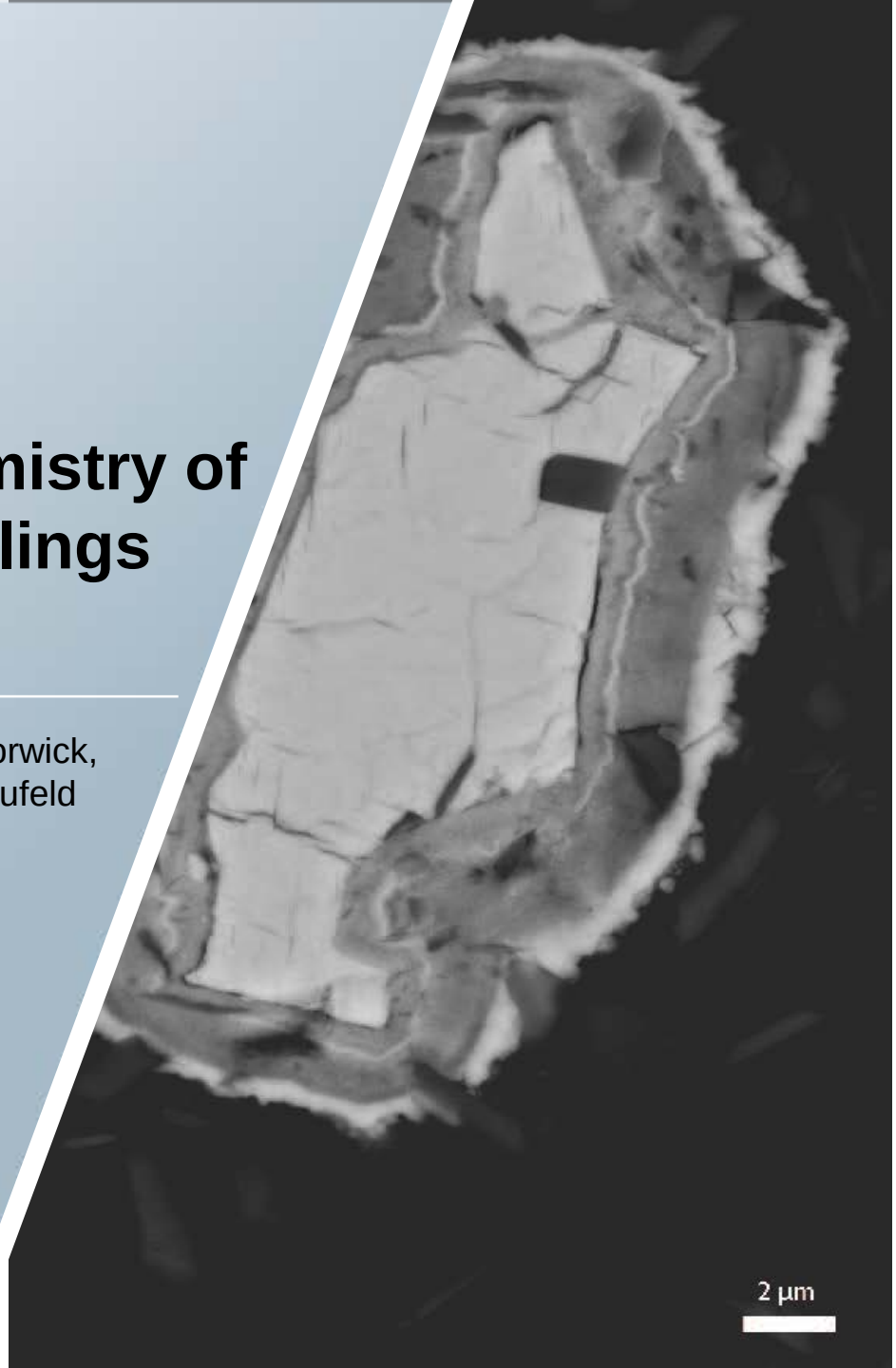
UiT

THE ARCTIC
UNIVERSITY
OF NORWAY

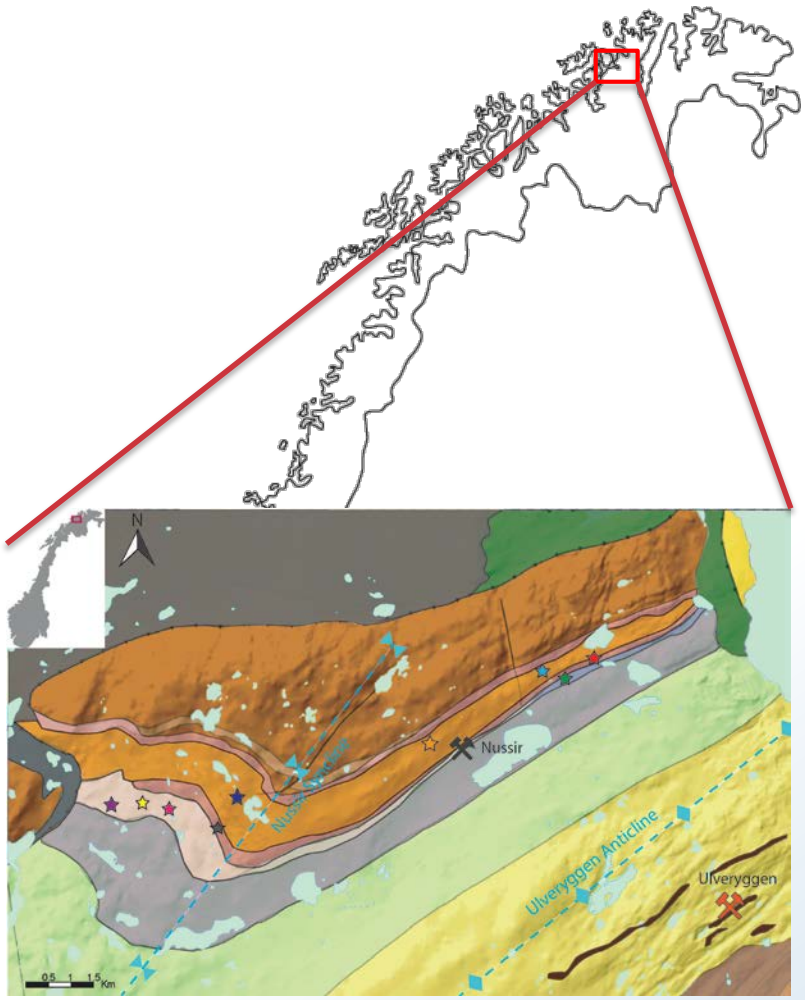
Environmental geochemistry of sub-sea and on-land tailings from Cu-sulfide mines

Yulia Mun, Sabina Strmic Palinkaš, Matthias Forwick, Kristine Bondo Pedersen, Juho Junttila, Kai Neufeld

