Results from the flooded Stekenjokk tailings

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Based on papers by

Ljungberg, J., Lindvall, M., Holmström, H. and Öhlander, B. *1997*.

Holmström, H., Ljungberg, J. and Öhlander, B. *1999*.

Holmström, H. and Öhlander, B. *1999*.

Holmström, H., Ljungberg, J. and Öhlander, B. *2000*.

Holmström, H. and Öhlander, B. *2001*.

Eriksson, N., Lindvall, M. and Sandberg, M. *2001*.

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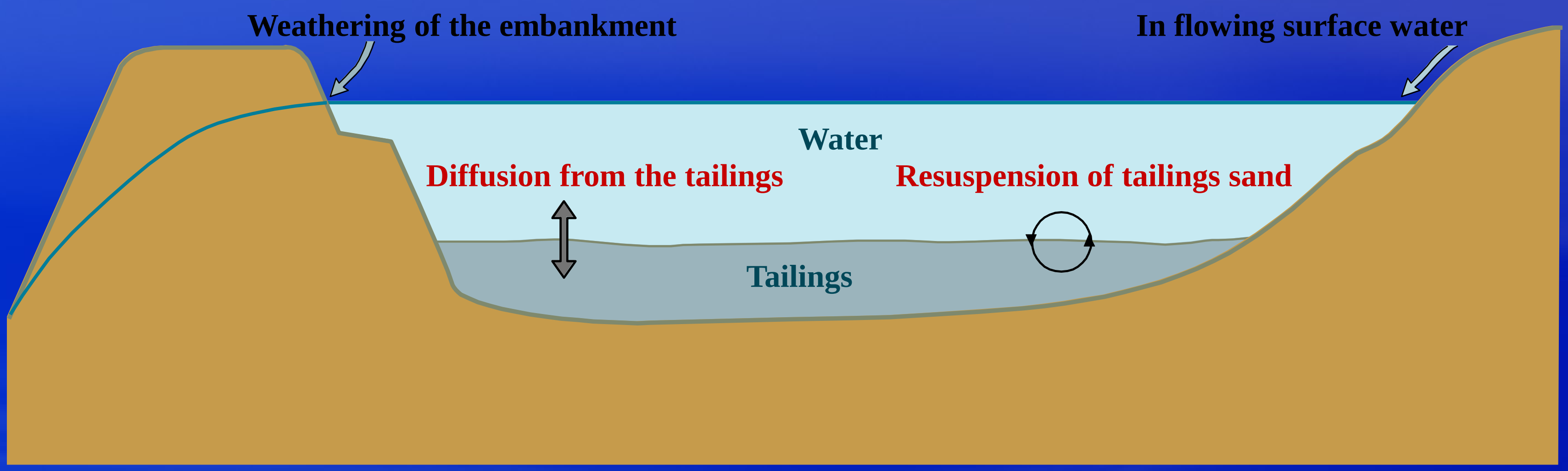

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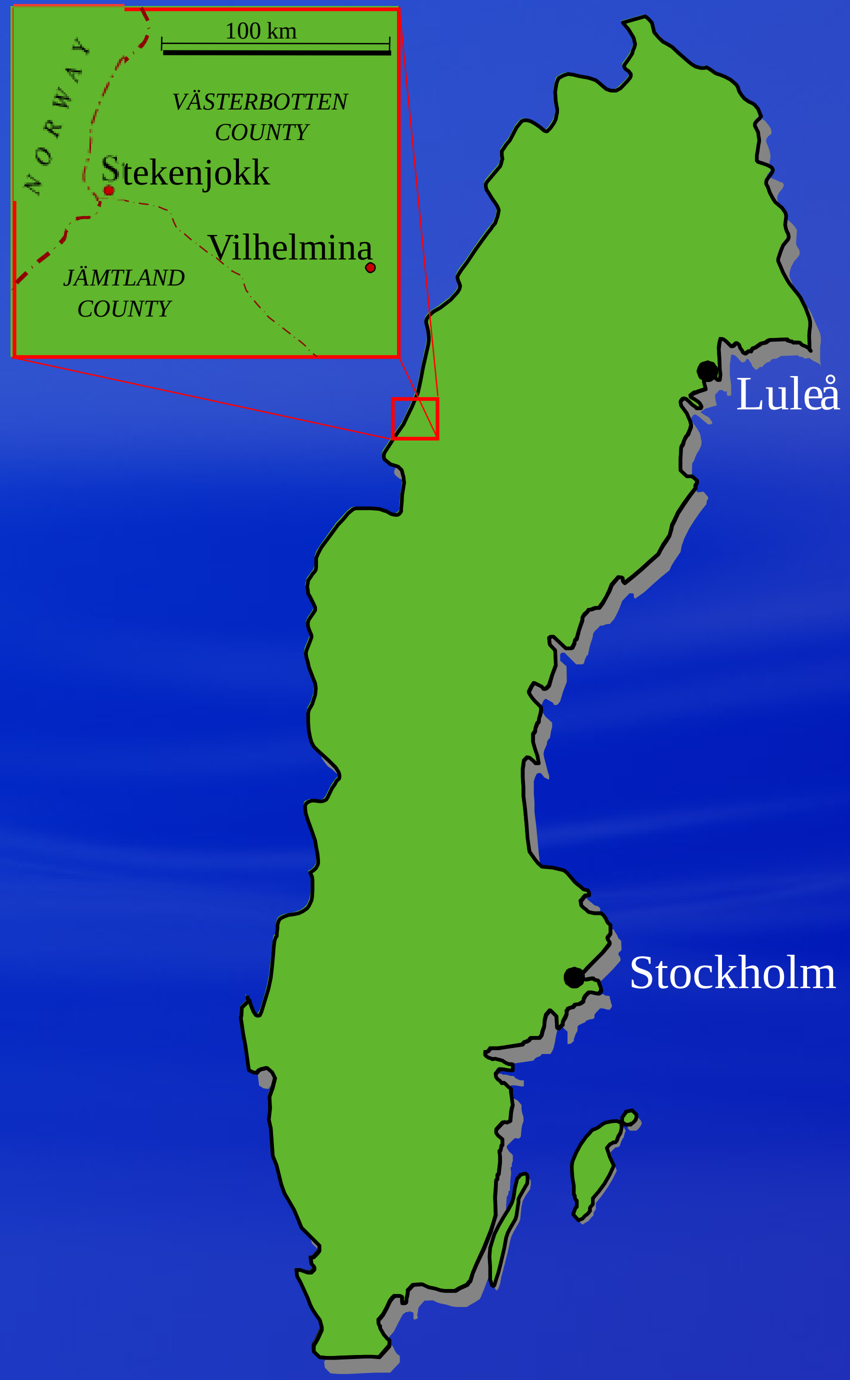
100 km
NORWAY
VÄSTERBOTTEN COUNTY
Stekenjokk
Vilhelmina
JÄMTLAND COUNTY
Luleå
Stockholm

Short facts about Stekenjokk

* Stekenjokk was mined between 1976 and 1988.

* The ore was a stratabound volcanogenic Zn - Cu deposit.

* Main sulfides were pyrite, sphalerite and chalcopyrite.

* Gangue minerals were quartz, feldspar, sericite, chlorite and carbonates.

* Mining left minor waste rocks dumps and 4.4 million tons taillings containing c. 20% sulphur, mainly as pyrite.

* The tailings were flooded in 1991 by raising the existing dykes.

* Water depth in the dam varies between 0.7-7 m.

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MINERALOGICAL COMPOSITION OF TAILINGS

Gangue minerals	***Sulphide minerals***
Quartz	Pyrite
Muscovite	Pyrrholite
Chlorite	Sphalerite
Calcite	Chalcopyrite
	Galena
	Arsenopyrite

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Average chemical composition of tailings

	%		*ppm*
SiO_2	34.8	As	1280
Al_2O_3	5.8	Ba	300
CaO	6.5	Cd	30
Fe_2O_3	27.6	Co	60
K_2O	0.8	Cr	26
MgO	4.8	Cu	1900
MnO	0.09	Mo	48
Na_2O	0.04	Ni	22
P_2O_5	0.2	Pb	1600
TiO_2	0.15	Sr	92
S	17.5	V	160
LOI	17.7	W	10
		Zn	6600

