REPORT

Under Oslo

WP1 – RHOMB PORPHYRY - DATA REPORT

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Summary

Samples of rhomb porphyry have been characterized with chemical analyses and different leaching experiments (column, container and standard leaching tests) to study their composition and leaching properties.

Results presented in this report show that rhomb porphyry is a stable rock with low concentrations of sulphur and heavy metals (included uranium and thorium), exhibiting a low risk of leaching high concentrations of metals to the environment when exposed to weathering.

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Review and reference page

1 Introduction

Rhomb porphyry is a magmatic rock with light coloured rhombus feldspar crystals. The rock can be found at multiple locations around the Oslo area. The rhomb porphyry is characterized by the shape of the feldspar crystals and in total 26 different rhomb porphyries are identified in the Oslo field. Different rhomb porphyries might have a varying content of metals, including the radioactive metals uranium and thorium.

2 Characterisation of rhomb porphyry

Rhomb porphyry from Bjønndalen Bruk in Nittedal (Feiring AS) has been used in this study. The rhomb porphyry is considered stable/ unreactive and is used in construction projects.

The rhomb porphyry was characterised with geochemical analyses. Rock samples were analysed for a wide range of heavy metals and elements in a combination designed for identifying black shales. The rock samples were analysed for As, Ba, Be, Cd, Co, Cr, Cu, Hg, Mo, Nb, Ni, Pb, S, Sc, Sn, Sr, V, W, Y, Zn, Zr, Th and U. The combination is called "the alum shale package." The quantity of SiO_2, Al_2O_3, CaO, Fe_2O_3, K_2O, MgO, MnO, Na_2O, P_2O_5, TiO_2 and LOI (loss on ignition) was also estimated. Analyses were performed at the accredited laboratory ALS Laboratory Group AS on ICP-SFMS after the standards ISO 17294-1 and EPA 200.8. Hg was analysed with AFS after ISO 17852. The content of total organic carbon (TOC) and total inorganic carbon (TIC) was determined by colometry, using the standards ISO 10694, EN 13137 and EN 15936.

An alum shale sample from Kleggerud (horizon 2 or 3a) was also included to compare the geochemical properties. We also have included results from a study of a rhomb porphyry from Skoppum stone-crushing plant reported by NGI (2017). This rock was analysed for the elements only and not for the oxides.

The results from the chemical analyses are shown in Table 1. In general, the alum shale has a much higher concentration of metals than the rhomb porphyry. The contents of uranium and the heavy metals cadmium, chrome, copper, nickel and zinc are all ten times higher or more in the alum shale than in the rhomb porphyry. The contents of sulphur and organic matter are 567 mg S/kg and 0.24 % TOC in the rhomb porphyry (Nittedal) and 18 900 mg S/kg and 5.9 % TOC in the alum shale.

The distribution of the different oxides in the rocks are similar. The exceptions are for Na_2O and CaO, where the content is ten and four times higher respectively in the rhomb porphyry (Nittedal) than in the alum shale.

According to NGU the average concentration of uranium and thorium in the earth's crust is 3-4 mg U/kg and 10-12 mg Th/kg. The contents of uranium and thorium found in the rhomb porphyry (Nittedal) and the alum shale are over average, while the rhomb porphyry from Skoppum has a lower content.

Table 1 Chemical concentration in rhomb porphyry and alum shale

ELEMENT		Rhomb porphyry (Nittedal)	Rhomb porphyry (Skoppum)	Alum shale
As	mg/kg	<3	2.6	46
Ba	mg/kg	1000	17	733
Be	mg/kg	6.5	1.8	3.6
Cd	mg/kg	0.080	<0.1	7.0
Co	mg/kg	7.2	3.8	19
Cr	mg/kg	9.5	0.9	89
Cu	mg/kg	6.1	11	94
Hg	mg/kg	<0.02	<0.2	0.0767
Mn	mg/kg	-	809	-
Mo	mg/kg	3.06	<0.4	102
Ni	mg/kg	3.8	<5.0	238
Pb	mg/kg	6.0	2.4	31
S	mg/kg	567	-	18 900
Sc	mg/kg	7.9	-	17
Sn	mg/kg	4.4	-	3.7
Sr	mg/kg	929	108	93
V	mg/kg	64	5.6	1860
W	mg/kg	4.9	-	2.5
Y	mg/kg	44	-	39
Zn	mg/kg	35	73	379
Th	mg/kg	28	3.8	17
U	mg/kg	6.6	1.5	69
TOC	%	0.24	-	5.9
TIC	%	0.625	-	0.269
SiO_2	%	51	-	53
Al_2O_3	%	16.3	-	16.0
CaO	%	4.4	-	1.2
Fe_2O_3	%	6.6	-	5.3
Fe	mg/kg	-	3083	-
K_2O	%	4.6	-	5.1
MgO	%	1.5	-	1.6
MnO	%	0.0991	-	0.0268
Na_2O	%	4.9	-	0.476
P_2O_5	%	0.654	-	0.185
P	mg/kg	-	2190	-
TiO_2	%	1.5	-	0.936
Loss on ignition (LOI)	%	1.1	-	9.1

XRD was performed on the rock samples to identify the mineral composition of the rock. In the rhomb porphyry the main mineral is plagioclase, followed by amorphous material and K-feldspar. The XRD results show that pyrite is not detected in the rhomb porphyry while the alum shale consists of 4.9 % pyrite. The rhomb porphyry contains twice the amount of calcite, indicating a higher buffering capacity.

Table 2 XRD-results (in %)

Mineral	Rhomb porphyry (Nittedal)	Alum shale
Smectite	0.4	ND
Illite/Smectite	ND	ND
Illite + Mica	1.8	49.2
Kaolinite	ND	0.1
Chlorite	8.4	Trace
Quartz	Trace	32.9
K-Feldspar	17.3	6.8
Plagioclase	45.8	4.7
Calcite	2.8	1.4
Dolomite	ND	Trace
Pyrite	ND	4.9
Amorphous	23.4	-

Trace - < 0.5 %, ND – not detected

The data from the geochemical analyses was plotted together with reference materials of different Cambro-Ordovician formations in triangular diagrams, normally used for classifying black shales. The results from the triangular plots are shown in Figure 1. The rhomb porphyry (Nittedal) falls outside the clusters of known reference samples but is closest to horizon 4a.