27.11.2018

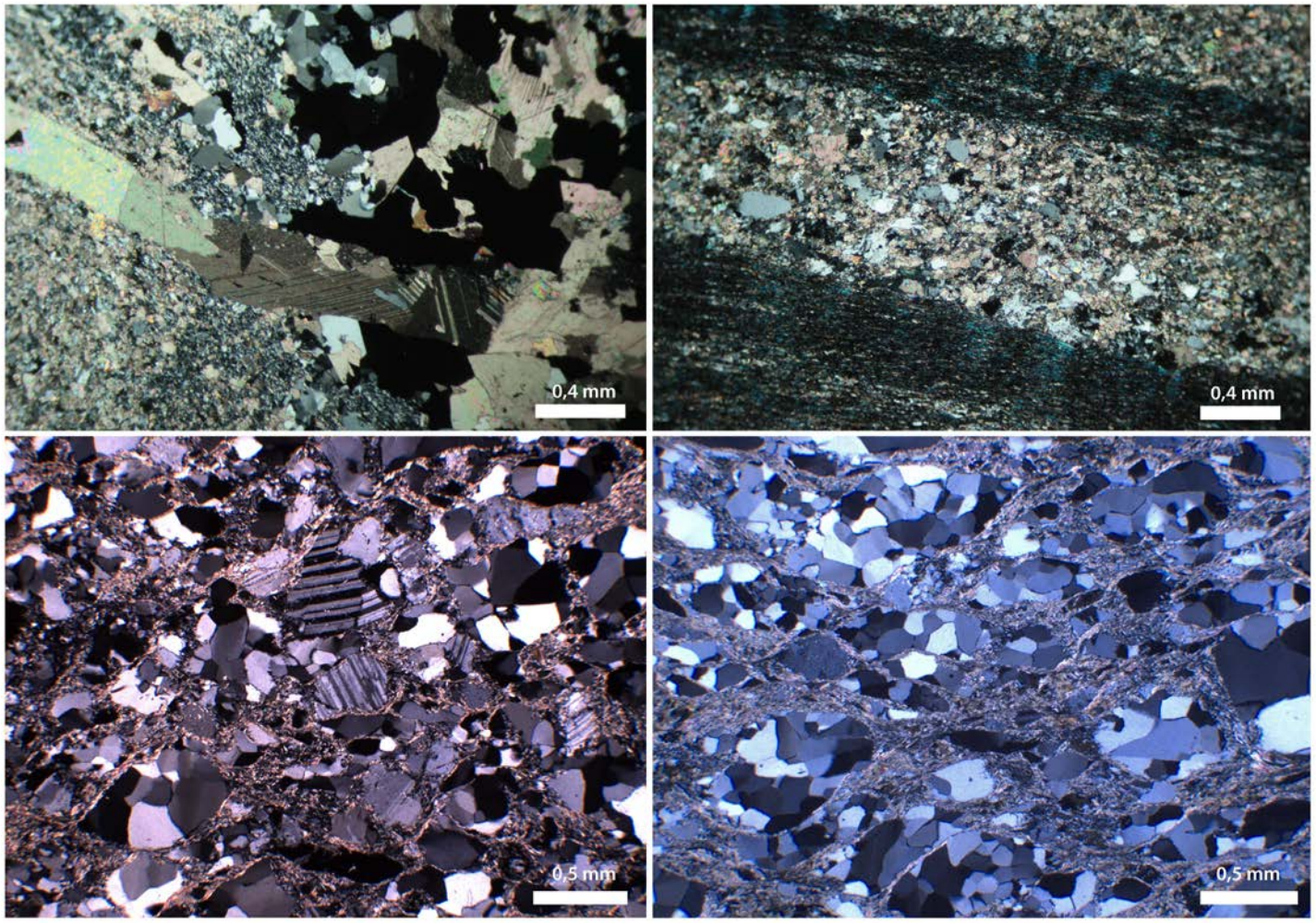


Past and future of mining in the Repparfjord area. Cu century…

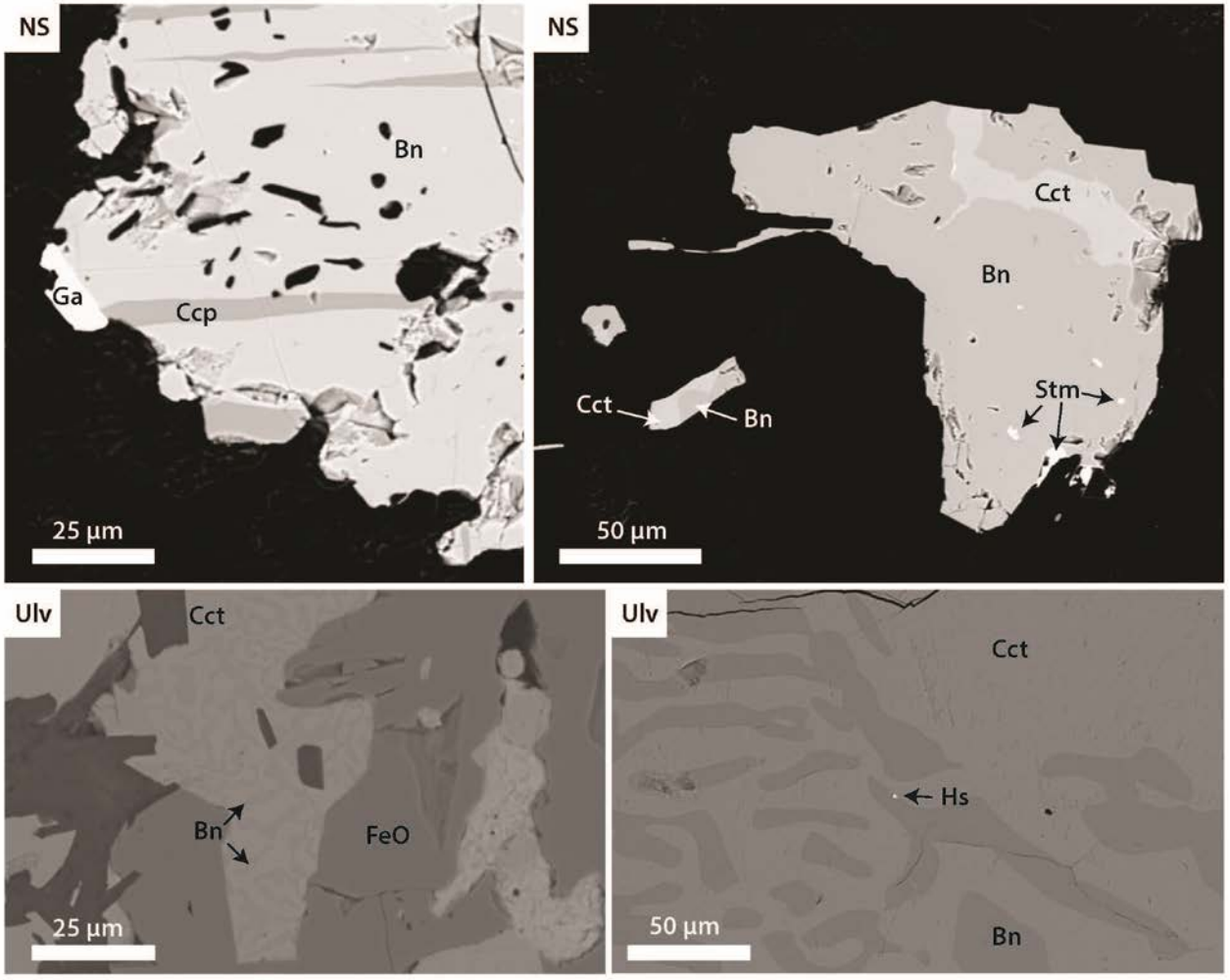


- Ulveryggen was discovered in 1900-s
- Nussir was discovered later in 1970-s
- From 1972 until 1978/1979 Ulveryggen was in production by Folldal Verk AS, from early 2000-s is owned by Nussir ASA.
- About 1 Mt of mine waste was deposited into the Repparfjord (*Kvasness and Iversen, 2013*)
- Ulveryggen: approx. 3.7 Mt of indicated resources (~0.8% Cu grade) (*http://www.nussir.no/en_projec_ulvery.php accessed on 19.11.2018*)
- Nussir: approx. 5.8 Mt of indicated resources (1.15% Cu grade) (*http://www.nussir.no/en_projec_nussir.php accessed on 19.11.2018*)
- 19.12.2016 Nussir ASA gained permission to place tailings into the fjord (*http://www.nussir.no/index.php*)
- Green Shift requires Cu

What is the starting material?



What is the starting material?



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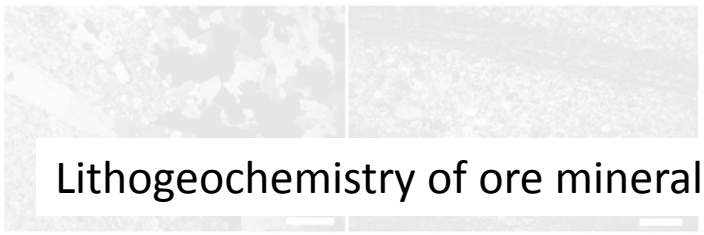

Lithogeochemistry of ore minerals: NS-35 chalcopyrite; Ulv -2 bornite

#sample	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	As	Rb	Sr	Mo	Ag	In	Sn	Sb	Cs	Ba	Ta	W	Tl	Pb	Bi	Th	U
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
LD	5	20	1	20	10	30	1	0,5	5	1	2	2	0,5	0,1	1	0,2	0,1	3	0,01	0,5	0,05	5	0,1	0,05	0,01
NS-35	5	< 20	85	100	> 10000	310	< 1	< 0.5	< 5	< 1	48	< 2	0,5	0,5	< 1	< 0.2	< 0.1	12	< 0.01	0,6	3,69	< 5	0,3	< 0.05	0,05
Ulv-2	27	140	2	< 20	> 10000	< 30	6	0,6	< 5	24	186	5	< 0.5	< 0.1	< 1	< 0.2	0,4	527	0,13	< 0.5	0,96	< 5	0,1	3	3,02

Chemistry of selected Cu minerals (wt%)

Lab	Mineral	Sample	S	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Ag	Cd	Te	Hg	Bi	Au	Total
UiO	*Ccp*	NS-12	35,95	30,94				0,05									0,09	100,92
UiO	*Ccp*	NS-42	34,7	29,77			33,29	0,07	0,01	0,03	2,86	0,03						100,76
UiO	*Bn*	NS-32	25,2	10,93		0,02	62,42	0,04		0,12	1,92	0,15		0,03	0,06			100,92
UiO	*Bn*	NS-40	24,95	10,72		0,04	62,83	0,11		0,42	2,18							101,26
UiO	*Cct*	NS-32	20,5	0,19	0,01	0,01	78	0,14		0,17	1,59	0,22						100,83
UiO	*Cct*	NS-40	20,63	0,03	0,01		78,05	0,17		0,31	1,54	0,01			0,1			100,85
UiO	*Dg*	NS-16	20,9	0,12			79,21	0,11				0,17						100,38
UiO	*Dg*	NS-26	22,81	0,73			75,09	0,07				0,6						99,19
UiO	*Cv*	NS-14	25,98	11,5			62,53	0,07	0,06			0,29						100,36
UiO	*Cv*	NS-26	25,45	11,36			62,37	0,11	0,05			0,14						99,44
UCR	*Bn*	Ulv-5	24,79	12,6			60,72											98,11
UCR	*Cct*	Ulv-5	20,65	1,02			77,96											99,63
UCR	*Cct*	Ulv-14	21,51	0,36			77,54											99,42

What is the starting material?