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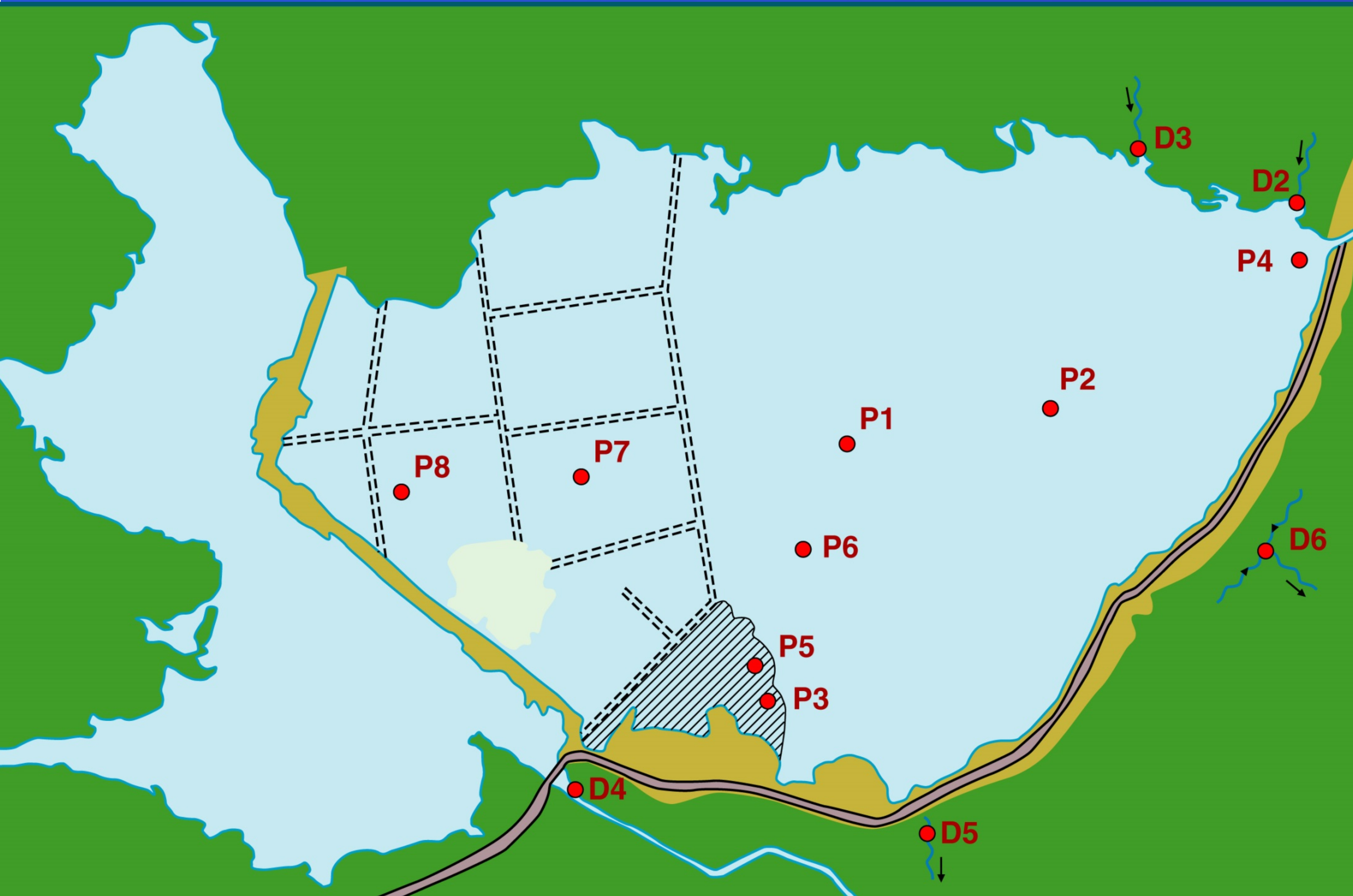

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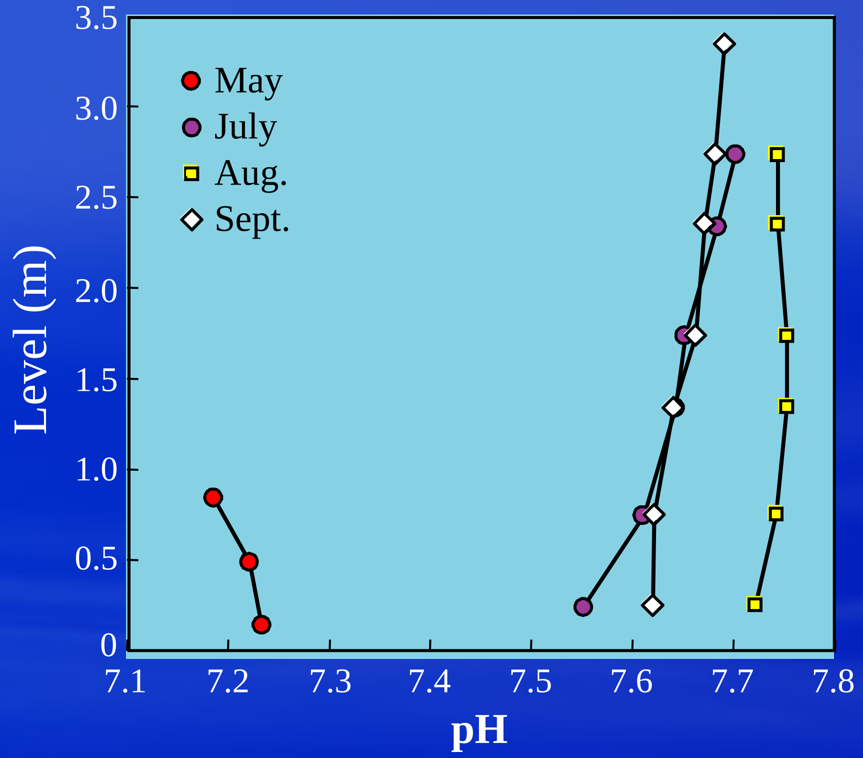
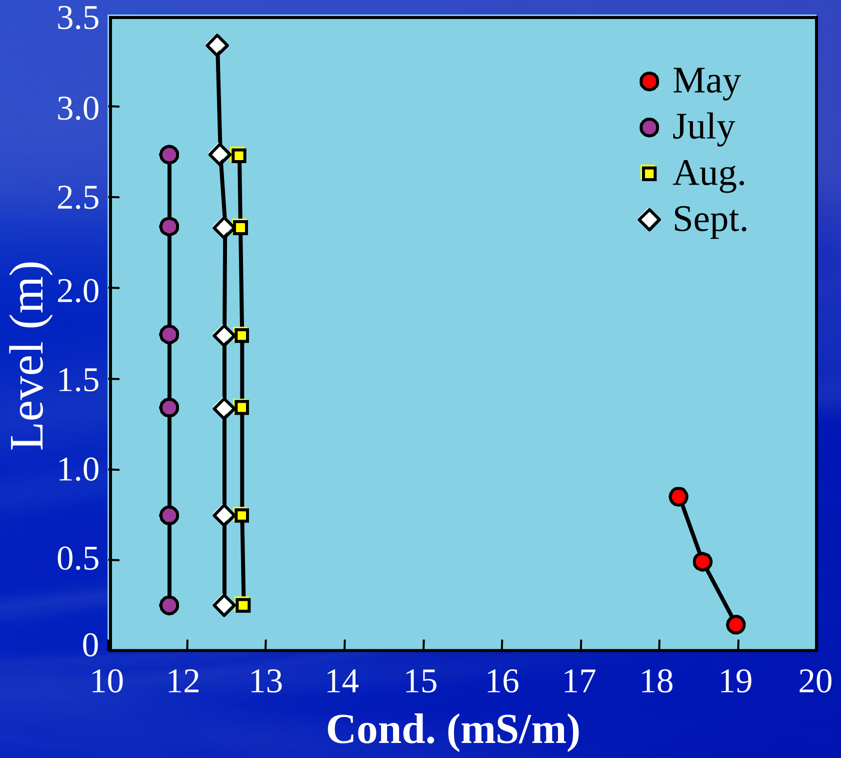
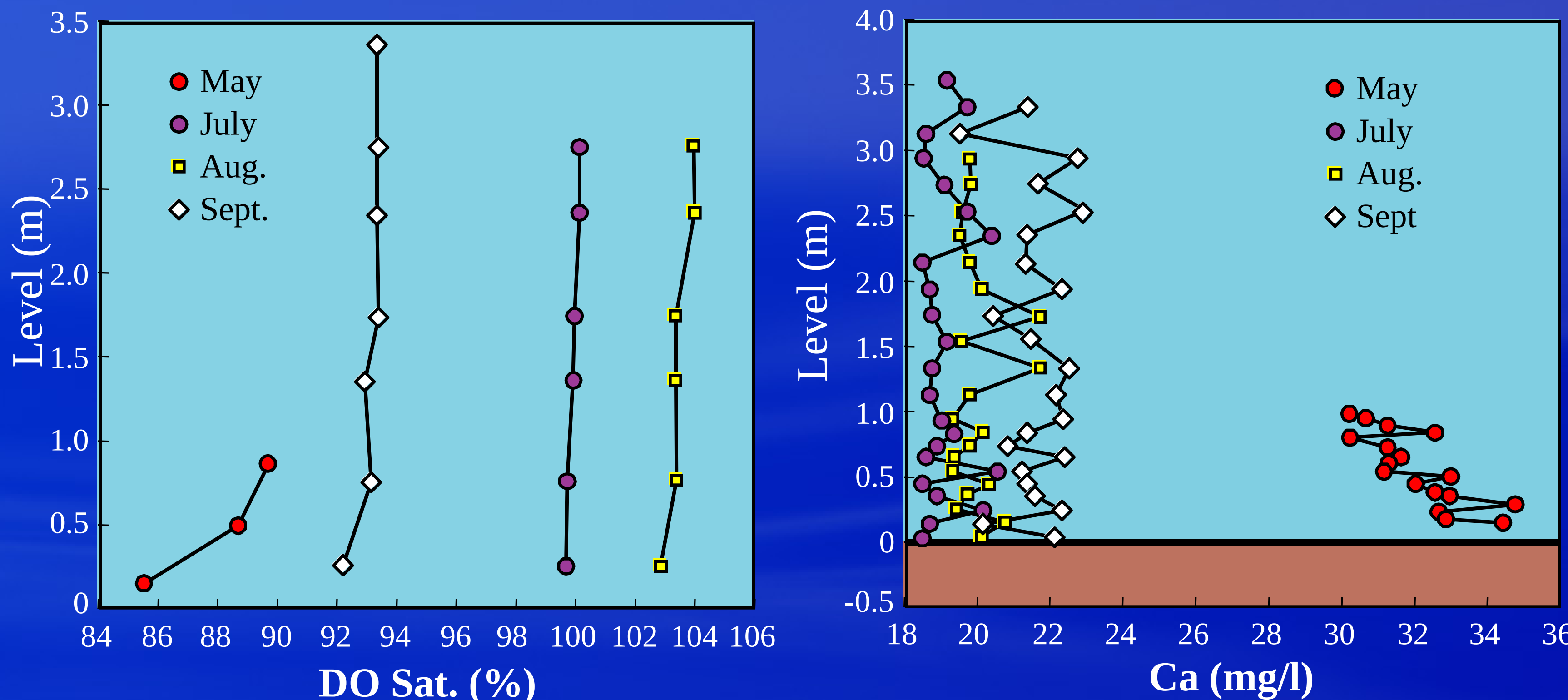


