PHASE 2 INITIAL BOREHOLE DRILLING AND TESTING, IGNACE AREA

WP04F Data Report: Measurement of Surface Area and Cation Exchange Capacity of Core Samples for IG_BH05

APM-REP-01332-0393 **August 2024**

WSP Canada Inc.

NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

This report has been prepared under contract to NWMO. The report has been reviewed by NWMO, but the views and conclusions are those of the authors and do not necessarily represent those of the NWMO.

Nuclear Waste Management Organization
22 St. Clair Avenue East, 4th Floor
Toronto, Ontario
M4T 2S3
Canada

Tel: 416-934-9814
Web: www.nwmo.ca

REPORT

PHASE 2 INITIAL BOREHOLE DRILLING AND TESTING AT IG_BH04/05/06

WP04F Data Report - Measurement of Surface Area and Cation Exchange Capacity of Core Samples for IG_BH05

Submitted to:

Nuclear Waste Management Organization

4th Floor
22 St. Clair Avenue East
Toronto, Ontario, M4T 2S3

Submitted by:

WSP Canada Inc.

6925 Century Avenue,
Mississauga, Ontario L5N 7K2, Canada

+1 (905) 567-4444

NWMO Document: APM-REP-01332-0393

2001102 / 20253946

August 2024

Distribution List

e-copy - NWMO

e-copy - WSP Canada Inc.

e-copy - Hydroisotop

WP4C REPORT – MEASUREMENT OF SURFACE AREA AND CATION EXCHANGE CAPACITY OF CORE SAMPLES FOR IG_BH05

CLIENT INFORMATION

Project Name:	Phase 2 Initial Borehole Drilling and Testing at IG_BH04/05/06, Ignace Area
Project Number:	20253946
Client PO Number:	2000141
Document Name:	20253946 IG_BH05 WP04F Rpt 05Aug2024 R4a

Client:	Nuclear Waste Management Organization (NWMO)	
Address:	22 St. Clair Avenue East, 4th Floor	
City:	Toronto	
Province:	Ontario	
Postal Code:	M4T 2S3	
Client Contact:	Tammy Yang	Warwick Watt
Telephone:	647-259-3032	647-972-3669
Email:	tyang@nwmo.ca	wwatt@nwmo.ca

ISSUE/REVISION INDEX

Issue Code	Revision					Revision Details
	No.	By	Revd.	App.	Date	
RR	0	VW	FE/GWS		4 March 2024	First draft released for review and comments
RR	1	VW	FE/GWS		6 June 2024	Revised draft for review and comments
RR	2	VW	FE/GWS		25 June 2024	Final draft for acceptance
RI	3	VW	FE/GWS	KDV	5 July 2024	Revised final for acceptance
RI	4	VW	FE/GWS	KDV	5 August 2024	Revised final for acceptance

Issue Codes: RR = Released for Review and Comments, RI = Released for Information

SIGNATURES

Reviewed by: ______________________________

Dr. Florian Eichinger
Hydroisotop GmbH

Reviewed by: ______________________________

George Schneider, M.Sc., P.Geo.
Senior Geoscientist

Approved by: ______________________________

Ken DeVos, M.Sc., P.Geo.
Senior Hydrogeochemist

Table of Contents

TABLES

FIGURES

APPENDICES

1.0 INTRODUCTION

The Initial Borehole Drilling and Testing project in the Wabigoon Lake Ojibway Nation (WLON) – Ignace Area, Ontario is part of Phase 2 Geoscientific Preliminary Field Investigations of the Nuclear Waste Management Organization's (NWMO) Adaptive Phased Management Site Selection Phase. This project includes the drilling and testing of six deep boreholes at the Revell site, as well as additional on-going studies, located within the northern portion of the Revell batholith.

This project involves testing of deep borehole IG_BH04 and the drilling and testing of deep boreholes IG_BH05 and IG_BH06 in the Revell site within the identified Potential Repository Area (PRA) as shown on Figure 1. The work comprises a total of eleven work packages and was carried out by a team led by WSP Canada Inc. (WSP) on behalf of the NWMO. The IG_BH05 program is described in a Borehole Characterization Plan (BCP) for IG_BH05.