Chemistry of selected Cu minerals (wt%)																	
Lab	**Mineral**	**Sample**	**S**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Se**	**Mo**	**Ag**	**Cd**	**Te**	**Hg**	**Bi**	**Au**	**Total**
UiO	*Ccp*	NS-12	35,95	30,94				0,05									0,09	100,92
UiO	*Ccp*	NS-42	34,7	29,77			33,29	0,07	0,01	0,03	2,86	0,03						100,76
UiO	*Bn*	NS-32	25,2	10,93		0,02	62,42	0,04		0,12	1,92	0,15		0,03	0,06			100,92
UiO	*Bn*	NS-40	24,95	10,72		0,04	62,83	0,11		0,42	2,18							101,26
UiO	*Cct*	NS-32	20,5	0,19	0,01	0,01	78	0,14		0,17	1,59	0,22						100,83
UiO	*Cct*	NS-40	20,63	0,03	0,01		78,05	0,17		0,31	1,54	0,01			0,1			100,85
UiO	*Dg*	NS-16	20,9	0,12			79,21	0,11				0,17						100,38
UiO	*Dg*	NS-26	22,81	0,73			75,09	0,07				0,6						99,19
UiO	*Cv*	NS-14	25,98	11,5			62,53	0,07	0,06			0,29						100,36
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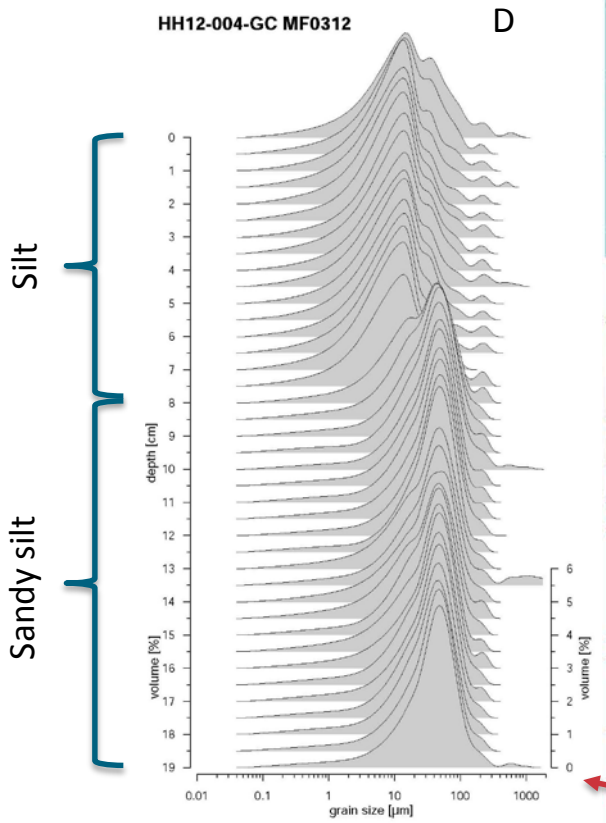
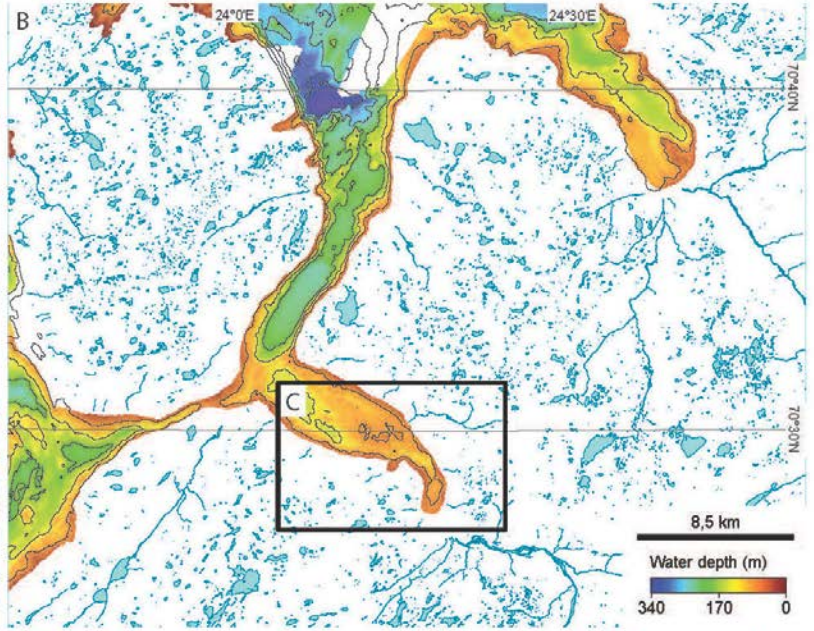
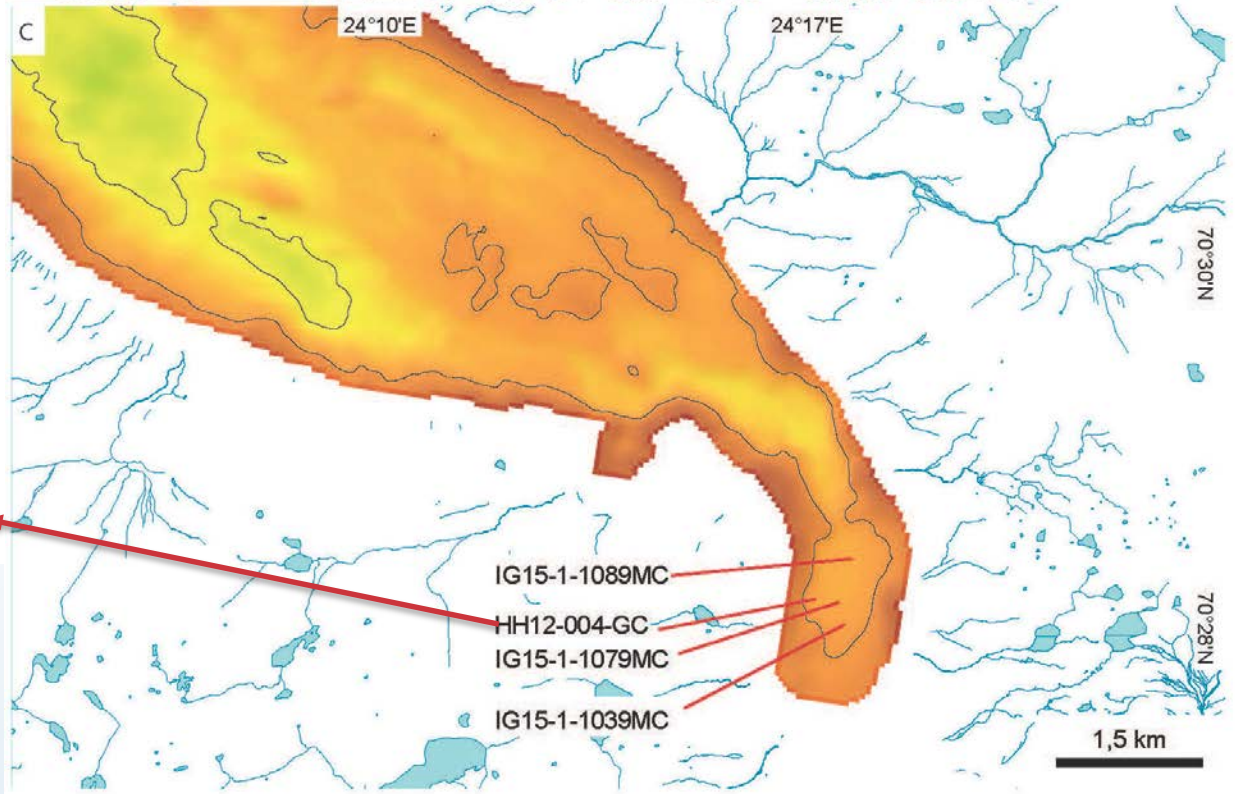
Repparfjorden Bathymetry and sampling sites



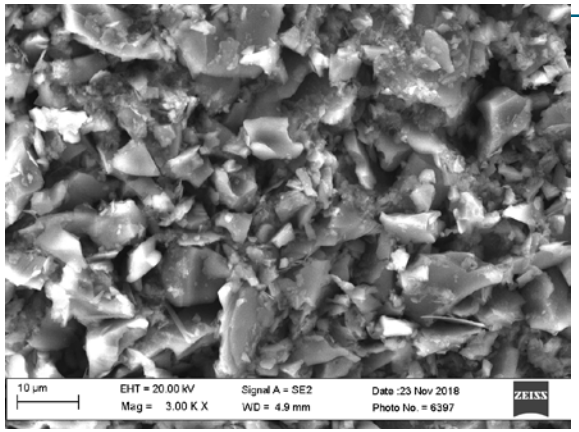


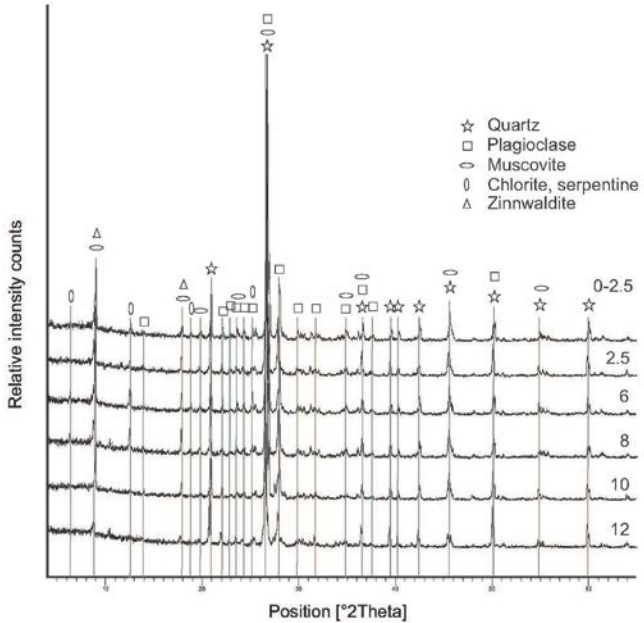


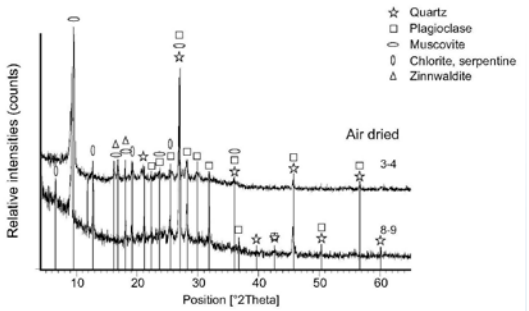
A-C: Location and bathymetry map of Repparfjorden showing sampling sites of multi- (MC) and gravity-core (GC). *D:* Grain size analysis of first 20 cm of HH-12-004-GC