3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
Level (m)
May
July
Aug.
Sept.
7.1 7.2 7.3 7.4 7.5 7.6 7.7 7.8
pH



3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
Level (m)
May
July
Aug.
Sept.
10 12 13 14 15 16 17 18 19 20
Cond. (mS/m)



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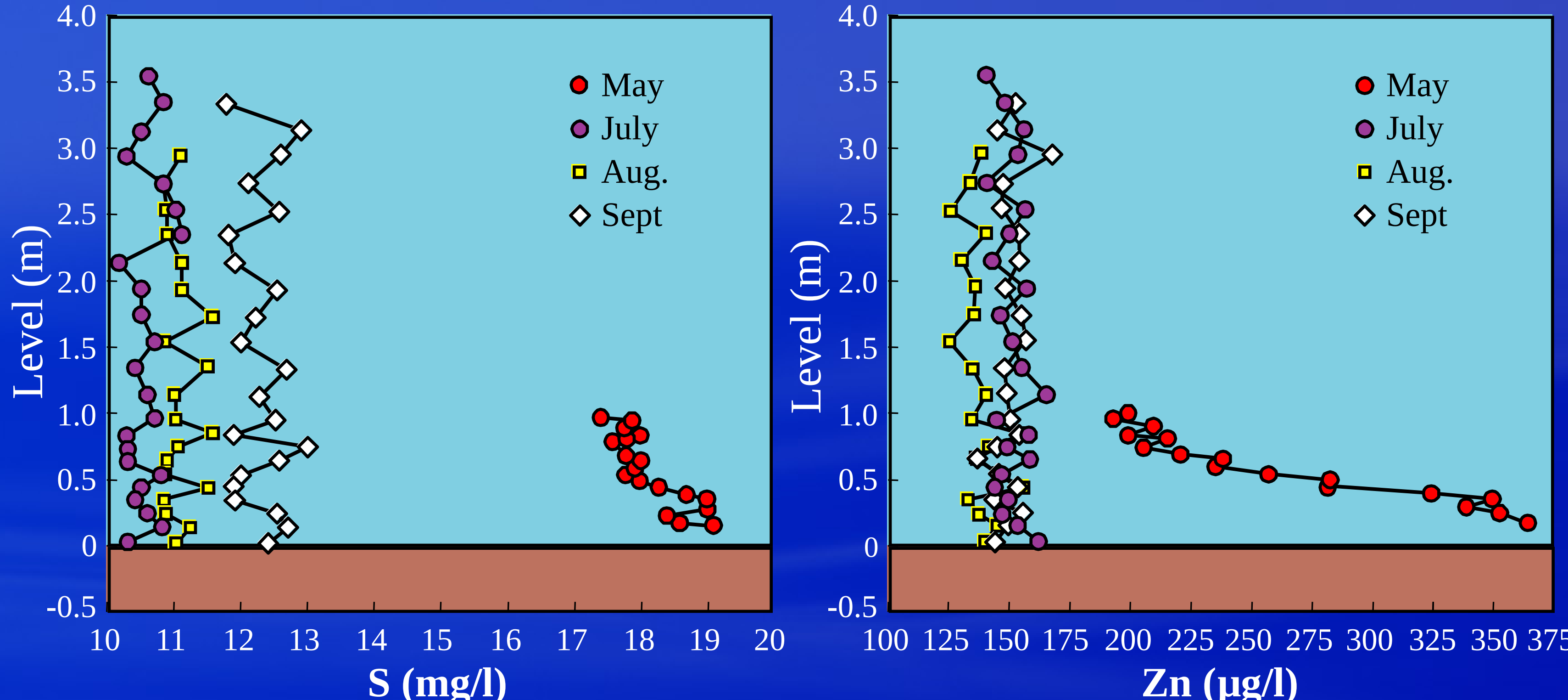

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Average composition of the water column (dissolved phase) during a year(1995).
The background has been sampled in the stream Stekenjokken upstream from the pond.

Element	Winter/Spring (May) 38 samples	Summer (July/August) 107 samples	Autumn (September) 50 samples	Background (September) 1 sample
[mg/l±s.d]				
Ca	32.0±1.2	19.7±1.0	21.8±0.8	6.9
Fe	0.009±0.005	0.042±0.013	0.011±0.004	0.028
K	0.51±0.13	0.58±0.34	0.35±0.09	b.d
Mg	1.12±0.04	0.68±0.06	0.78±0.03	0.46
Na	1.30±0.18	1.00±0.24	0.85±0.10	0.75
S	18.1±0.5	10.9±0.5	12.2±0.4	1.7
Si	0.33±0.14	0.96±3.40	0.26±0.19	0.61
[μg/l±s.d]				
Al	1.04±0.73	3.97±0.68	2.01±0.71	10.30
As	0.44±0.11	0.34±0.09	0.34±0.11	b.d
Ba	2.85±0.13	1.89±0.27	1.99±0.16	1.34
Cd	1.07±0.20	0.69±0.06	0.65±0.06	0.06
Co	0.07±0.03	0.16±0.05	0.13±0.02	0.17
Cu	2.03±0.44	1.71±0.18	1.57±0.20	1.18
Hg	0.25±0.03	b.d	b.d	b.d
Mn	7.9±7.8	24.5±8.9	8.0±1.2	30.4
Ni	2.21±0.24	1.38±0.35	2.17±0.22	0.37
Pb	0.23±0.16	0.18±0.06	0.16±0.06	0.11
Sr	66.6±2.8	43.7±2.3	47.7±1.4	22.0
Zn	268±53	142±15	150±8	13

b.d = below the detection limit.

Distribution range of analysed elements between the dissolved and suspended phase.
A high value indicates that the major part of the element is dissolved and vice versa.

Element	Winter/Spring (May) 5 samples [Diss./(Diss.+Susp.)%]	Summer (August) 7 samples [Diss./(Diss.+Susp.)%]	Autumn (September) 3 samples [Diss./(Diss.+Susp.)%]
[%±s.d[2]]			
Si	92.9±0.0	87.1±0.1	88.1±0.0
Al	24.7±0.1	21.1±0.1	12.2±0.0
Ca	~100	~100	~100
Fe	b.d	40.4±0.1	16.8±0.1
K	99.8±0.0	99.1±0.0	99±0.0
Mg	99.9±0.0	99.5±0.0	99.5±0.0
Mn	26.8±0.1	92.7±0.0	79.4±0.0
Na	99.9±0.0	99.6±0.0	99.8±0.0
As	78.5±0.0	70.4±0.1	79.6[1]
Ba	95.5±0.1	92.4±0.0	95.4±0.0
Cd	92.4±0.0	95.7±0.0	95.7±0.0
Co	64.1±0.1	93.5±0.0	90.1±0.0
Cu	72.7±0.1	69.9±0.0	57.5±0.2
Hg	99.7±0.0	b.d	b.d
Ni	97.3±0.0	96.7±0.0	97.8±0.0
Pb	b.d	35.8±0.04	b.d
Sr	~100	99.9±0.0	99.9±0.0
Zn	97.7±0.0	95.1±0.0	96.5±0.0
S	~100	~100	~100

b.d = The analysis of the dissolved phase was below the detection limit.
1 = Only one value.
2= The standard deviation is very small for most elements and has been rounded off.

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Average composition of the suspended phase in the pond during a year (1995).

