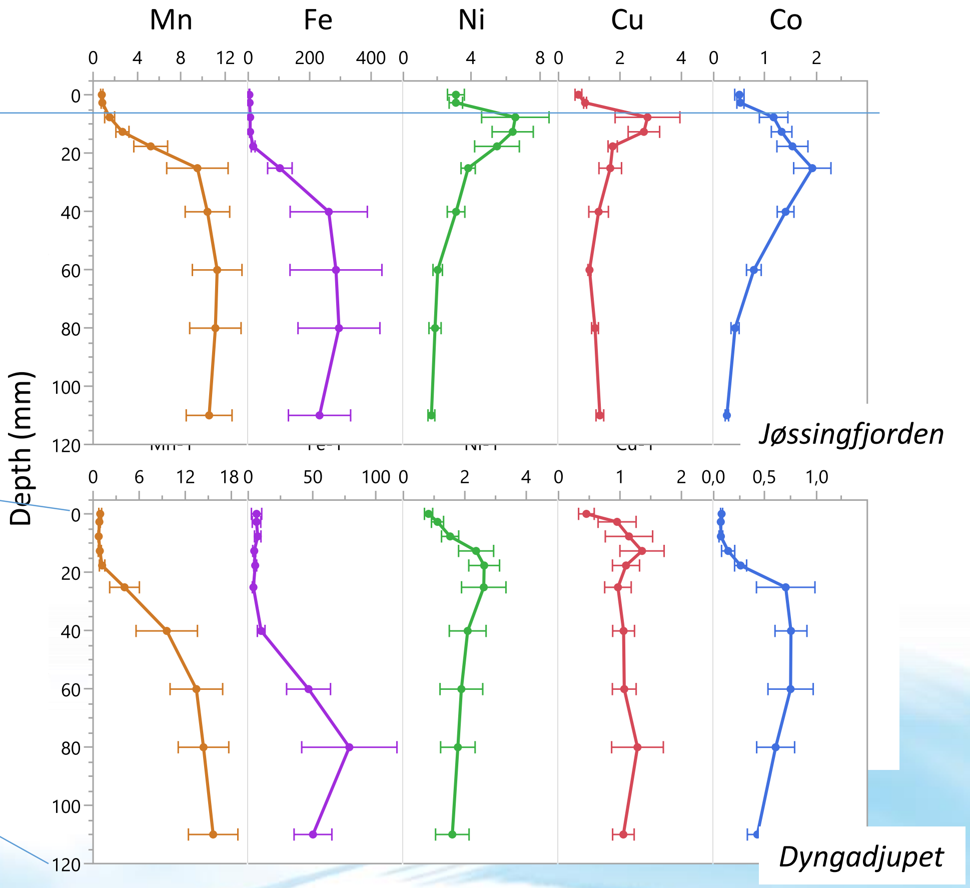


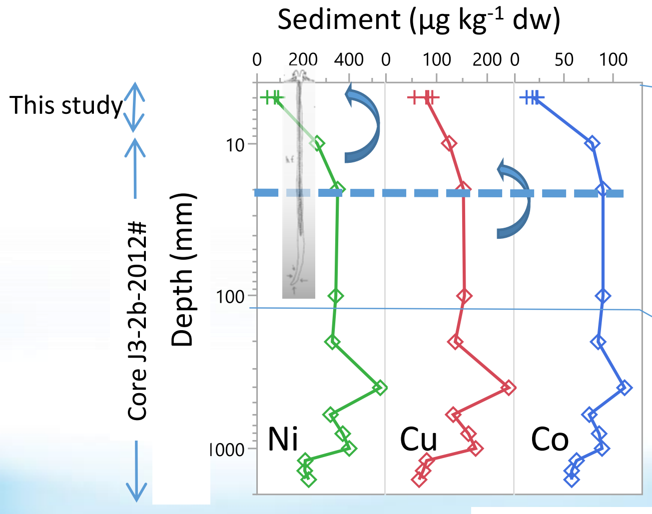


Risk of «acute toxic effects from short term exposure» in STD sediments in Jøssingfjorden and Dyngadjupet