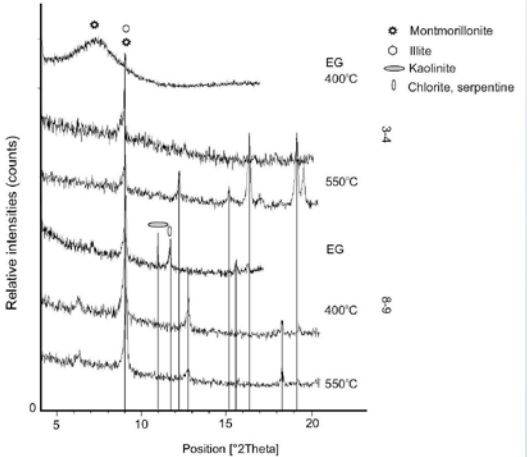
Modified after Sternal et al. (2017)

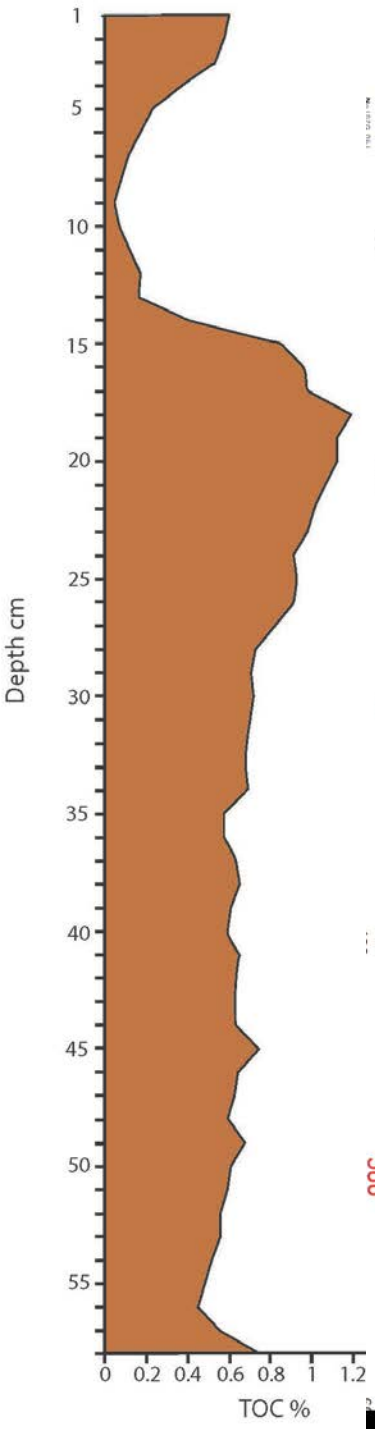
TOC, XRD (bulk, clays)