Parameter	Winter/Spring (May) 5 samples	Summer (August) 7 samples	Autumn (September) 3 samples	Average composition 15 samples
[mg/l±s.d]				
Suspended load[1]	0.17±0.08	0.28±0.11	0.27±0.10	0.23±0.50
[weight%±s.d]				
Si	9.9±1.6	18.4±2.6	19.1±3.1	15.0±6.1
Al	2.01±0.34	5.06±0.66	6.96±3.04	4.27±2.48
Ca	5.68±0.50	4.51±0.69	4.14±0.97	4.52±1.43
Fe	21.0±3.8	20.5±4.5	17.8±5.1	19.3±6.3
K	0.55±0.47	1.26±0.33	1.35±0.25	1.05±0.50
Mg	0.84±0.15	1.28±0.14	1.59±0.28	1.13±0.43
Mn	8.91±1.63	0.51±0.14	0.80±0.24	2.92±4.04
Na	0.64±0.63	1.34±0.35	0.82±0.25	0.90±0.53
P	0.89±0.14	0.59±0.13	0.63±0.18	0.63±0.21
Ti	0.09±0.03	0.33±0.07	0.40±0.11	0.26±0.16
[ppm±s.d]				
As	724±157	485±120	380±133	545±186
Cd	534±127	122±30	121±40	261±215
Co	173±35	36±10	61±29	87±68
Cu	4682±1014	2895±696	6179±5730	4157±2635
Hg	4.28±1.27	3.46±1.18	3.06±1.30	3.66±1.23
Ni	395±82	170±43	211±110	254±124
Pb	1940±432	1215±338	1330±607	1483±518
Sr	153±28	220±22	170±20	181±57
V	91±39	125±51	120±26	108±51
Y	36±9	52±6	56±14	46±15
Zn	39627±8256	27032±6775	23185±8293	30551±9804
S	39938±7086	37061±8970	34618±11534	37616±8377

[1] The amount of non-organic material (calculated with the ashweight), i.e the actual load including organic material may be several times higher.