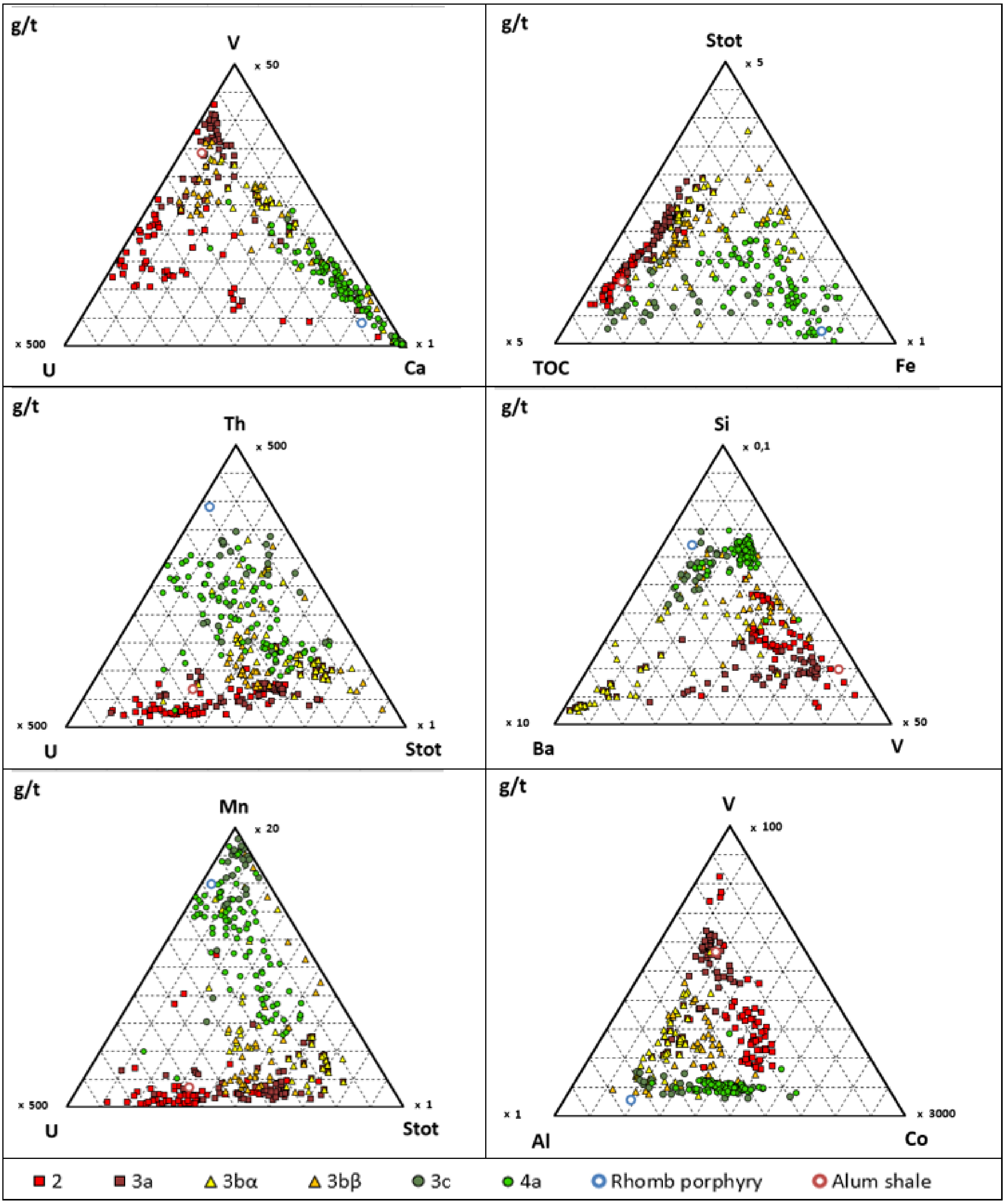


Figure 1 Relative content in rhomb porphyry (Nittedal) and alum shale 2/3a, compared with reference samples from black shales in the Oslo area (2, 3a, 3b, 3c and 4a)

To evaluate the potential acid rock drainage (ARD) from the rhomb porphyry (Nittedal) and the alum shale samples, AP and NP were plotted as seen in Figure 2. The rhombus porphyry has a very low acidification potential and some neutralising potential, and ends up in the neutralizing zone, classified as a rock with a low potential for ARD. The alum shale ends up in the acidification zone and is expected to produce ARD.

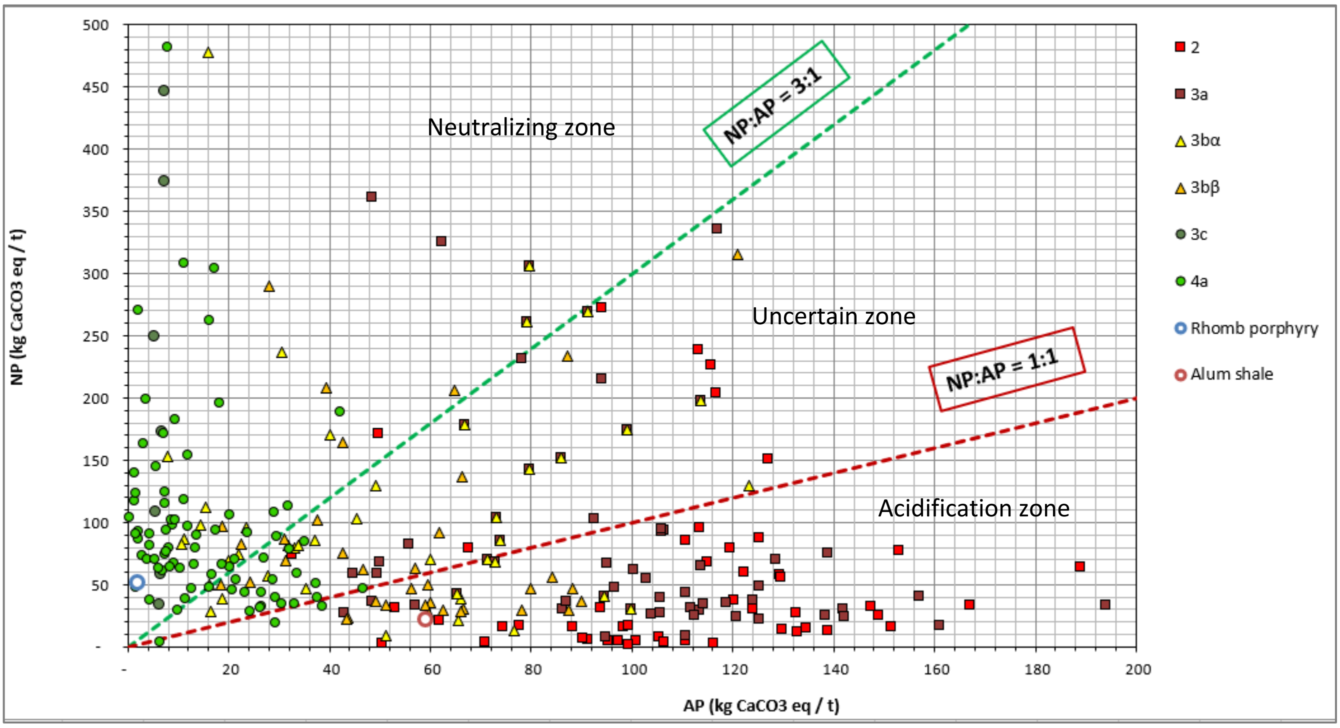


Figure 2 *Acidification potential plotted against neutralizing potential for the alum shale from Kleggerud and Rhombus porphyry from Nittedal, and reference samples (2, 3a, 3bα, 3bβ, 3c and 4a).*

The ratio between iron and sulphur can be used as an indicator if the metals are tied up as sulphides or silicates. If the iron is in surplus compared to sulphur, it indicates that a greater part of the metals in the sample is combined in silicates or oxides. Heavy metals tied in silicates or oxides are less exposed to leaching since these minerals will not be oxidised and therefore are less soluble.