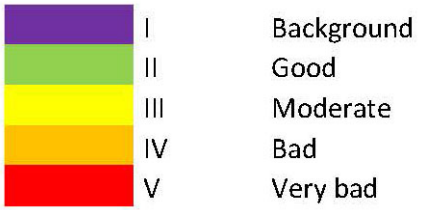












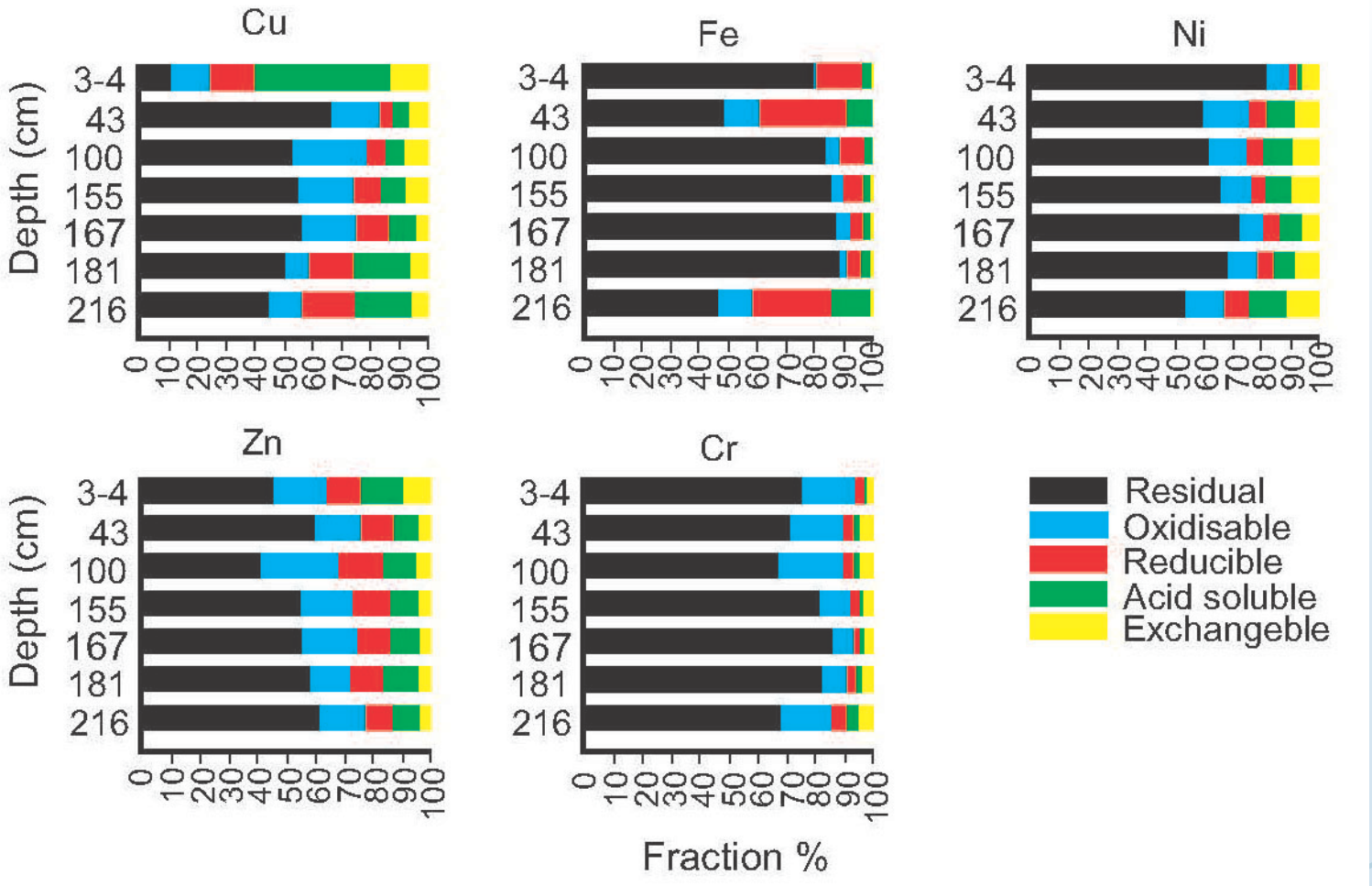
Lithogeochemistry

According to SFT, 2008

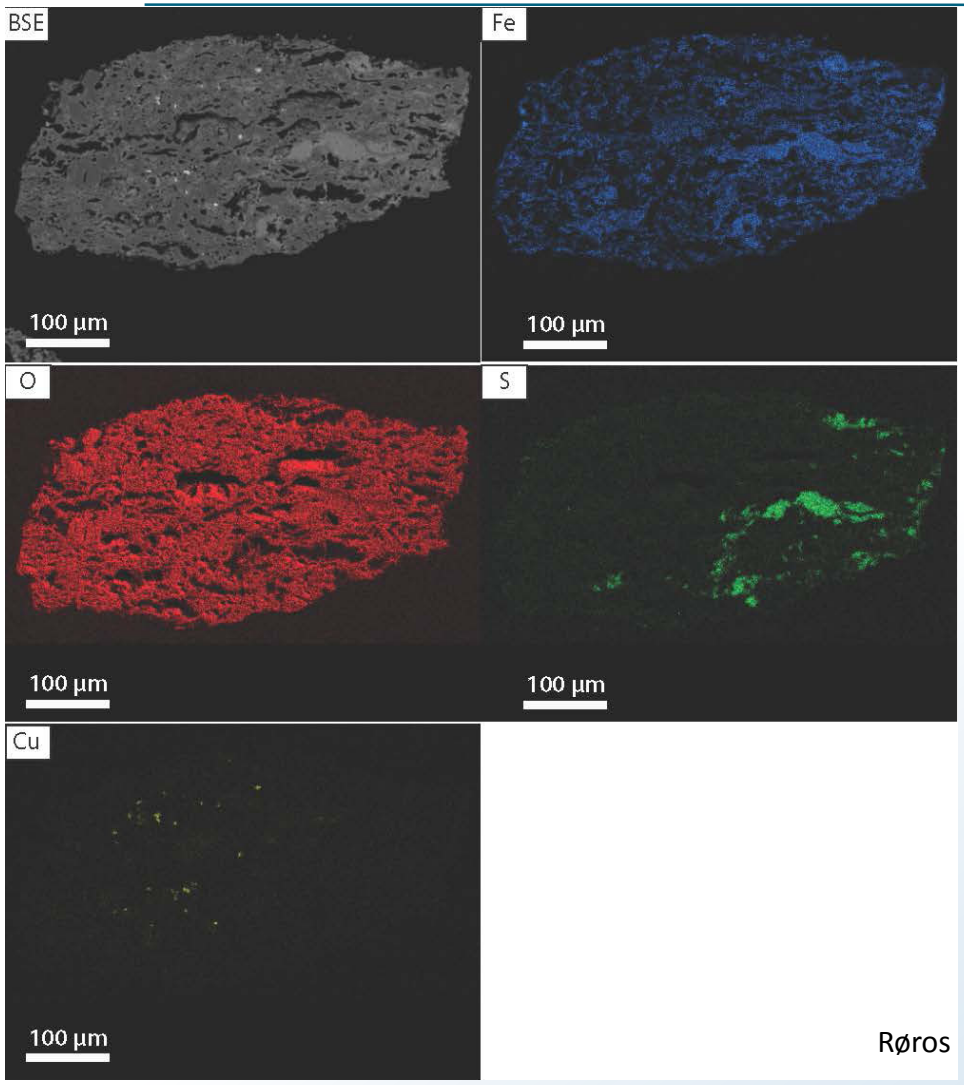
Acmelabs	Int	SiO2	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	TiO2	P2O5	MnO	Cr	Ba	Ni	Sc	Be	Co	Cs	Ga	Hf	Nb	Rb	Sn	Sr	Ta	Th	U	V	W	Zr	Y	Mo	Cu	Pb	Zn	Ni	As	Cd	Sb	Bi	Ag	Au	Hg	Tl	Se
	(cm)	%	%	%	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
DL		0,01	0,01	0,04	0,01	0,01	0,01	0,01	0,01	0,01	0,01		1	20	1	1	0,2	0,1	0,5	0,1	0,1	0,1	1	0,5	0,1	0,2	0,1	8	0,5	0,1	0,1	0,1	0,1	0,1	1	0,1	0,5	0,1	0,1	0,1	0,1	0,5	0,01	0,1	0,5
HH-004	0	68,1	11,81	4,57	1,78	1,14	2,84	3,19	0,44	0,09	0,03	342,0972	1216	49	8	4	13,6	1,6	14,9	3,7	6,6	93	2	109,4	0,6	6,7	2	86	<0,5	142	12,8	1,7	640,8	7,4	31	29,6	5	<0,1	0,2	0,3	<0,1	3,4	0,02	0,2	<0,5
-	2,5	69,89	12,41	4,14	1,81	0,5	2,83	3,41	0,43	0,07	0,03	396,8327	1356	52	8	1	13,4	2	16,1	3	5,3	97,9	2	82	0,6	6,4	2,2	92	0,6	116,4	10,9	1,8	518	5,3	21	30,9	3,8	<0,1	0,1	0,4	<0,1	3,2	0,04	0,2	<0,5
-	6	70,82	12,08	4,44	1,81	0,51	2,8	3,26	0,38	0,06	0,02	403,6746	1377	49	8	1	12,6	1,6	15,2	2,5	4,4	87,5	1	72,3	0,3	5,9	1,8	86	<0,5	91,3	8,7	0,6	747,7	3,2	21	32,1	2,1	<0,1	0,1	0,4	<0,1	4,8	0,04	0,1	<0,5
-	8	68,65	12,72	5,05	2,17	0,6	2,7	3,42	0,41	0,06	0,03	417,3585	1097	59	9	3	16	1,7	16,4	2,9	4,5	95	1	62,8	0,4	6,5	1,8	96	<0,5	107,4	10,7	1,1	486,6	3,4	19	37,7	2	<0,1	<0,1	0,4	<0,1	3,5	0,02	0,1	<0,5
-	10	69,42	10,96	4,3	1,7	1,82	2,87	2,46	0,62	0,13	0,04	150,5228	618	87	10	<1	11,4	2	13	6,7	8,9	80,3	2	179,6	0,7	7	2,6	81	<0,5	265,1	19,8	1,1	237,6	8,7	33	22,4	3,9	<0,1	0,1	0,1	<0,1	2,5	0,02	0,1	0,8
-	12	71,26	10,6	3,73	1,55	1,94	2,82	2,21	0,65	0,13	0,04	95,7872	536	27	10	1	10	2,2	11,5	7,9	10,1	76	2	186,6	0,7	6,9	2,9	71	0,7	297,9	22,7	1,1	86,6	8,7	37	18,3	3,9	<0,1	0,1	<0,1	<0,1	2,8	0,03	0,2	0,8
ActLabs																																													
DL		0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,001	0,01	0,001	20	2	20	1	1	1	0,1	1	0,1	0,2	1	1	2	0,01	0,05	0,01	5	0,5	1	0,5	2	10	5	30	20	5	*nd*	0,2	0,1	0,5		*nd*	0,05	
Rpelv		70,69	9,82	3,66	0,95	1,65	2,01	2,02	0,714	0,14	0,077	100	561	50	9	1	11	1,9	13	9	7,7	74	<1	189	0,87	7,85	3,45	60	4,5	344	28,4	< 2	10	18	40	50	< 5	*nd*	1,4	<0,1	0,6		*nd*	0,06	

Acmelabs	Interval cm	Cr	Ni	Cu	Pb	Zn	As	Cd	Hg
		ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
DL			20	0.1	0.1	1	0.5	0.1	0.01
HH-004	0	342.1	49	640.8	7.4	31	5	<0.1	0.02
-	2.5	396.8	52	518	5.3	21	3.8	<0.1	0.04
-	6	403.7	49	747.7	3.2	21	2.1	<0.1	0.04
-	8	417.4	59	486.6	3.4	19	2	<0.1	0.02
-	10	150.5	87	237.6	8.7	33	3.9	<0.1	0.02
-	12	95.8	27	86.6	8.7	37	3.9	<0.1	0.03
ActLabs									
DL		20	20	10	5	30	5	*nd*	*nd*
Repparfjordelva		100	50	10	18	40	< 5	*nd*	*nd*

Sequential extraction: HH-12-004-GC-MF0312



On-land conditions. Pyrite FeS_2



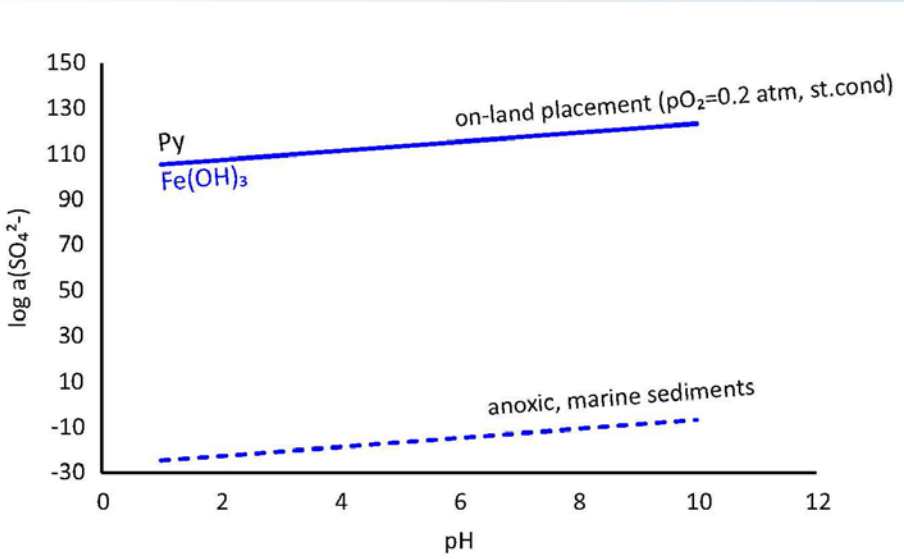
Røros

$$4FeS_2+14H_2O+15O_2 \leftrightarrow 4Fe(OH)_3+16H^+ +8SO_4^{2-}$$

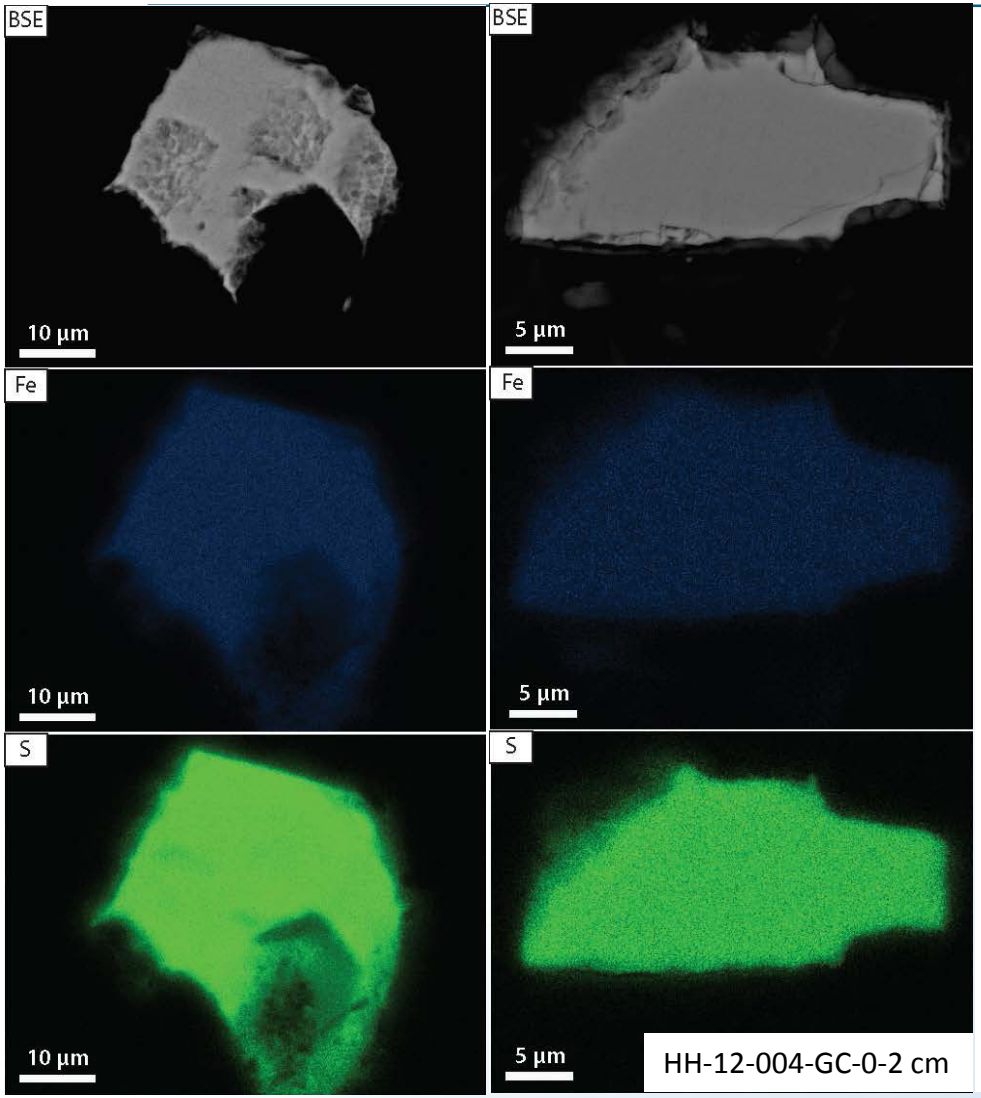
$$K=\frac{[H^+]^{16}[SO_4^{2-}]^8}{pO_2^{15}}/log$$