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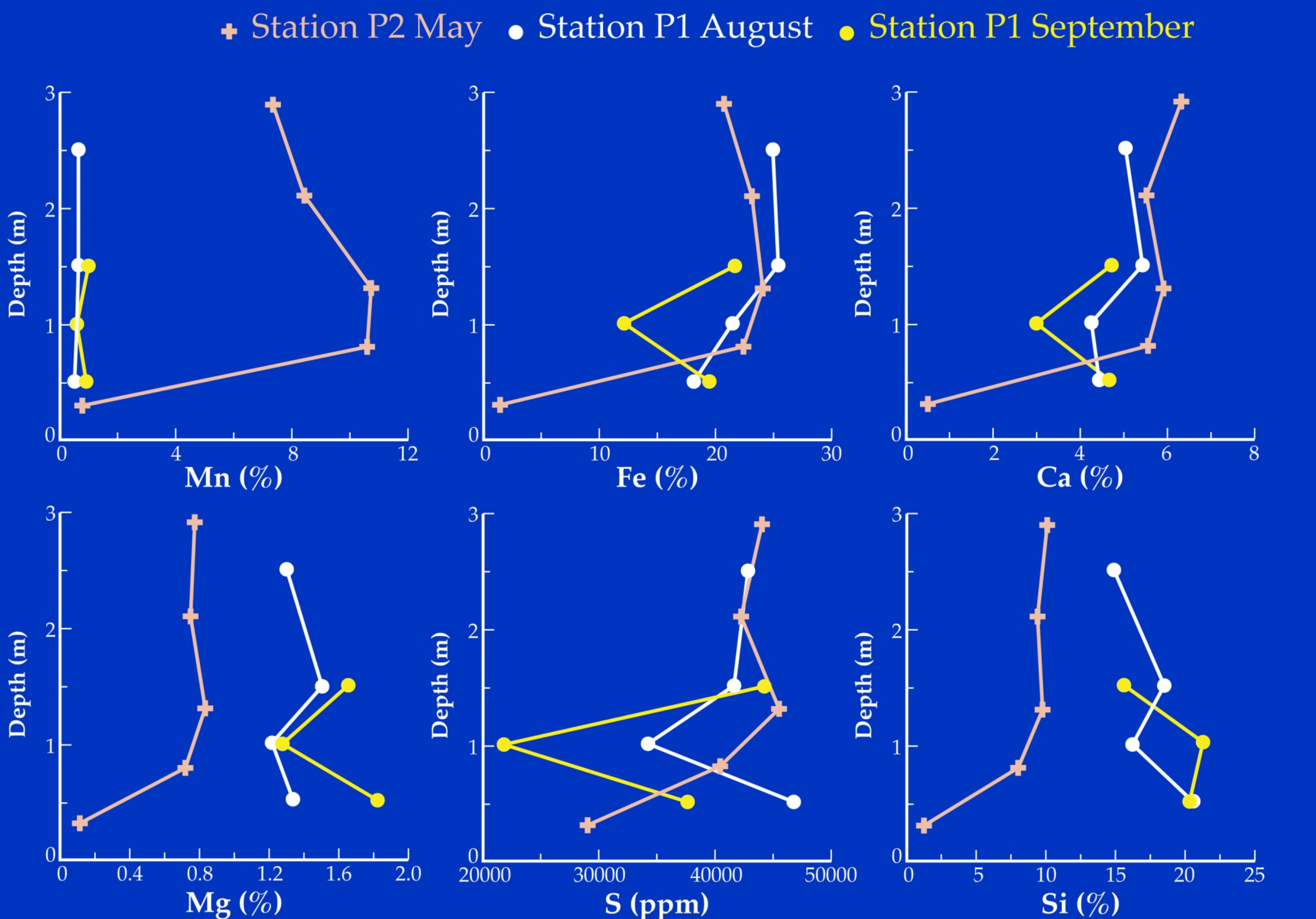
Station P2 May
Station P1 August
Station P1 September
Depth (m)
Mn (%)
Fe (%)
Ca (%)
Mg (%)
S (ppm)
Si (%)
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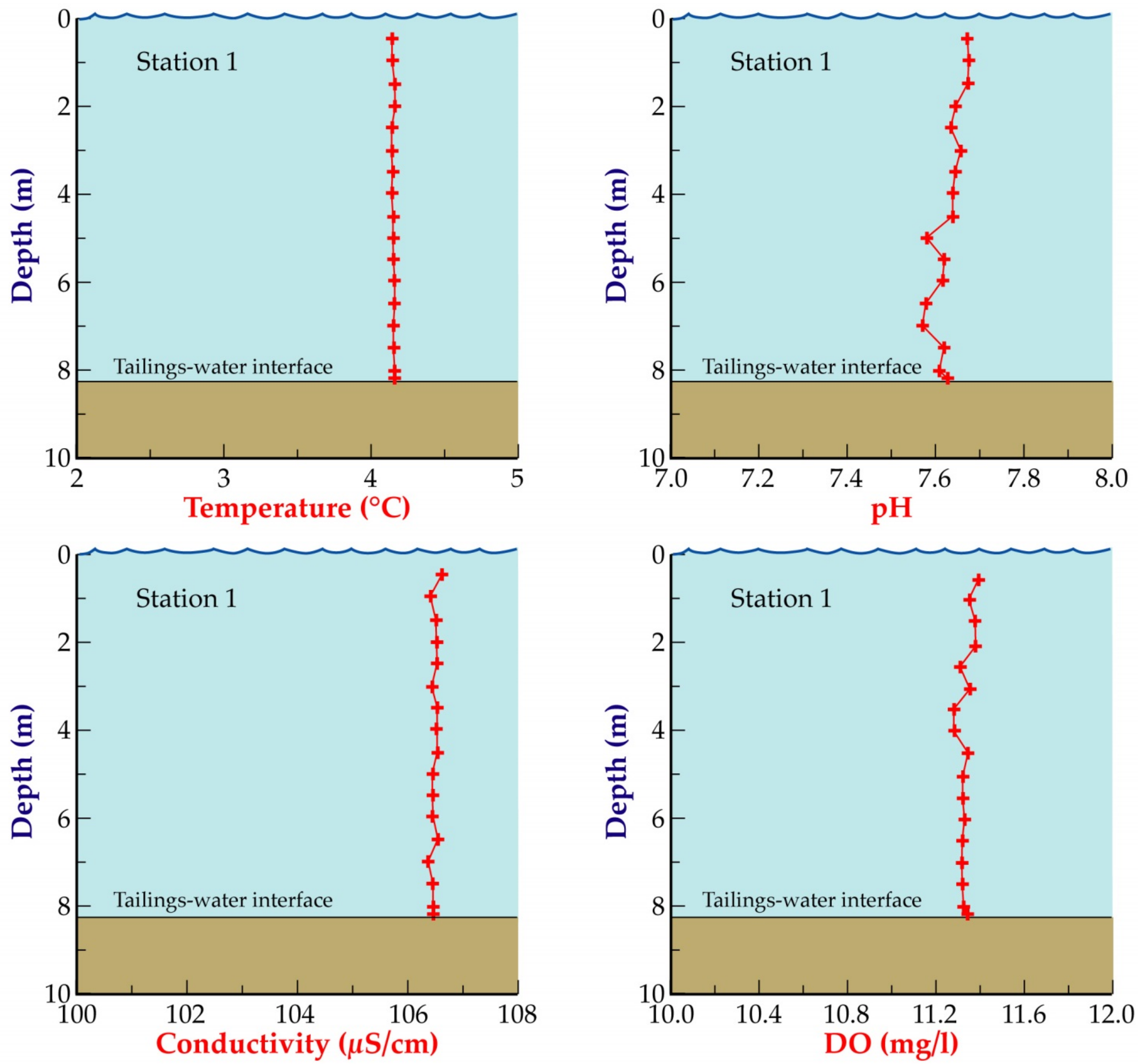
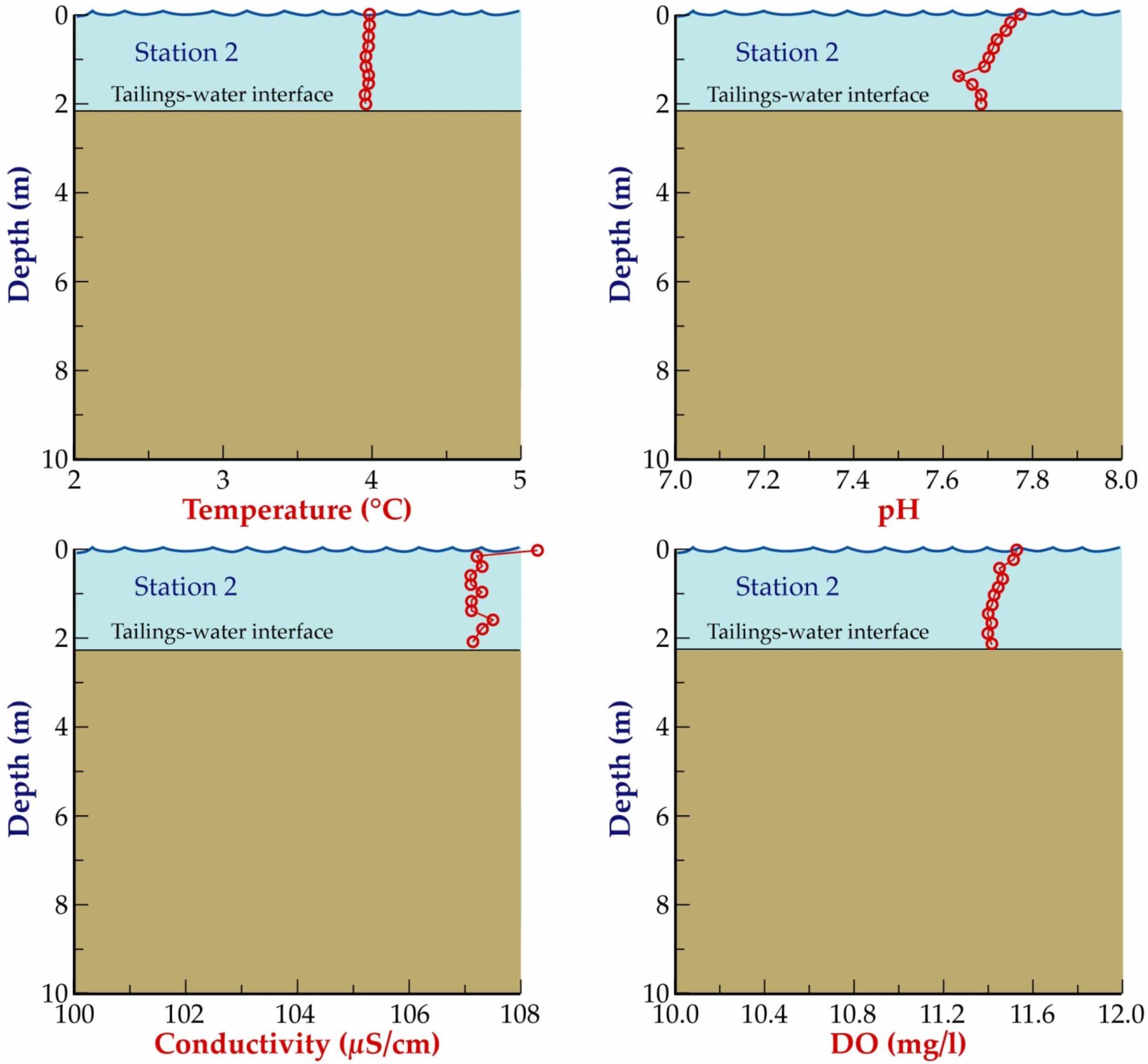
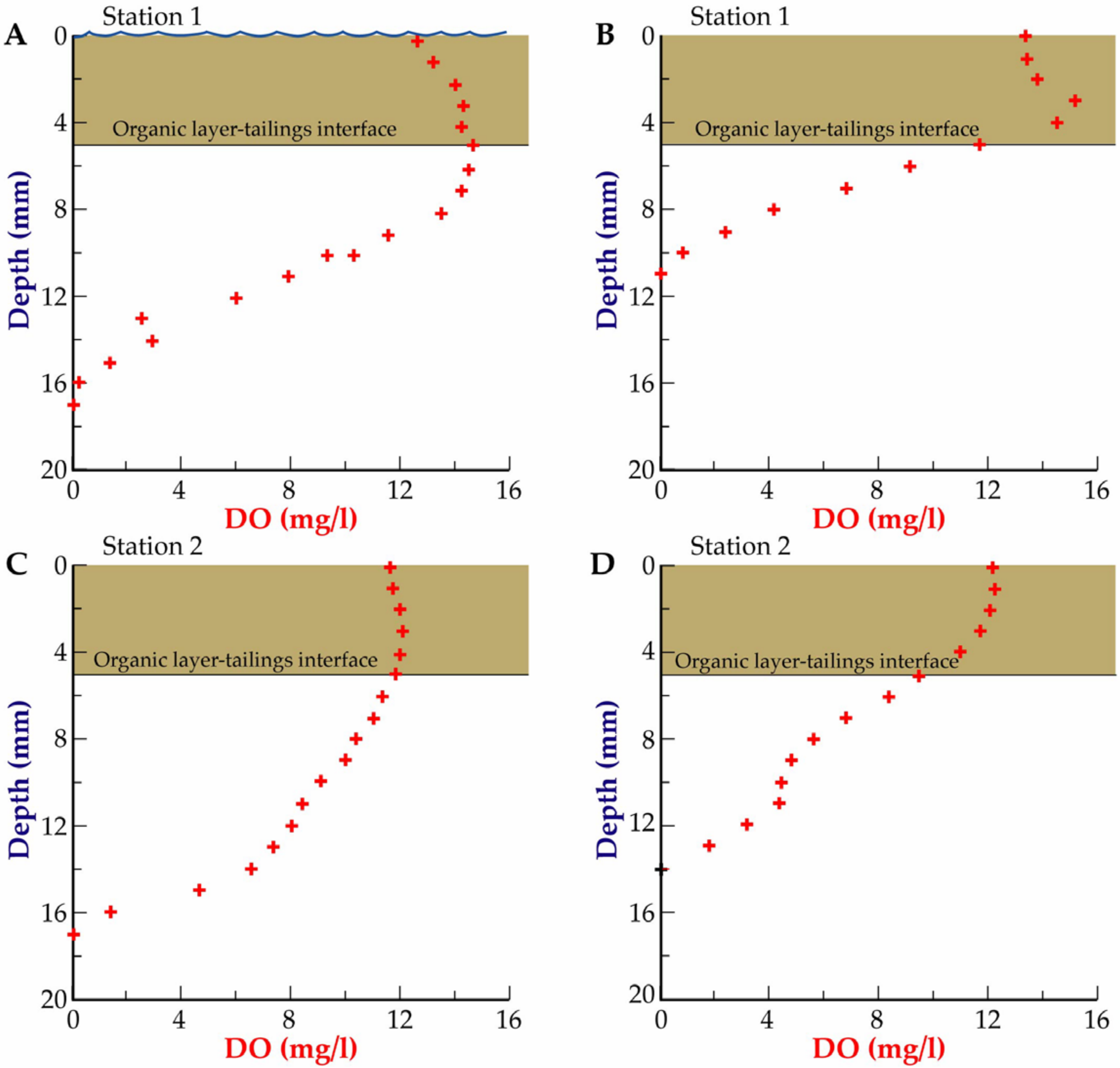
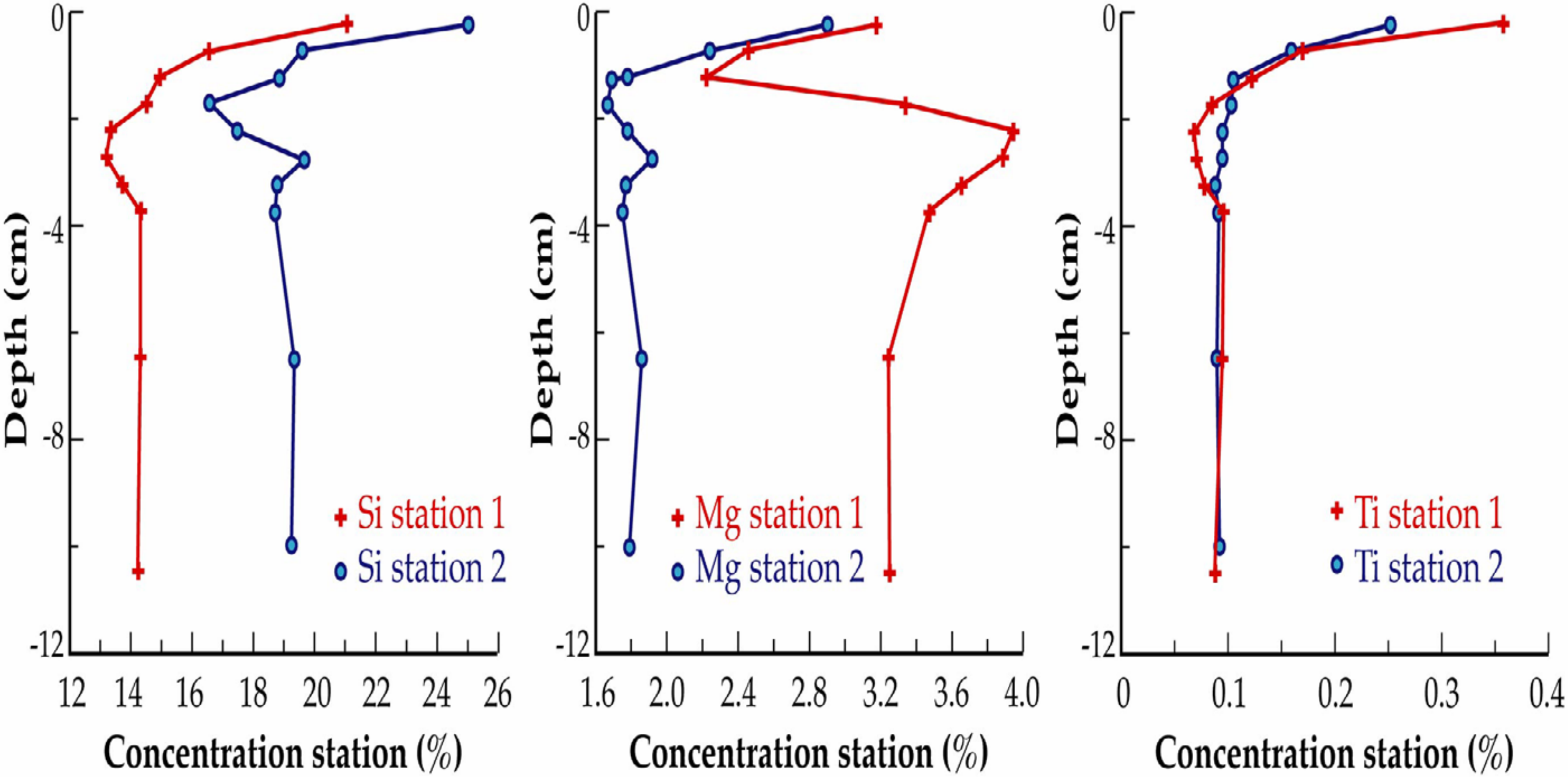
STEKENJOKK
Station 1
Station 2
N