Metal distribution





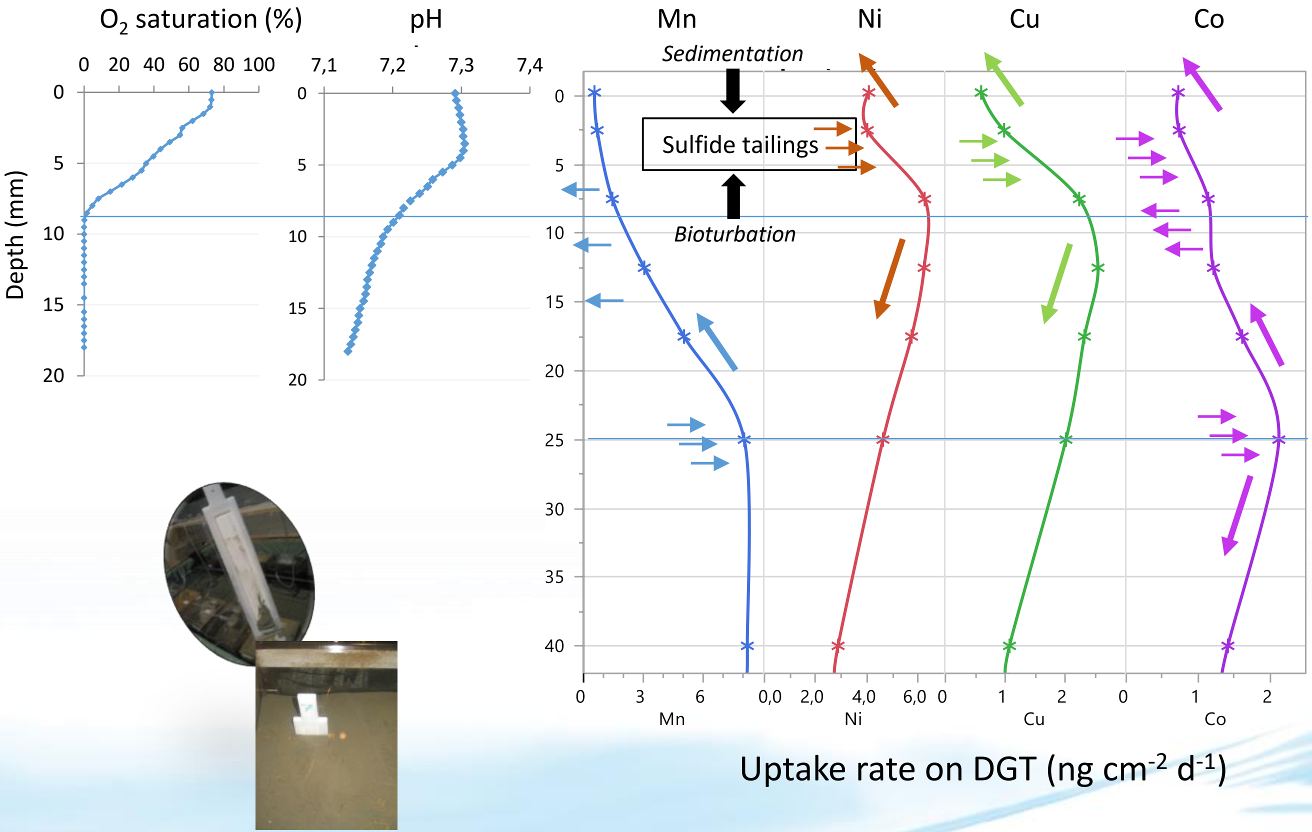


Dyngadjupet

20 y * 1mm y^{-1} =20 mm
Last deposition?