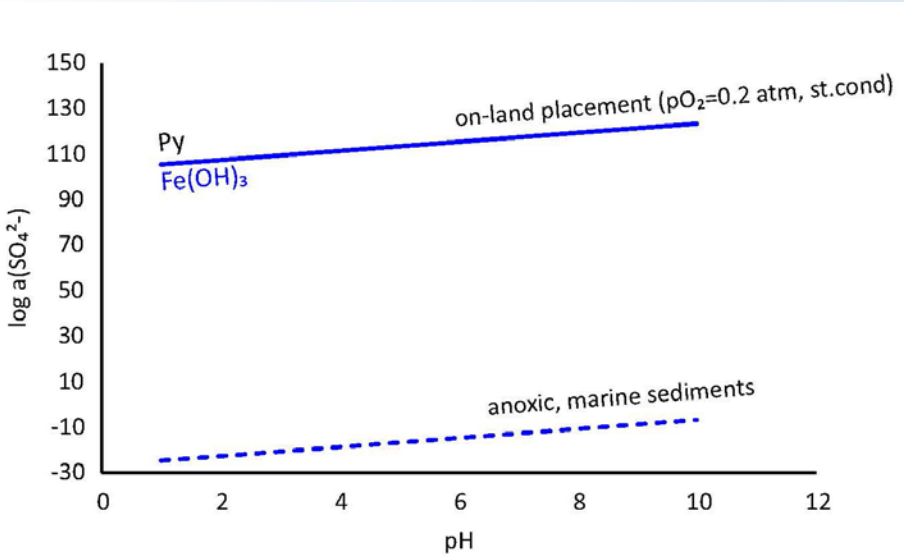
Redox

$$logK = 16log[H^+]+ 8log[SO_4^{2-}]- 15logpO_2$$



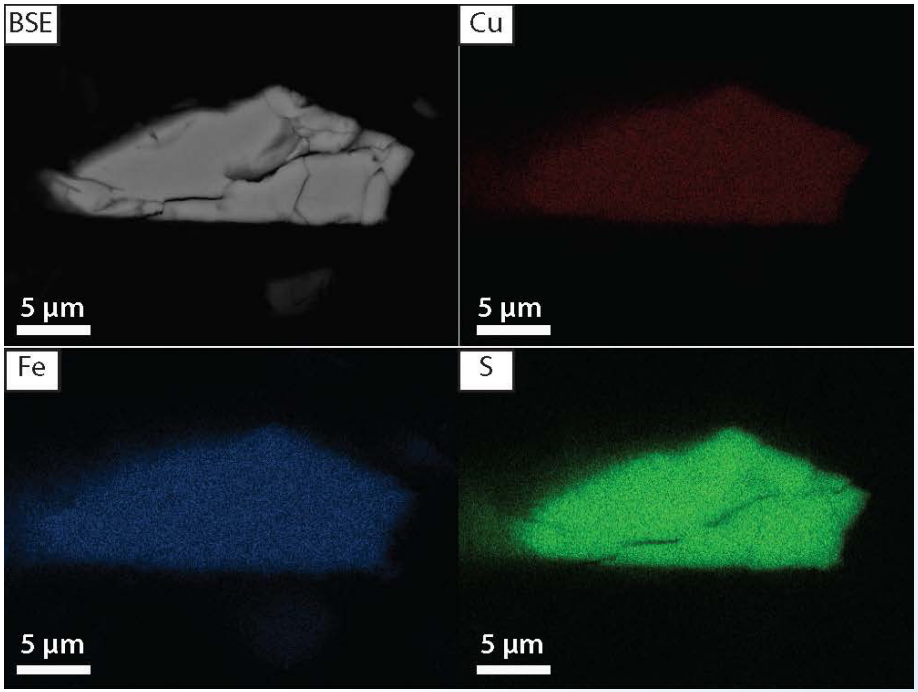
Anoxic marine sediments conditions.
Ore mineralogy and thermodynamic modelling. Pyrite.



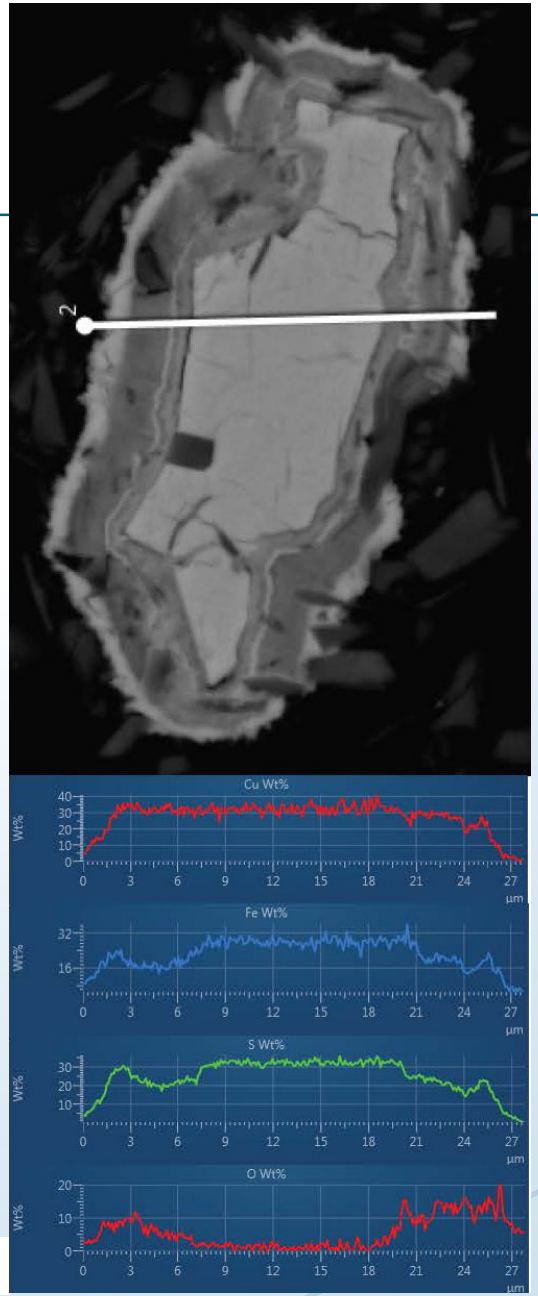


Chalcopyrite $CuFeS_2$

Fresh chalcopyrite



Partly oxidized chalcopyrite



HH-12-004-GC 3-4 cm

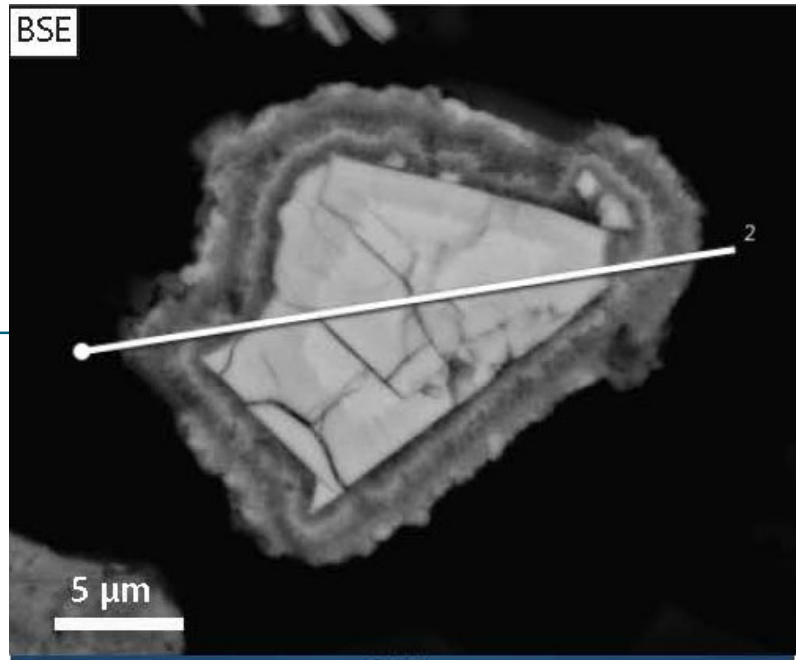
Chalcopyrite. Thermodynamics

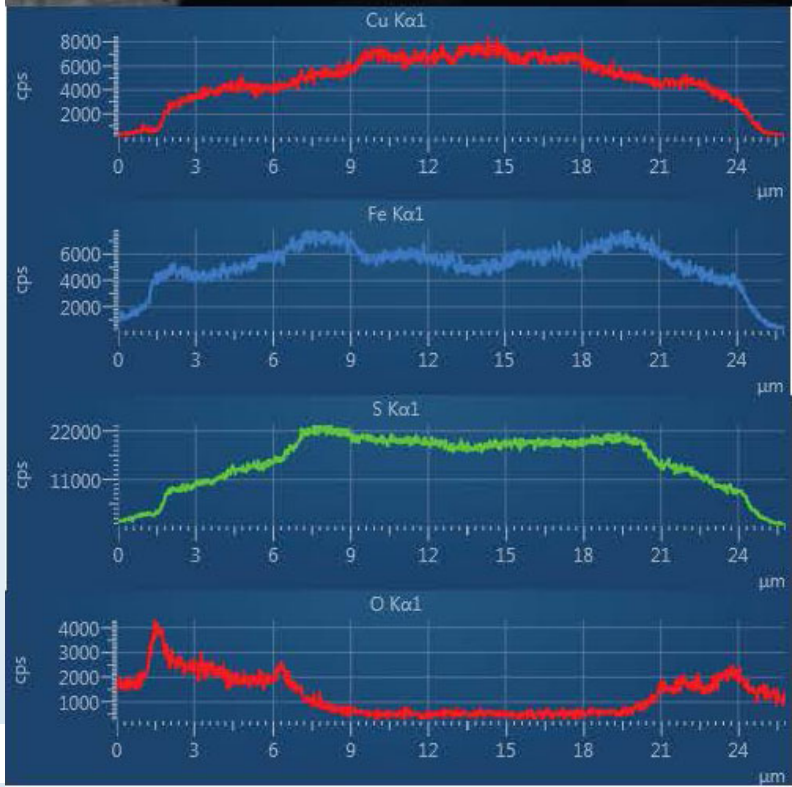
$4CuFeS_2+14H_2O+15O_2 \leftrightarrow 4Cu^{2+}+4Fe(OH)_3 + 8SO_4^{2-} +16H^+$