Station 1
Tailings-water interface
Depth (m)
Temperature (°C)
Station 1
Tailings-water interface
Depth (m)
pH
Station 1
Tailings-water interface
Depth (m)
Conductivity (µS/cm)
Station 1
Tailings-water interface
Depth (m)
DO (mg/l)

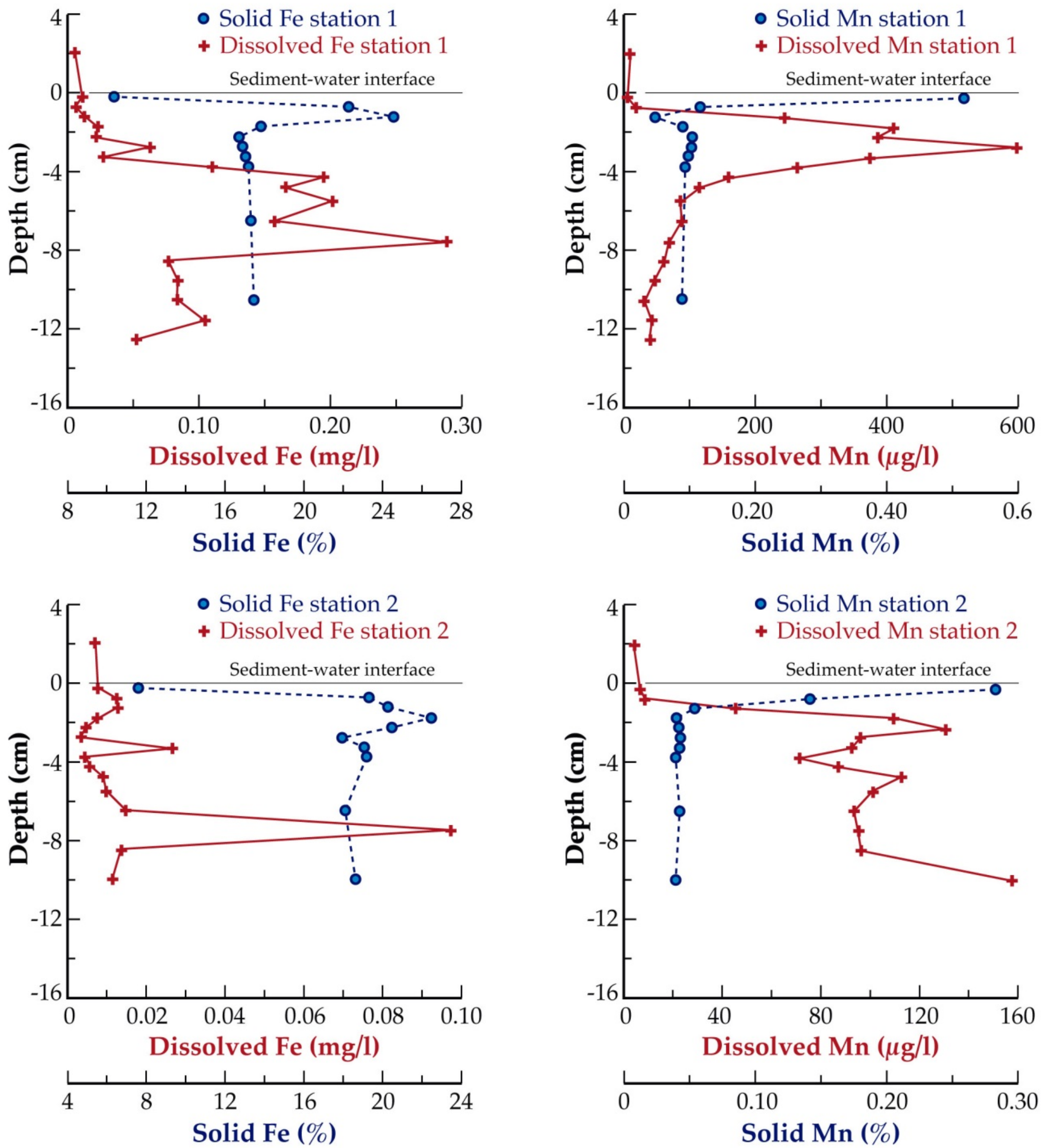

Station 2
Tailings-water interface
Depth (m)
Temperature (°C)
pH
Conductivity (µS/cm)
DO (mg/l)