#Gravdal, 2012. Master theses, University of Bergen

Metal cycling in sediment surface layer



Stable species
Mn(IV), Co(III), Cu(II), Ni(II)

Ni-Cu-Co-sulfide oxidation

Mn(II) → Mn(IV)oxide

Co(II) → Co(III)oxide

Co(III)oxide→Co(II)

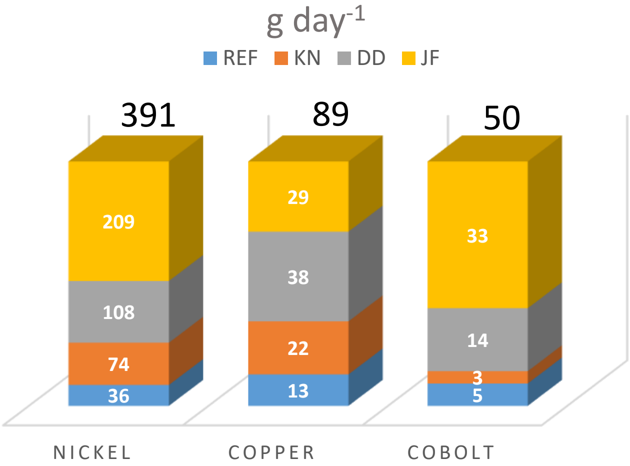
Mn(IV)oxide →Mn(II)

reduction & dissolution

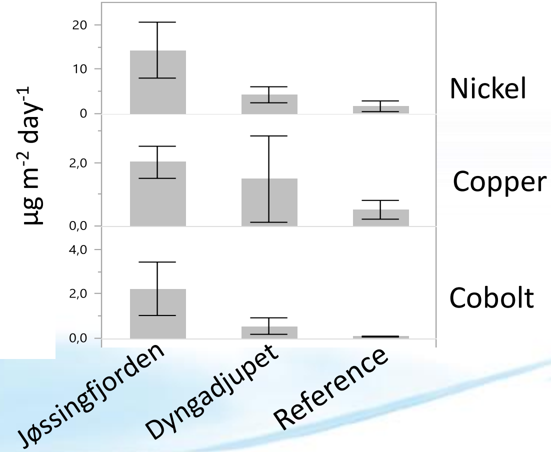
Stable species
Mn(II), Co(II), Cu(II), Ni(II)