$$K=\frac{[Cu^{2+}]^4[SO_4^{2-}]^8[H^+]^{16}}{pO_2^{\ 8}}/log$$

$$logK=4log[Cu^{2+}]+8log[SO_4^{2-}]+16log[H^+]-8log\,pO_2$$

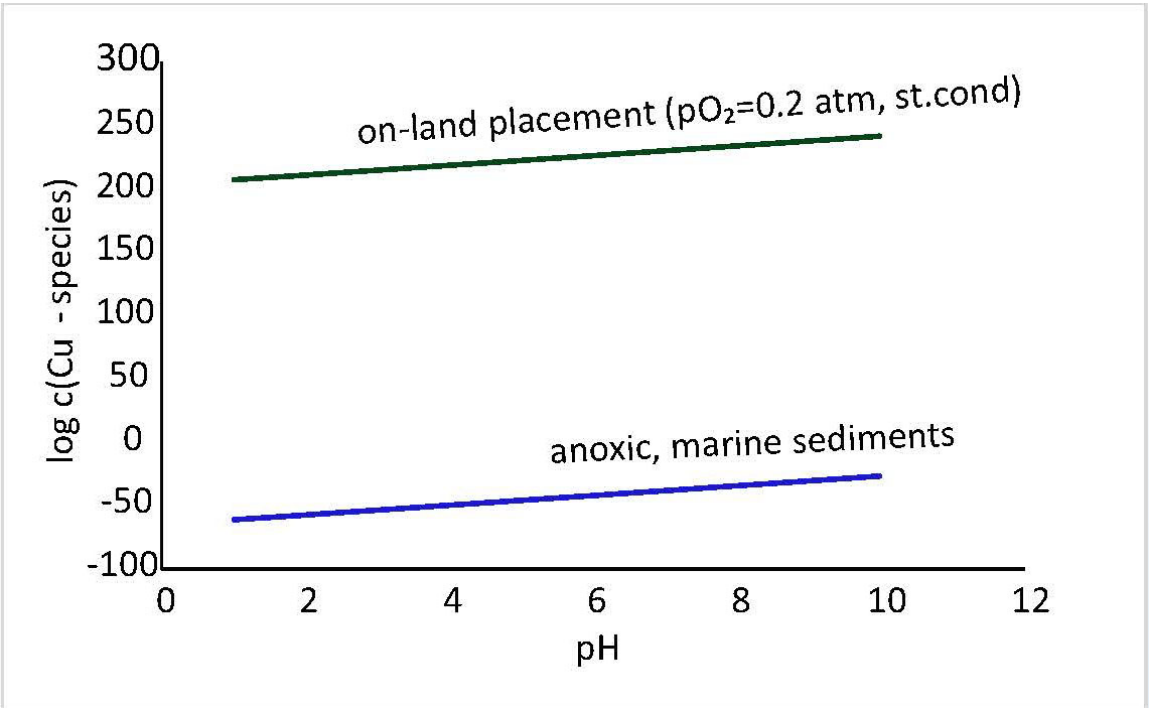
Redox

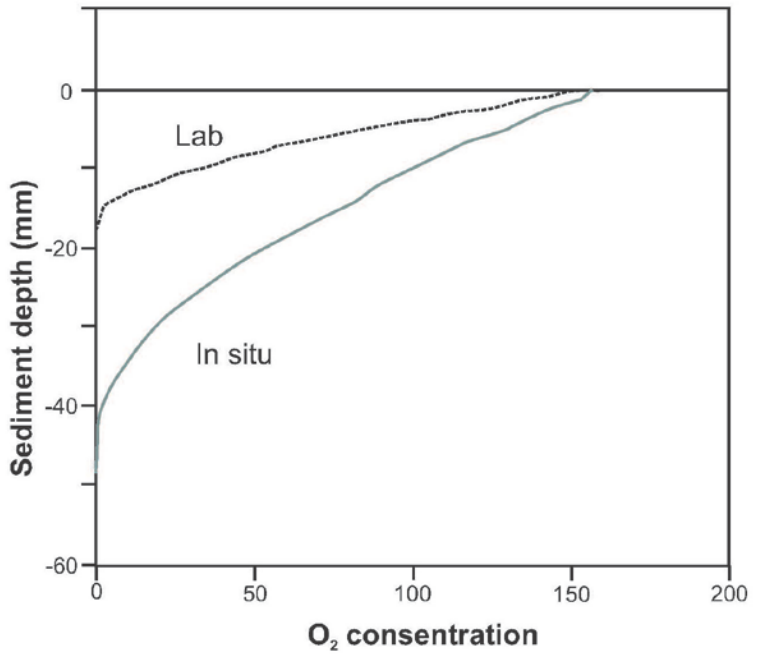




IG-15-1-1039-MC-3-4 cm

Chalcopyrite.





From Guld RN (2008)

Bornite Cu_5FeS_4

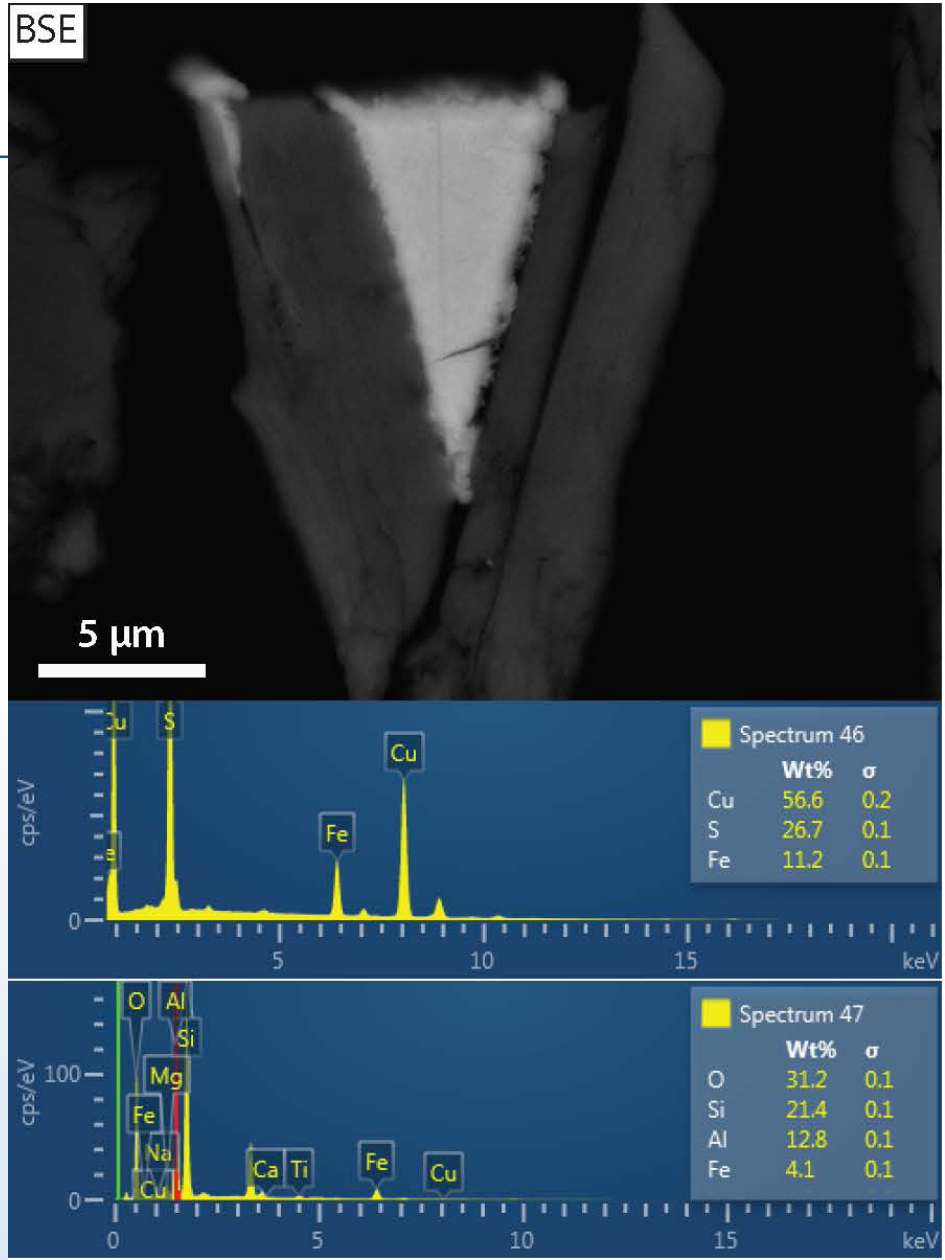
$4Cu_5FeS_4+22H_2O+27O_2 \leftrightarrow 20Cu^{2+}+4Fe(OH)_3 + 16SO_4^{2-} +32H^+$

$$K=\frac{[Cu^{2+}]^{20}[SO_4^{2-}]^{16}[H^+]^{32}}{pO_2^{27}}/log$$

Vs.