Samples at the line Fe = S 1:1 line in Figure 3 indicate that the metals mainly are combined as sulphide minerals. Samples over the Fe:S = 2:1 line indicate that the metals mainly are combined in silicates and oxides. The rhombus porphyry sample is placed well above the Fe:S = 2:1 line, indicating that iron and other metals mainly are combined as silicate minerals, not as sulphides. This means that the metals are strongly attached and not very mobile and that the rock does not have a considerable potential for liberating metals. The metals in the alum shale, at the other hand, are likely mainly combined as sulphides with an elevated potential for leaching.

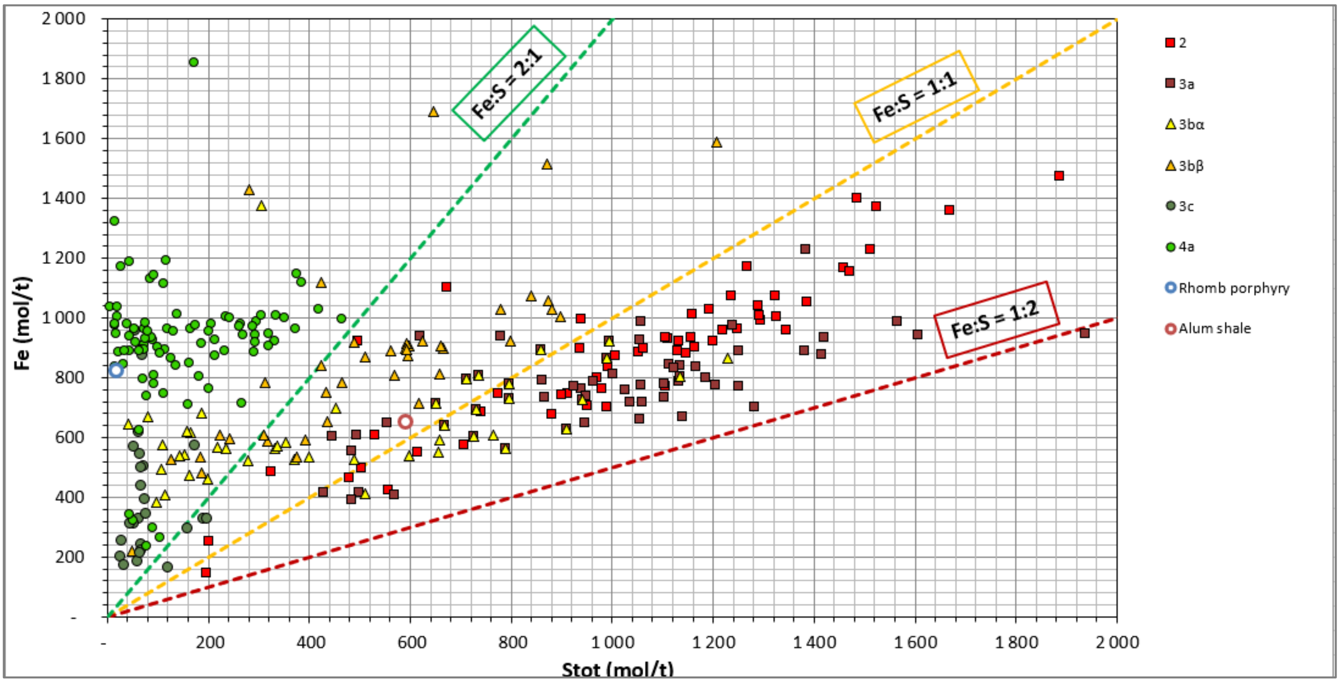


Figure 3 *Total content of sulphur plotted against iron for the alum shale from Kleggerud and Rhombus porphyry from Nittedal, and reference samples (2, 3a, 3bα, 3bβ, 3c and 4a).*

3 Column experiments

Rhomb porphyry (Nittedal) and alum shale were used for column experiments investigating the effect of grain size and mixing ratio on the leaching of metals and pH development. In this report the column with 100 % rhomb porphyry and 100 % alum shale are reported only. For details about the set-up of the column experiments and results for the mixed columns, see NGI (2021).

Four kg rhomb porphyry with grain size distribution 0-20 mm was built into a column. The inner diameter of the column was 10 cm and the hight of the masses was 31.5 cm. The same was done with 4 kg alum shale with grain size distribution 0-20 mm and the hight of the masses in this column was 35 cm. See Figure 4 for picture of the experimental set-up.

The columns were watered manually with 500 mL distilled water five days a week for eight weeks (55 days) and sporadically thereafter for a total of 365 days. At every day with watering, pH, conductivity and redox potential were measured in the eluates.

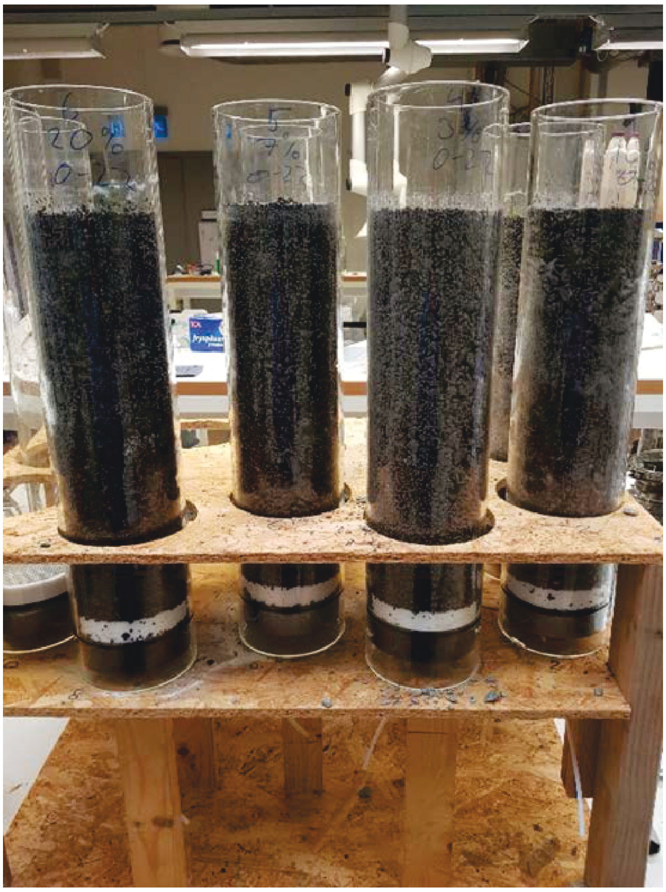
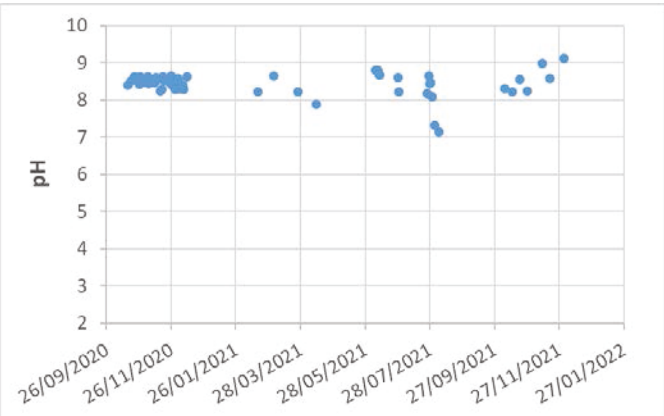


Figure 4 *Experimental set-up of the column experiments in NGI's laboratory*

The eluates from the column with 100 % rhomb porphyry show a pH value between 7 and 9 during the first year. There is no sign of acid rock drainage and the pH was fairly stable. The conductivity was also low and stable (< 233 µS/cm), see Figure 5.