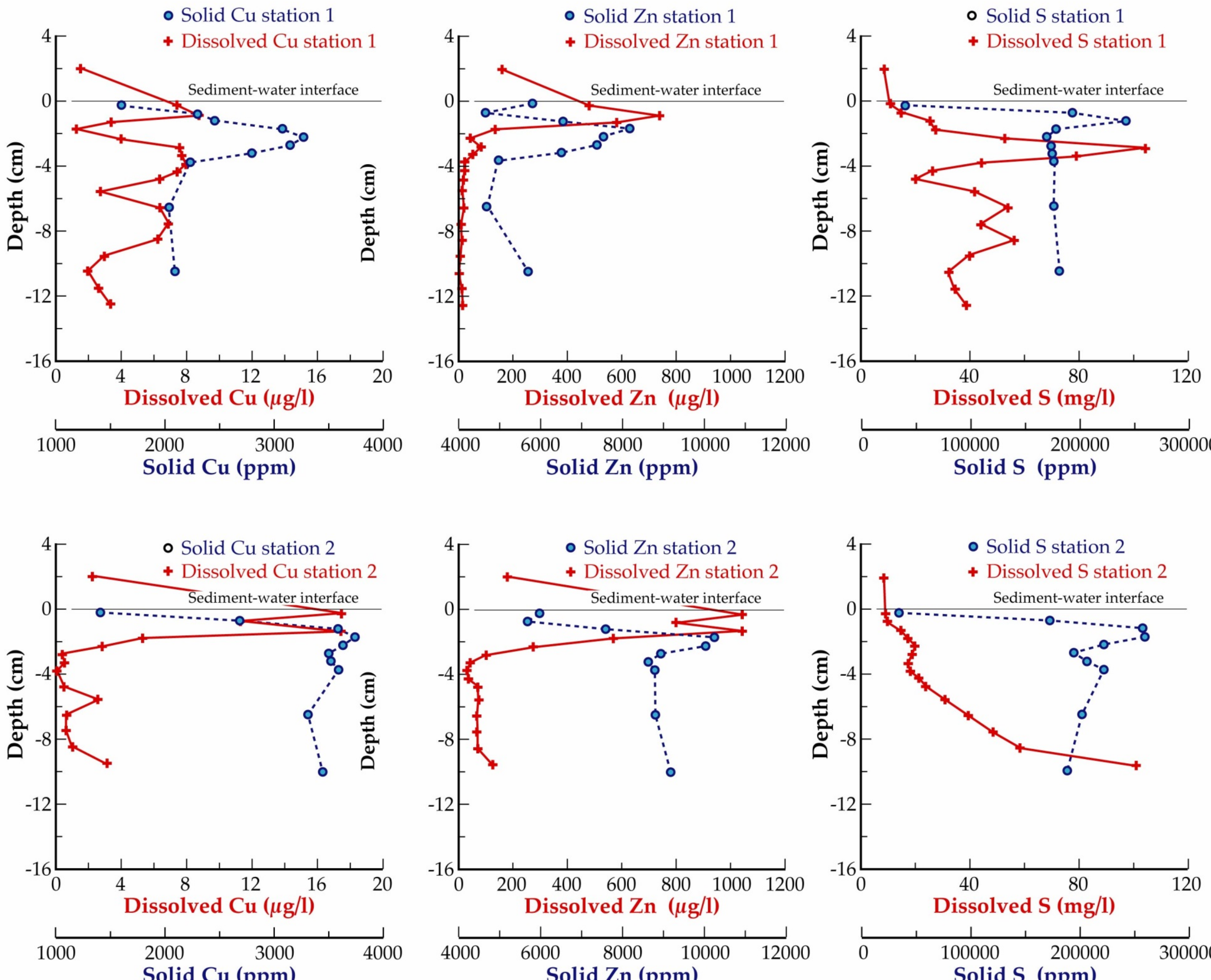
A
Station 1
B
Station 1
C
Station 2
D
Station 2
Organic layer-tailings interface
Depth (mm)
DO (mg/l)

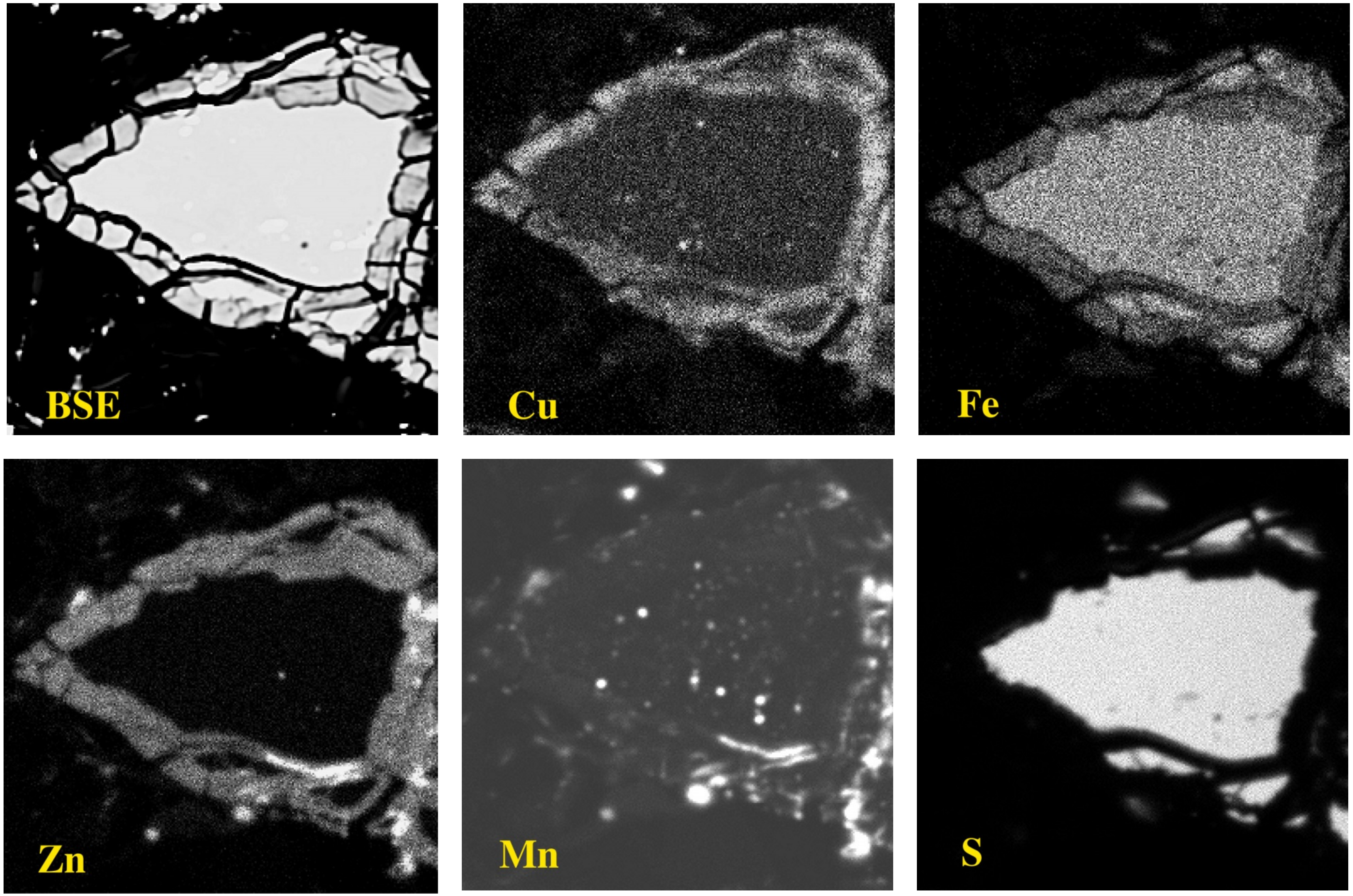


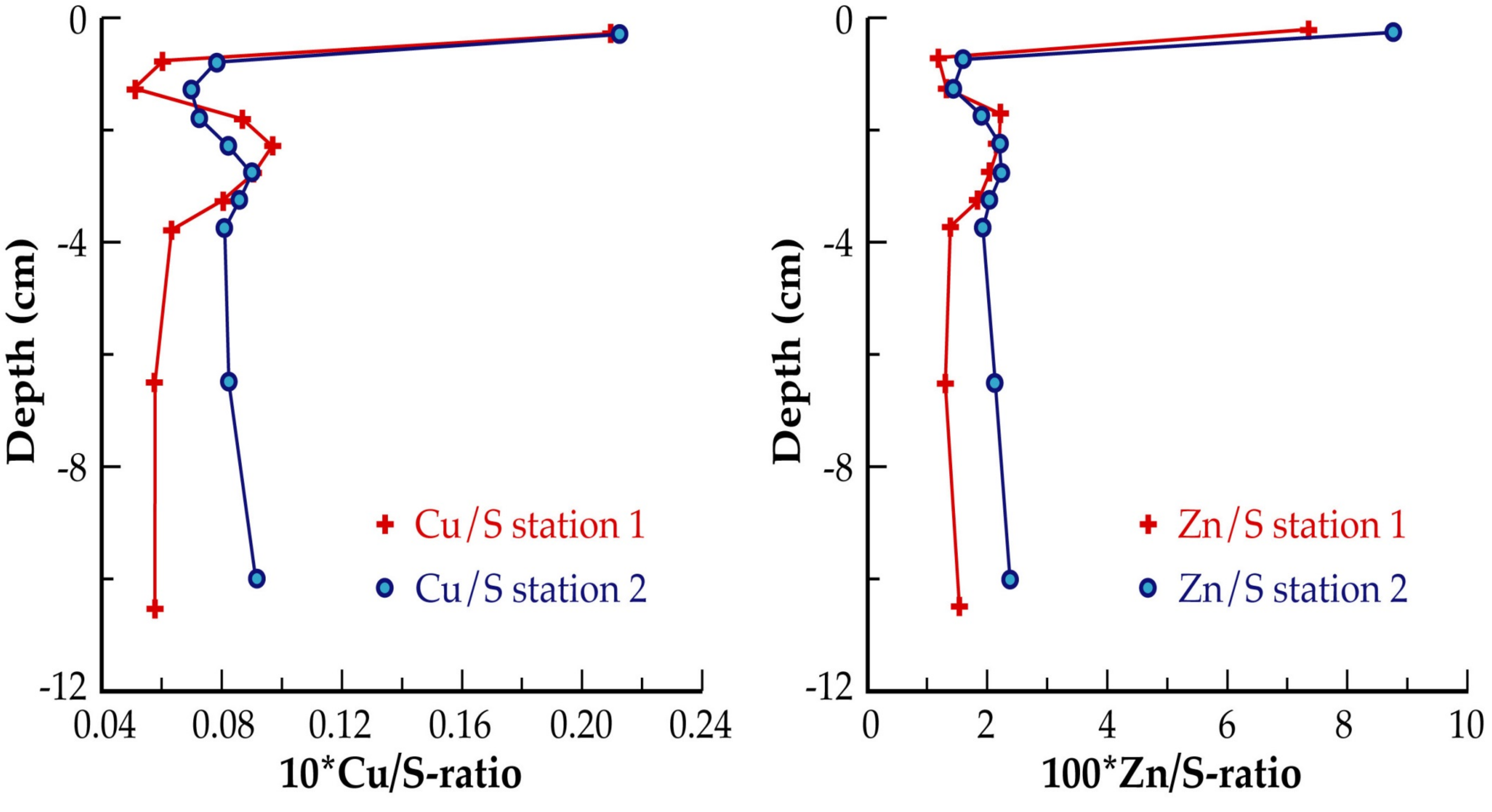
0
-4
-8
-12
Depth (cm)
12
14
16
18
20
22
24
26
Concentration station (%)
Si station 1
Si station 2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
Mg station 1
Mg station 2
0
0.1
0.2
0.3
0.4
Ti station 1
Ti station 2