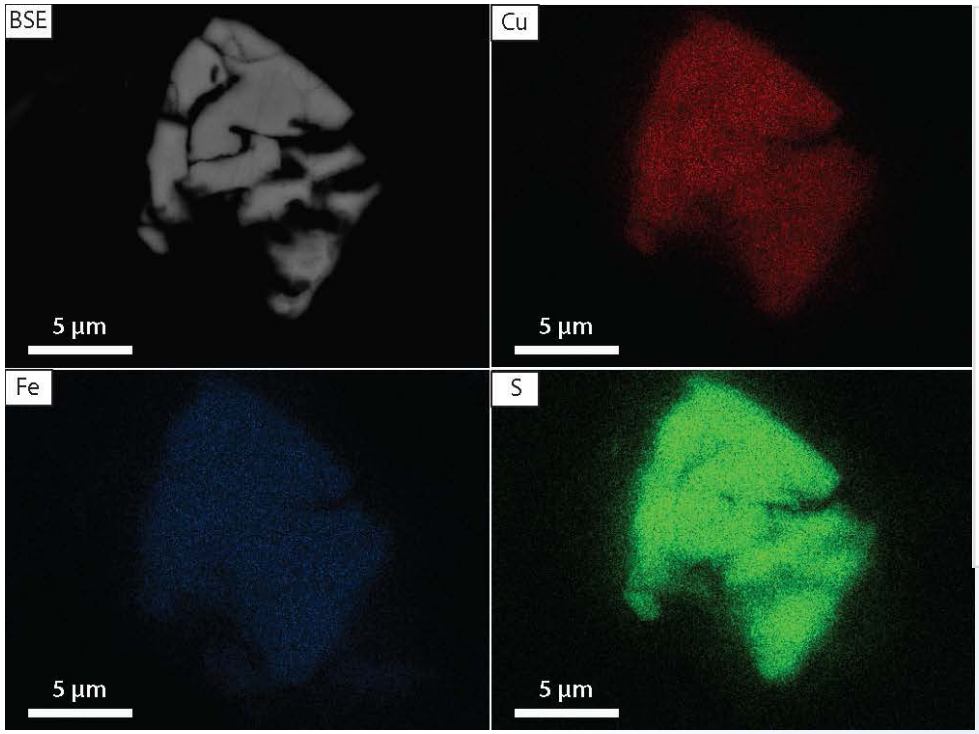
$4Cu_5FeS_4+22H_2O+27O_2 +20Cl^- \leftrightarrow 20CuCl_2\,(aq)+4Fe(OH)_3 + 16SO_4^{2-} +32H^+$

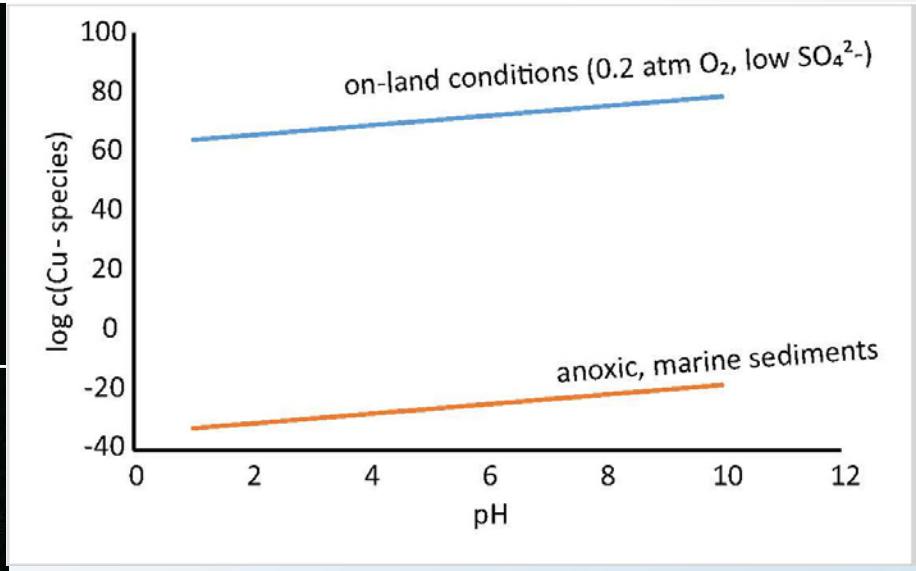
$$K=\frac{[CuCl_2]^{20}[SO_4^{2-}]^{16}[H^+]^{32}}{pO_2^{27}[Cl^-]^{20}}/log$$



IG-15-1-1039-MC-3-4 cm

Bornite Cu_5FeS_4



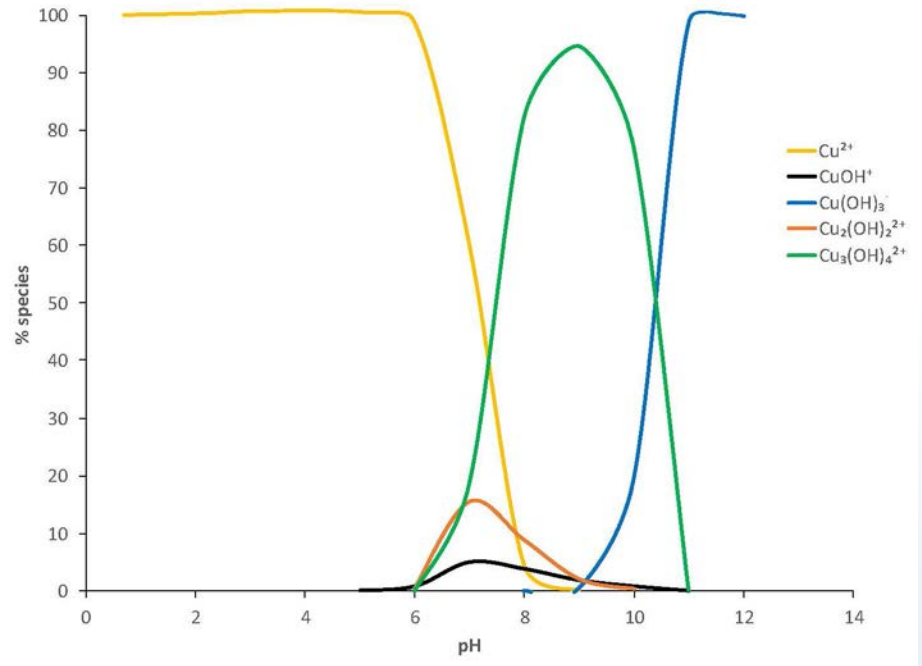


Bornite Cu_5FeS_4

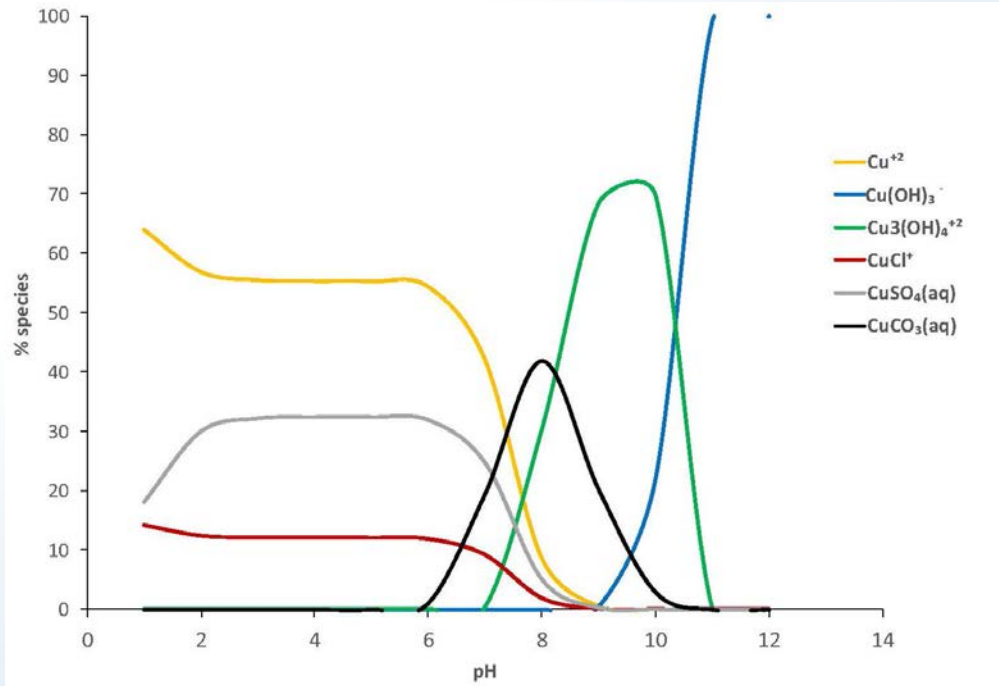
HH-12-004-GC 0-2 cm

Speciation of Cu in sub-sea vs. on-land conditions

Fresh water



Seawater



Conclusion

- The mineralization at Nussir and Ulveryggen deposits is characterized by a high Cu and lo As and Cd).
- The host volca n compatible elements, including Cr an
- The Cu conten
- The main ore m weakly weathered (cha he disposal)
- Thermodynami edox potential/oxygen fugacity is the r lfide minerals deposited in the tailngs
- Dissolved Cu^{2+} th in sea water and fresh water
- Cu-chloride co nificant importance
- At near neutral ffect the solubility of Cu sulphides in the sea water conditions.

Chalcopyrite with Cl in sea water