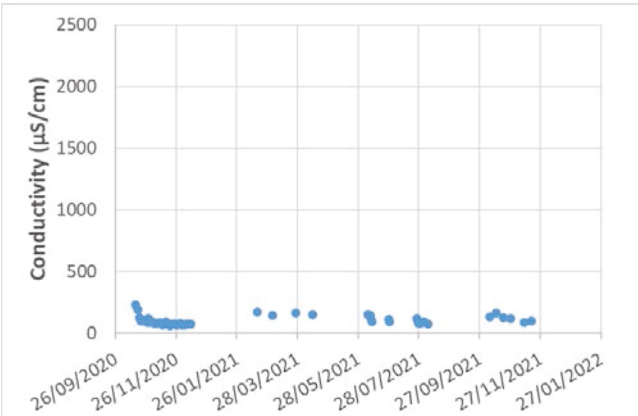


Figure 5 *Development of pH and conductivity with time for eluates from column with 100 % rhomb porphyry (grain size distribution of 0-22 mm).*

The eluates from the column with 100 % alum shale show a gradual decrease in pH from around 8 in the beginning to around 7 after 55 days and down to 4 after a year. The conductivity is increasing from around 300 µS/cm from the start to 847 µS/cm after 40 days and 2070 µS/cm after a year (Figure 6).

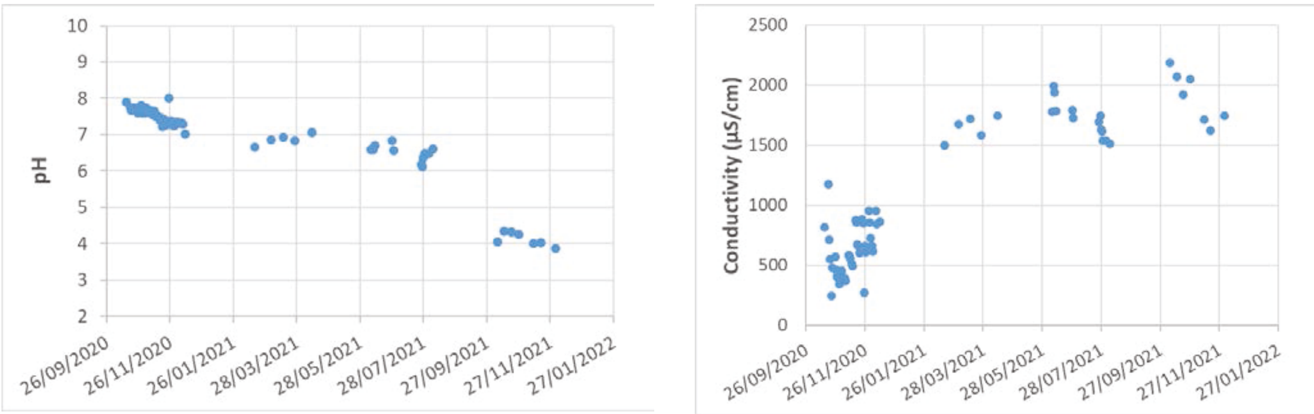


Figure 6 *Development of pH and conductivity with time for eluates from columns with 100 % alum shale (grain size distribution of 0-22 mm).*

The difference between the pH and conductivity in the eluates from the two columns are striking. The rhomb porphyry has a stable and high pH and a stable and low conductivity, while the alum shale has a decreasing pH and an increasing, high conductivity.

At day 40 and 365 of the column experiment eluates were sent to chemical analyses and results are presented in Table 3.

The concentrations of elements and compounds are low in both eluates from the rhomb porphyry but seems to be a little higher in average after a year. In the alum shale eluate, at the other hand, there is a significant increase with time for most of the metals and compounds in the eluates.

The contents of uranium, sulphate and sulphur have increased in eluates from both rocks after a year, but the concentrations in the alum shale eluates are at a much higher level, see Figure 7. The concentrations of the metals nickel, zinc, cadmium, copper and cobalt are also increasing in the alum shale eluates and are present at a much higher level than in the rhomb porphyry eluates (Figure 8 and Figure 9).

A decrease in concentrations is measured for Th and the N-components NO_3 and NO_2 in both columns.

Table 3 Results chemical analyses of eluates from columns at day 40 and 365

	Unit	Rhomb porphyry (Nittedal)		Alum shale	
Element/ compound	**Day**	**40**	**365**	**40**	**365**
Al	µg/l	111	64	0.206	1070
Alkalinity pH 4.5	mmol/l	0.71	0.72	1.5	<0.05
NH4+	mg/l	<0.004	0.052	0.062	0.0072
As	µg/l	0.184	0.243	0.197	<0.2
Ba	µg/l	12.3	12.9	20.5	12.2
Ca	mg/l	13.9	20.2	159	395
Cd	µg/l	0.039	<0.03	3.97	505
Co	µg/l	<0.005	0.0104	5.29	461
Conductivity	mS/m	9.3	-	74	-
Cr	µg/l	0.269	0.424	<0.01	<0.05
Cu	µg/l	<0.1	0.679	<0.1	280
Fe	mg/l	<0.0004	0.00264	<0.0004	0.0555
Fluoride	mg/l	0.46	0.62	0.064	0.17
Hg	µg/l	<0.002	<0.002	<0.002	<0.002
K	mg/l	1.55	1.46	9.44	13.2
Chloride	mg/l	1.3	2.0	0.9	<1
Mg	mg/l	0.811	1.04	22.5	63
Mn	µg/l	4.21	12.2	388	5170
Mo	µg/l	32	92	319	0.64
Na	mg/l	0.838	0.985	0.862	1.55
Ni	µg/l	<0.05	0.374	960	10 500
Nitrate	mg/l	0.19	0.14	0.089	<0.10
Nitrite	mg/l	0.003	<0.001	0.1	0.001
P	µg/l	<1	<1	<1	<5
Pb	µg/l	<0.01	<0.01	<0.01	14.8
pH		7.5	-	7.9	-
S	mg/l	1.65	8.45	141	465
Si	mg/l	1.85	2.63	1.27	5.84
Sr	µg/l	173	219	1120	3190
Sulphate	mg/l	4.9	26	320	1300
Suspended matter	mg/l	16	-	3.3	-
Th	µg/l	0.055	<0.02	0.074	<0.02
TOC	mg/l	0.32	1.4	0.57	1.8
U	µg/l	1.27	2.44	75	410
V	µg/l	2.15	2.72	0.0131	0.0334
Zn	µg/l	0.949	0.274	300	20 600