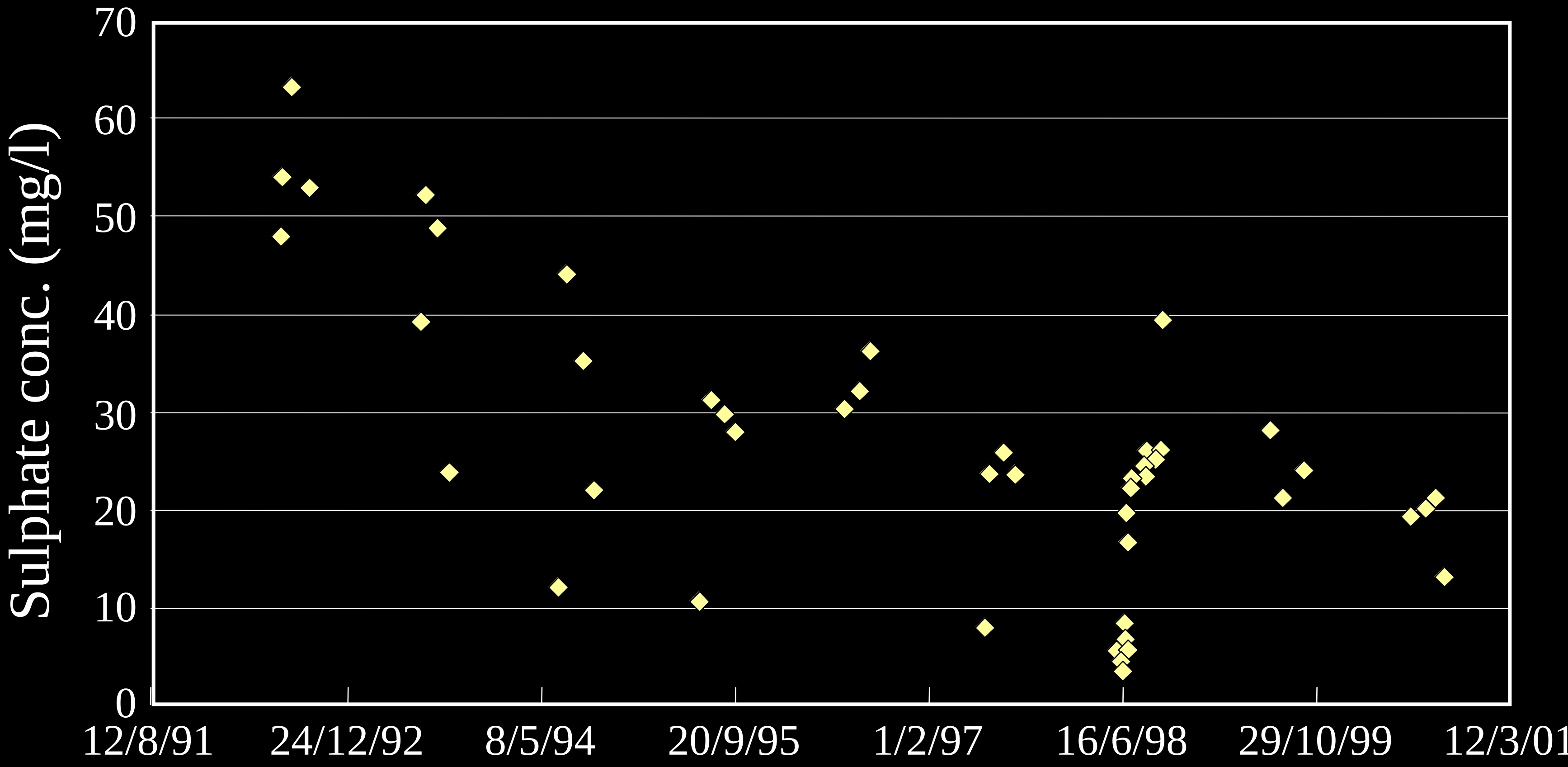


Solid Fe station 1
Dissolved Fe station 1
Sediment-water interface
Depth (cm)
Dissolved Fe (mg/l)
Solid Fe (%)
Solid Mn station 1
Dissolved Mn station 1
Sediment-water interface
Depth (cm)
Dissolved Mn (μg/l)
Solid Mn (%)
Solid Fe station 2
Dissolved Fe station 2
Sediment-water interface
Depth (cm)
Dissolved Fe (mg/l)
Solid Fe (%)
Solid Mn station 2
Dissolved Mn station 2
Sediment-water interface
Depth (cm)
Dissolved Mn (μg/l)
Solid Mn (%)


Solid Cu station 1
Dissolved Cu station 1
Sediment-water interface
Depth (cm)
Dissolved Cu (µg/l)
Solid Cu (ppm)
Solid Zn station 1
Dissolved Zn station 1
Dissolved Zn (µg/l)
Solid Zn (ppm)
Solid S station 1
Dissolved S station 1
Dissolved S (mg/l)
Solid S (ppm)
Solid Cu station 2
Dissolved Cu station 2
Solid Zn station 2
Dissolved Zn station 2
Solid S station 2
Dissolved S station 2


BSE
Cu
Fe
Zn
Mn
S


0
-4
-8
-12
Depth (cm)
0.04
0.08
0.12
0.16
0.20
0.24
10*Cu/S-ratio
Cu/S station 1
Cu/S station 2
0
-4
-8
-12
Depth (cm)
0
2
4
6
8
10
100*Zn/S-ratio
Zn/S station 1
Zn/S station 2


Sulphate conc. (mg/l)
70
60
50
40
30
20
10
0
12/8/91
24/12/92
8/5/94
20/9/95
1/2/97
16/6/98
29/10/99
12/3/01

Based on mass-balance calcuations of sulphateflux in the Stekenjokk tailings pond for the years 1992-2000,

Eriksson et al. (2001) estimated that

the oxygen flux from the water cover to the

tailings is less than $1*10^{-10}$ kg $O_2/m^2/s$

Conclusions

The flooding at Stekenjokk works well. Only minor sulphide oxidation occur in the uppermost parts of the tailings.

The pond water is well mixed and oxic during the ice-free season

Slightly higher metal concentrations occur below the ice during the winter, just above the sediment surface.

Diffusion from pore water is the major source of metals and other elements in the pond water. Previously weathered tailings release metals at a higher rate than unweathered tailings.

Resuspension is minor, and oxidation of resuspended sulphides is not an important metal source to the pond water

There is oxygen available to 16-17 mm depht in the tailings

During the years after the flooding, thin layers rich in Fe- and Mn-oxyhydroxides have formed in the uppermost part of the tailings, and a thin sediment layer rich in organic matter has been developed ontop of the tailings.

In the uppermost part of the tailings, 33-42 % of the As, 73-83 % of the Cd, 59-76 % of the Co, 60-72 % of the Cu, 55-66 % of the Mo, 81-91 % of the Ni, 44-69 % of the Pb and 76-81 % of the Zn are bound to other phases than sulphides, presumably Fe- and Mn-oxyhydroxides and organic material

The layers rich in Fe-and Mn-oxyhydroxides and organic material retain upwards diffusing metals, thereby lowering the amounts reaching the pond water.

The results show that it is possible that a flooded tailings pond may reach a state where the uppermost part of the tailings starts to function as a natural lake where sediments rich in organic matter and Fe- and Mn-oxyhydroxides control the diffusion of metals into the overlying water column, only a few years after remediation. However, it must be emphasised that the Stekenjokk tailings were flooded almost unoxidised and that the carbonate content of the tailings is relatively high.

The flooding at Stekenjokk works well, but if the flooding should be a walk-away solution, then dam stability is probably the weak point.

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