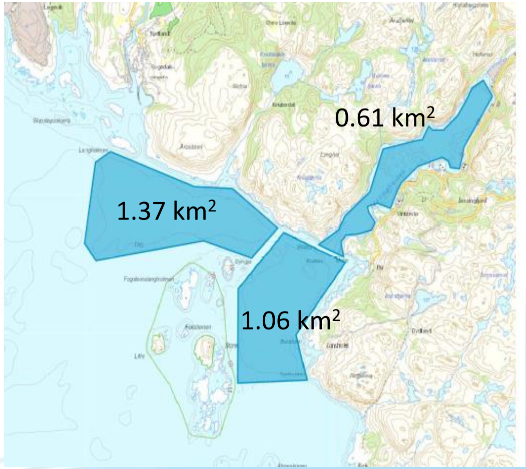
Fluxes from sediment to water

Leaching from land deposit = 7 500 g Ni day^{-1}

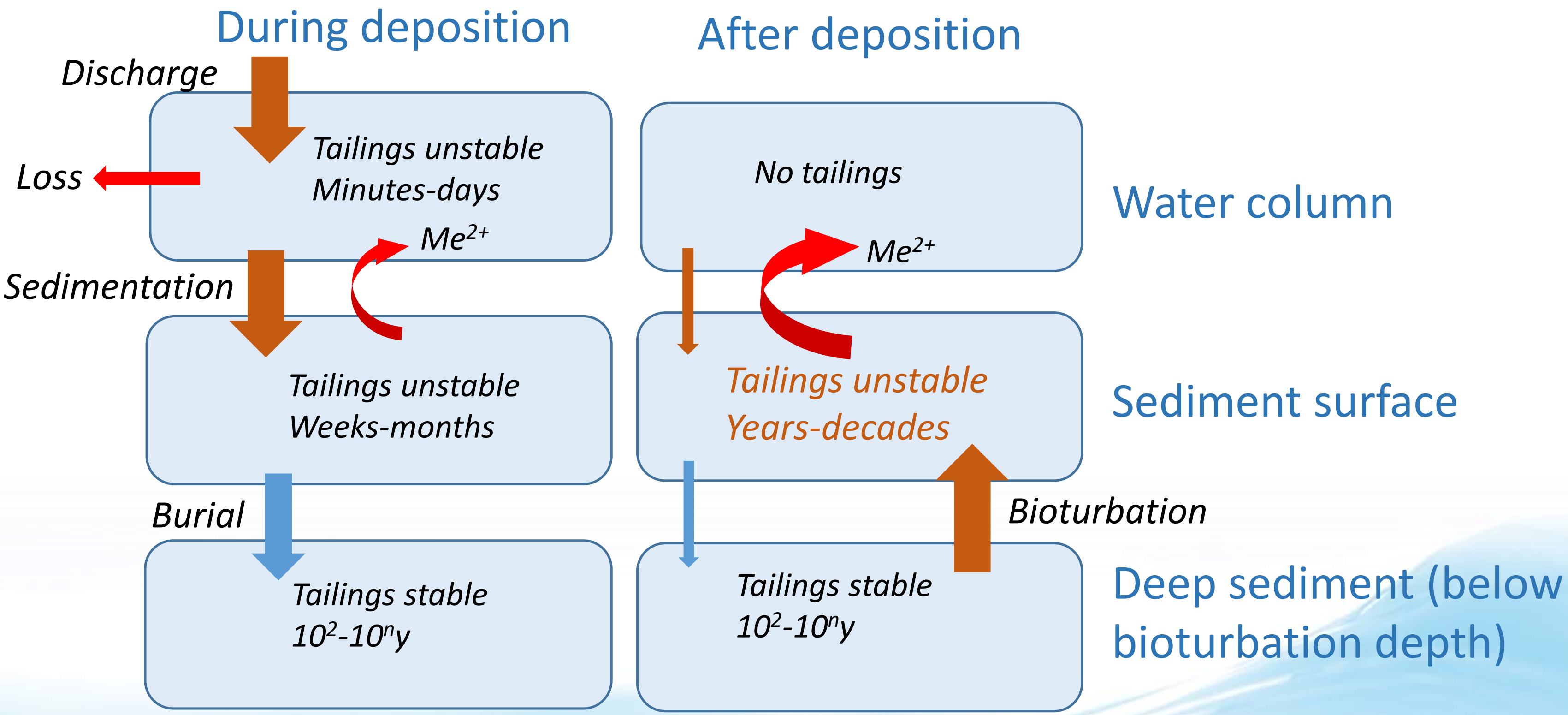


Flux of nickel from sea deposits corresponded to 5.2% of leakage from land deposit





Mobilization of metals from sea deposit



Summary of conclusions

Metals

- 20 years after last deposition, concentration of tailings-associated metals are decreasing at the sediment surface
- slow recovery in Dyngsdjupet due to bioturbation and low sedimentation rates
- significant ongoing discharge from mining activity to Jøssingfjorden
- DGT-profile maxima revealed mobilization of Ni, Cu and Co near the sediment surface
- no upwards transport of dissolved metals from deep deposit layers
- Cu and Ni exceed MAC-EQS in sediment and pore water implies risk of acute toxic effects

Fauna

- all stations classified as «good» or «very good»
- Cu, fine fractions and depth identified as significant environmental variables explaining the seawards improvement of the macrofauna community