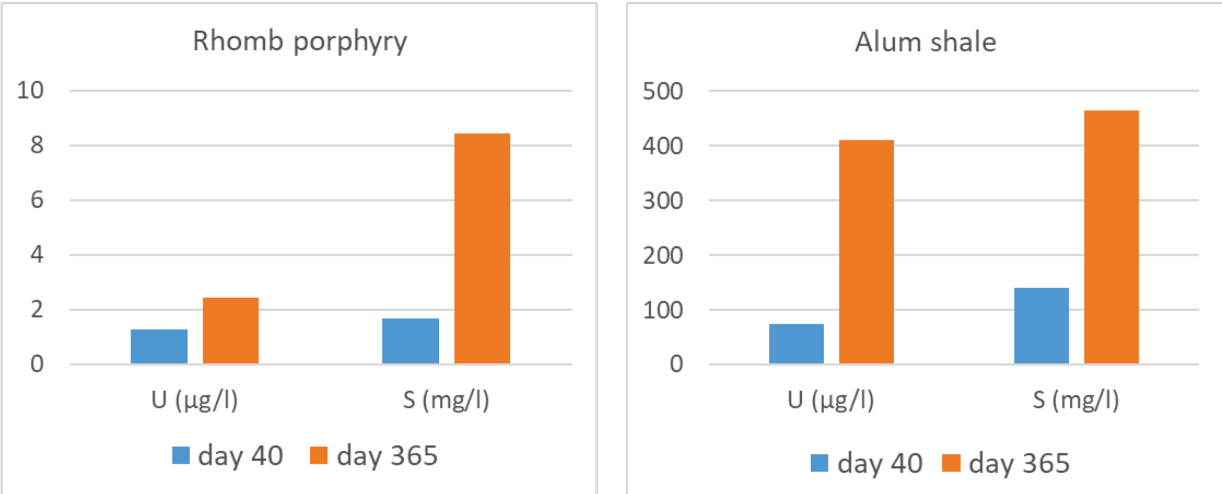


Figure 7 Concentration of uranium and sulphur in eluates from columns after 40 and 365 days.

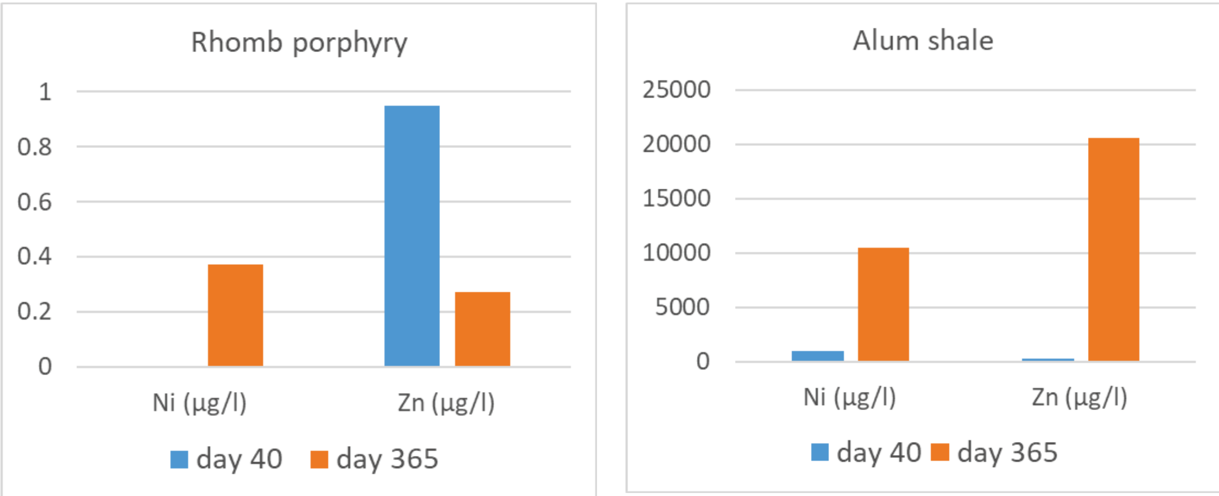


Figure 8 Concentration of nickel and zinc in eluates from columns after 40 and 365 days.

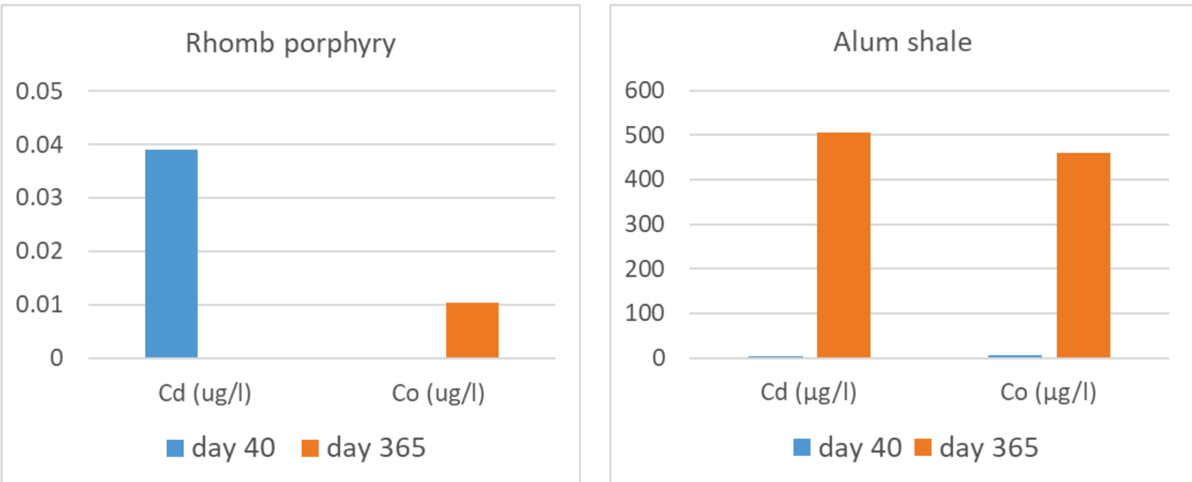


Figure 9 Concentration of cadmium and cobalt in eluates from columns after 40 and 365 days.

4 Container experiments

Container experiments were set up outside NGI with the intention of simulating rainwater percolating through rhomb porphyry (Nittedal) and alum shale masses. The rock masses were stored in an IBC container cut open for rain to pass through. The resulting leachate was analysed at the sampling times shown in Table 4 to investigate leaching of different compounds from the rocks. Results from the first year are presented here. A photo of the set-up of the container experiments is given in Figure 10, and in Figure 11 the containers with rhomb porphyry (Nittedal) and alum shale are shown.

Table 4 Experimental set-up at NGI with rhomb porphyry (Nittedal) and alum shale

Content	Repli-cates	Water addition	Start date	Sampling times full water analysis	Sampling times pH, temperature, conductivity, redox
200 L Rhomb porphyry (Nittedal)	2	Rain	21.10. 2020	1 day, 2, 4, 8 weeks, 6 months, 1 year	The first 8 weeks: weekly Later: Monthly
200 L Alum shale	2	Rain	21.10. 2020	1 day, 2, 4, 8 weeks, 6 months, 1 year	The first 8 weeks: weekly Later: Monthly

Figure 10 Set-up of container experiment at NGI.

Figure 11 Content of container with 100 % rhomb porphyry to the left and alum shale to the right

Field measurements of pH and conductivity in the eluates from the first year are presented in Figure 12. For both types of masses the pH has not declined during the first year of measurements and is between 7 and 8.5. The conductivity in the rhomb porphyry eluates is low and stable throughout the year, but the alum shale eluate has increasing values after about six months.

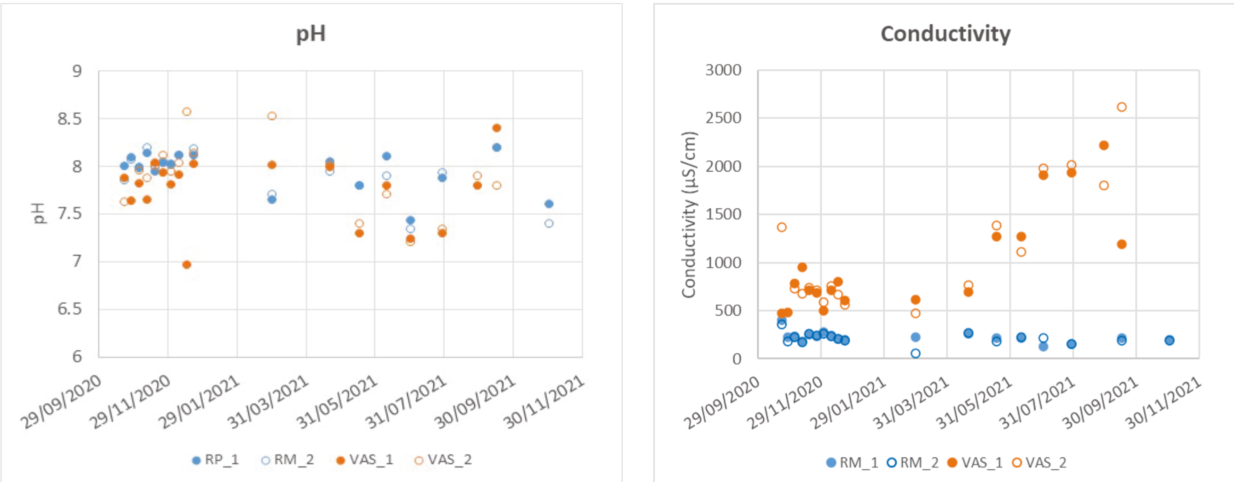


Figure 12 pH and conductivity in the containers with rhomb porphyry (RM_1 and RM_2) and alum shale (VAS_1 and VAS_2) (field measurements).

Results from the analyses performed on the eluates after 1 and 12 months are presented in Table 5. There is a big difference between the concentrations of the rhomb porphyry and the alum shale eluates for many of the compounds. As found in the column experiment, the concentrations of uranium, sulphate, sulphur and the metals nickel, zinc, cadmium and cobalt are much higher.

Table 5 Results chemical analyses of eluates from containers after 1 and 12 months (Alum shale value is average of two samples)

	Unit	Rhomb porphyry (Nittedal)		Alum shale	
Element/ compound	**Month**	**1**	**12**	**1**	**12**
Al	µg/l	3010	773	453	72
Alkalinity pH 4.5	mmol/l	1.6	1.6	2.0	1.4
$NH4^+$	mg/l	0.006	<0.004	1.2	0.22
As	µg/l	<0.5	<0.5	1.2	0.64
Ba	µg/l	87	51	53	12.8
Ca	mg/l	45	31	122	368
Cd	µg/l	0.11	<0.05	1.46	13.6
Co	µg/l	0.84	0.25	2.47	9.8
Conductivity	mS/m	26	18	71	183
Cr	µg/l	<0.9	<0.9	<0.9	<0.9
Cu	µg/l	5.2	1.2	3.2	2.4
Fe	mg/l	4.7	0.85	0.56	0.11
Fluoride	mg/l	0.95	0.76	0.18	0.05
Hg	µg/l	<0.02	<0.02	<0.02	<0.02
K	mg/l	3.3	2.1	11.6	17.4
Chloride	mg/l	3.3	12	2.4	36
Mg	mg/l	6.1	3.1	13.9	91
Mn	µg/l	248	38	231	593
Mo	µg/l	89	50	454	242
Na	mg/l	4.7	1.8	6.0	3.9
Ni	µg/l	0.85	<0.6	270	1271
Nitrate	mg/l	6.3	1.9	0.1	<0.1
Nitrite	mg/l	0.0049	<0.001	0.102	0.029
P	µg/l	-	0.006	-	0.16
Pb	µg/l	1.8	<0.5	1.2	<0.5
pH		8.2	7.5	8.0	7.2
S	mg/l	13	4.2	257	431
Si	mg/l	2.2	2.2	-	1.1
Sr	µg/l	205	300	-	2350
Sulphate	mg/l	40	13	285	1255
Suspended matter	mg/l	170	28	21	8.8
Th	µg/l	1.5	0.57	0.4	<0.2
TOC	mg/l	3.5	5.6	5.1	8.6
U	µg/l	5.2	5.1	96	151
V	µg/l	3.7	1.3	11	0.563
Zn	µg/l	18	5.1	63	959

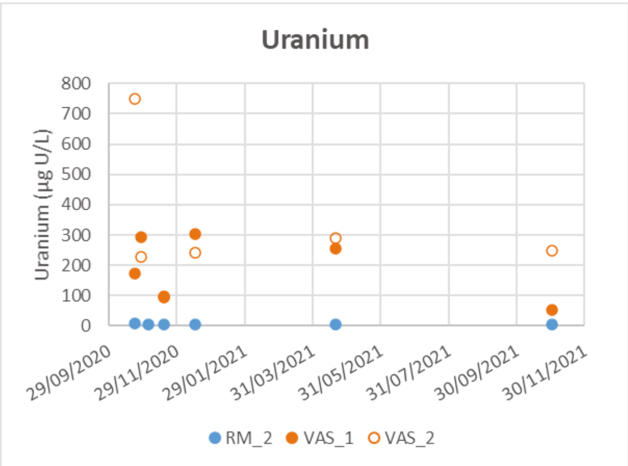
In Figure 13 to Figure 17 are the concentrations of uranium, sulphur, sulphate, alkalinity, nickel, zinc, cadmium, cobalt, copper and aluminium for the different sampling times presented (1 day, 2, 4, 8 weeks, 6 months and 1 year).

The uranium concentration in the rhomb porphyry leachate is low and between 3.1 and 8.4 µg U/L. For the alum shale the concentrations vary between 54 and 750 µg U/L (Figure 13). The leaching of uranium in both rocks seems to be highest in the beginning. This is also the case for copper and aluminium (Figure 17).

In the leachate from the rhomb porphyry the concentrations of sulphate, sulphur, and the metals nickel, zinc, cadmium, cobalt, copper and aluminium all show highest concentrations in analyses of the first eluate, followed by decreasing concentrations with time. This indicates that there is a limited availability of mobile elements in the rock.

The concentrations of metals in the alum shale eluates are much higher than in the rhomb porphyry eluates. Also, for the alum shale the concentrations in the first eluates are generally high and they are also decreasing with time. But unlike the rhomb porphyry, the concentration increases again at the end of the experiment. Highest concentrations of sulphur, sulphate and the metals Ni, Zn, Cd and Co are measured in the eluates after one year, indicating increased leaching of metals. The onset of leaching of these elements are happening before a reduction of pH is visible.

The alkalinity in the rhomb porphyry eluate is stable at around 1.5 mmol/L throughout the experiment, while the alum shale eluate shows a peak in the alkalinity after 2-3 months (2.1 mmol/L), followed by decreasing values.



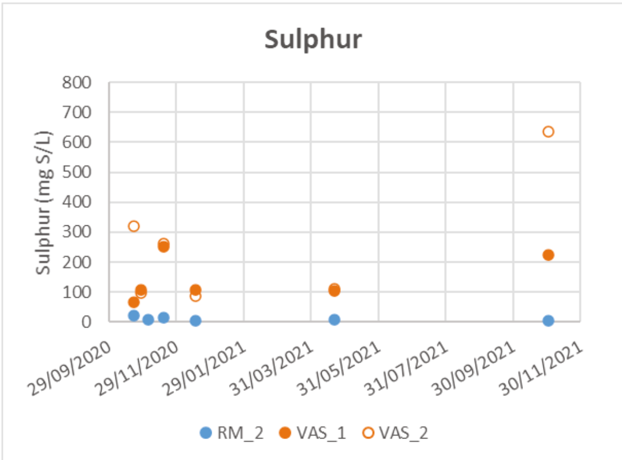
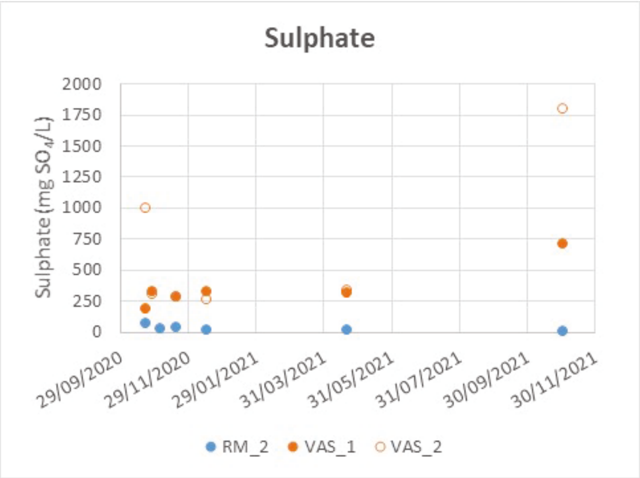


Figure 13 *Content of uranium and sulphur in the containers with rhomb porphyry (RM_2) and alum shale (VAS_1 and VAS_2).*



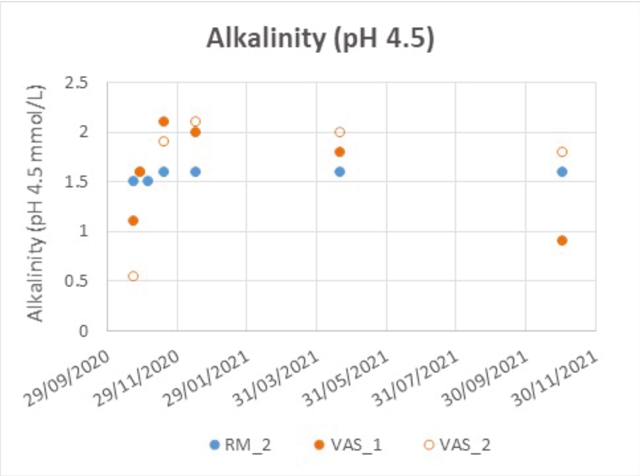
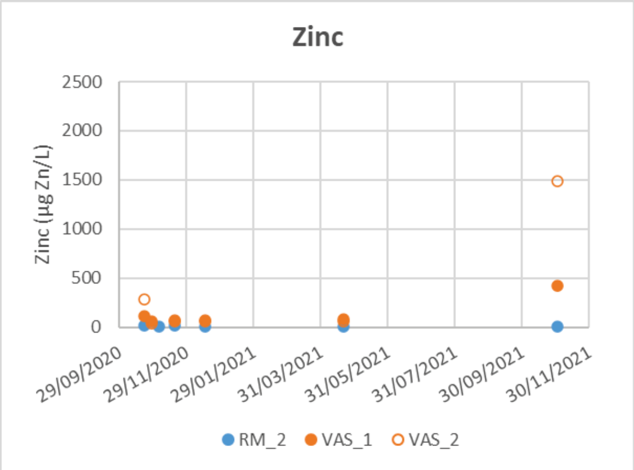


Figure 14 *Content of sulphate and alkalinity in the containers with rhomb porphyry (RM_2) alum shale (VAS_1 and VAS_2).*



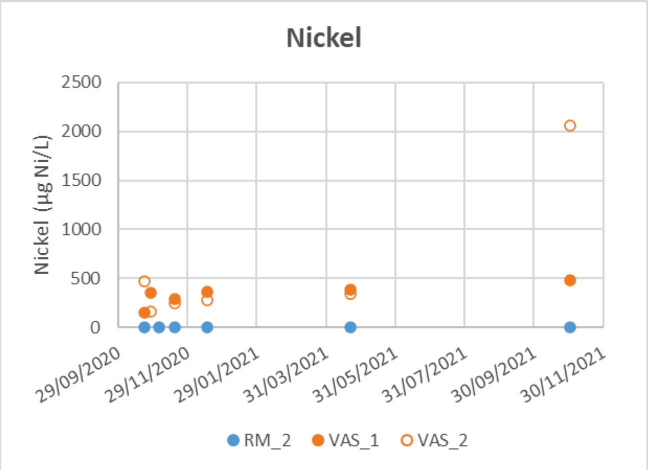
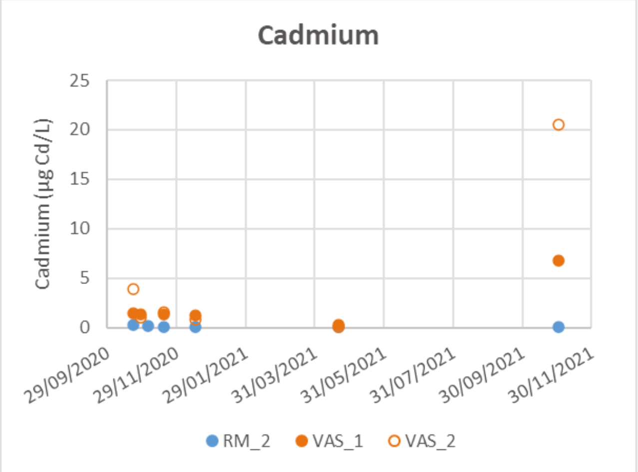


Figure 15 *Content of zinc and nickel in the containers with rhomb porphyry (RM_2) and alum shale (VAS_1 and VAS_2).*



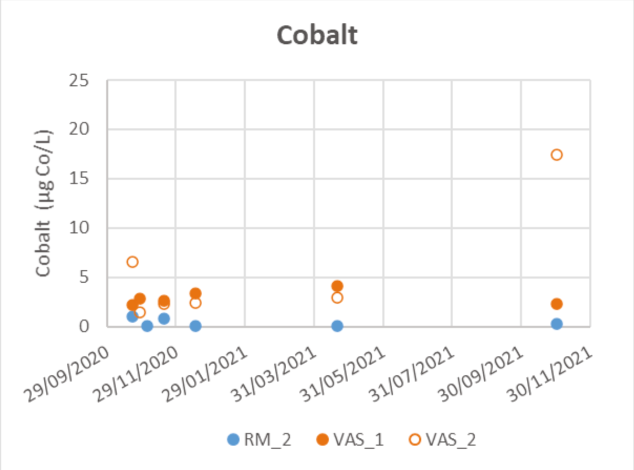


Figure 16 *Content of cadmium and cobalt in the containers with rhomb porphyry (RM_2) and alum shale (VAS_1 and VAS_2).*

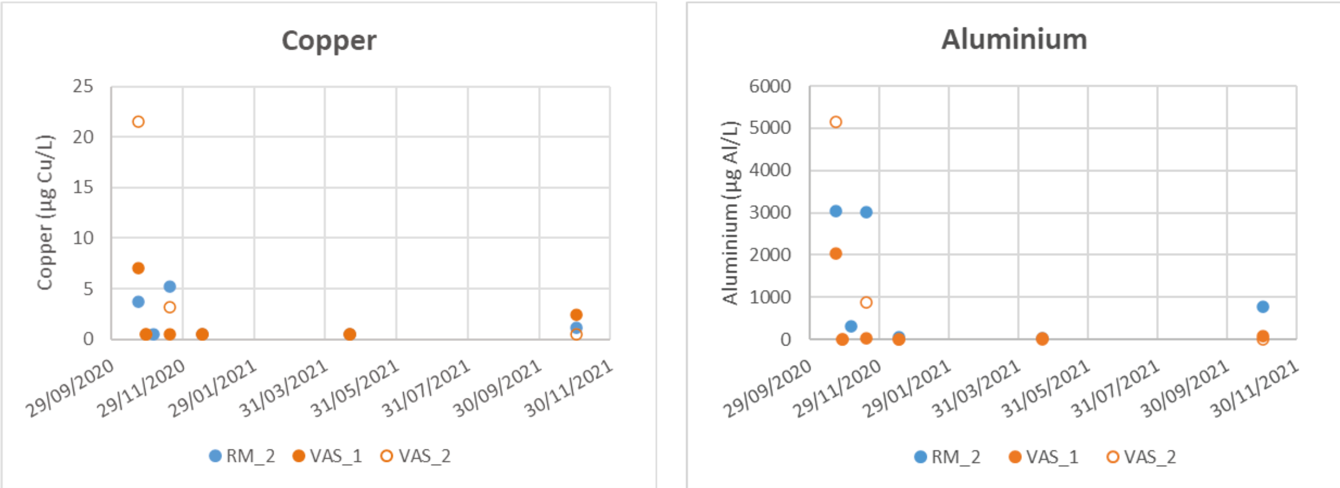


Figure 17 Content of copper and aluminium in the containers with rhomb porphyry (RM_2) and alum shale (VAS_1 and VAS_2).

5 Standard leaching tests with rhomb porphyry

The rhomb porphyry from Skoppum has been tested according to the European standard for characterization of waste, with a so-called one stage batch leaching test (EN-12457-2:2002) and an up-flow percolation test (CEN - EN 14405).

The one stage batch leaching test is a 24 hour long leaching test for granular waste materials and sludges at a liquid to solid ratio of 10 l/kg for materials with particle size below 4 mm (with or without size reduction).

In the percolation test the waste body is subjected to percolation with water as a function of liquid to solid ratio (L/S) = 0.1. The method is a once-through column leaching test producing eluates which can subsequently be characterized by chemical analyses.

The standards have been developed to investigate mainly inorganic constituents from wastes. By crushing the material, new surfaces are exposed which may lead to a change in leaching properties. The test may therefore give an overestimate of the short-term leaching properties of the tested material.

The eluates were analysed for the content of elements according to the Norwegian guidelines for deposition of waste (Avfallsforskriften kapittel 9 vedlegg II), results are given in Table 5 and Table 6.

From the tests it was found that the leachate from the samples had high pH (8.3 and 9.5) and very low levels of metals. Many of the elements are not detected in the eluate.

Table 6 *Results from one stage batch leachate test (L/S = 10) on rhomb porphyry (Skoppum) compared with guidelines for deposition of waste (mg/kg).*

	Rhomb porphyry 0 -20 mm (Skoppum) (L/S=10) (mg/kg)	**Inert waste (L/S=10) (mg/kg)**	**Ordinary waste (L/S=10) (mg/kg)**	**Hazardous waste (L/S=10) (mg/kg)**
As	0,00926	0.5	2	25
Ba	0.0256	20	100	300
Cd	<0.0005	0.04	1	5
Cr	<0.005	0.5	10	70
Cu	<0.01	2	50	100
Hg	<0.0002	0.01	0.2	2
Mo	0.00611	0.5	10	30
Ni	<0.005	0.4	10	40
Pb	<0.002	0.5	10	50
Sb	<0.001	0.06	0.7	5
Se	<0.03	0.1	0.5	7
Zn	<0.02	4	50	50
pH	9.5	-	-	-
Uranium	0.00548	-	-	-
Thorium	<0.002	-	-	-
Conductivity (mS/m)	6.2	-	-	-

Table 7 Results from percolation test (L/S = 0.1) on rhomb porphyry (Skoppum) compared with guidelines for deposition of waste (mg/kg).

	Rhomb porphyry (Skoppum) 0 -20 mm (L/S=0.1) (mg/L)	Inert waste (L/S=0.1) (mg/L)	Ordinary waste (L/S=0.1) (mg/L)	Hazardous waste (L/S=0.1) (mg/L)
As	0.00169	0.06	0.3	3
Ba	0.014	4	20	60
Cd	0.0000624	0.02	0.3	1.7
Cr	0.000627	0.1	2.5	15
Cu	0.00539	0.6	30	60
Hg	<0.00002	0.002	0.03	0.3
Mo	0.0103	0.2	3.5	10
Ni	<0.0005	0.12	3	12
Pb	0.000417	0.15	3	15
Sb	0.000203	0.1	0.15	1
Se	<0.003	0.04	0.2	3
Zn	0.0117	1.2	15	60
pH	8.3	-	-	-
Uranium	0.00509	-	-	-
Thorium	0.000545	-	-	-
Conductivity (mS/m)	3.26	-	-	-

6 Conclusions

The rhomb porphyry rock samples have low levels of TOC, S and metals, included uranium and thorium. Results from the different leachate experiments (column, container and standard leachate tests) show a stable high pH and a very low concentration of metals in the eluates. The rhomb porphyry can be characterized to be stable and to have a low potentially risk when it comes to leaching metals to the environment.

7 References

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NGI 2017. Innledende vurdering av miljørisiko fra rombeporfyr. NGI teknisk notat 20140654-04-TN.

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