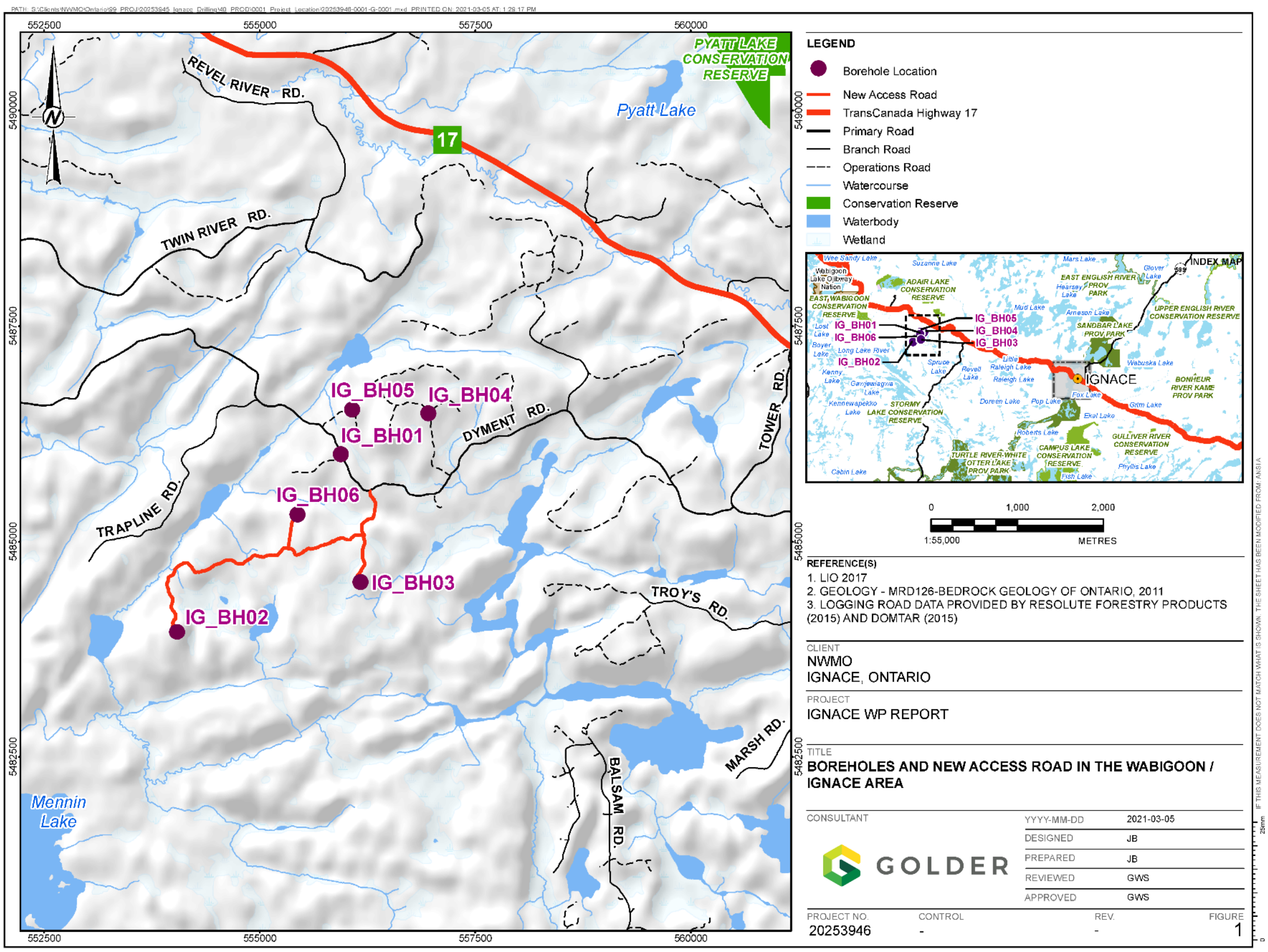


Figure 1: Location of IG_BH05 in relation to the Ignace Area

This data report describes the methodology, activities, and results for Work Package 4F (WP04F): Measurement of surface area and cation exchange capacity of core samples, on rock core samples recovered from borehole IG_BH05.

1.1 Geological Setting

The approximately 2.7 billion years old Revell batholith is located in the western part of the Wabigoon Subprovince of the Archean Superior Province. The batholith is roughly elliptical in shape trending northwest, is approximately 40 km in length, 15 km in width, and covers an area of approximately 455 km^2. Based on geophysical modelling, the batholith is approximately 2 km to 3 km thick through the center of the northern portion (SGL 2015). The batholith is surrounded by supracrustal rocks of the Raleigh Lake (to the north and east) and Bending Lake (to the southwest) greenstone belts (Figure 2).

IG_BH05 is located within an investigation area of approximately 19 km^2 in size, situated in the northern portion of the Revell batholith. Bedrock exposure in the area is generally very good due to minimal overburden, few water bodies, and relatively recent logging activities. Ground elevations generally range from 400 to 450 m above sea level. The ground surface broadly slopes towards the northwest as indicated by the flow direction of the main rivers in the area. Local water courses tend to flow to the southwest towards Mennin Lake (Figure 1).

Four main rock units are identified in the supracrustal rock group: mafic metavolcanic rocks, intermediate to felsic metavolcanic rocks, metasedimentary rocks, and mafic intrusive rocks (Figure 2). Sedimentation within the supracrustal rock assemblage was largely synvolcanic, although sediment deposition in the Bending Lake area may have continued past the volcanic period (Stone 2009; Stone 2010a; Stone 2010b). All supracrustal rocks are affected, to varying degrees, by penetrative brittle-ductile to ductile deformation under greenschist- to amphibolite-facies metamorphic conditions (Blackburn and Hinz 1996; Stone et al. 1998). In some locations, primary features, such as pillow basalt or bedding in sedimentary rocks are preserved, in other locations, primary relationships are completely masked by penetrative deformation. Uranium-lead (U-Pb) geochronological analysis of the supracrustal rocks produced ages that range between 2734.6 +/-1.1 Ma and 2725 +/-5 Ma (Stone et al. 2010).

Three main suites of plutonic rock are recognized in the Revell batholith, including, from oldest to youngest: a Biotite Tonalite to Granodiorite suite, a Hornblende Tonalite to Granodiorite suite, and a Biotite Granite to Granodiorite suite (Figure 2). Plutonic rocks of the Biotite Tonalite to Granodiorite suite occur along the southwestern and northeastern margins of the Revell batholith. The principal type of rock within this suite is a white to grey, medium-grained, variably massive to foliated or weakly gneissic, biotite tonalite to granodiorite. One sample of foliated and medium-grained biotite tonalite produced a U-Pb age of 2734.2+/-0.8 Ma (Stone et al. 2010). The Hornblende Tonalite to Granodiorite suite occurs in two irregularly-shaped zones surrounding the central core of the Revell batholith. Rocks of the Hornblende Tonalite to Granodiorite suite range compositionally from tonalite through granodiorite to granite and also include significant proportions of quartz diorite and quartz monzodiorite. One sample of coarse-grained grey mesocratic hornblende tonalite produced a U-Pb age of 2732.3+/-0.8 Ma (Stone et al. 2010). Rocks of the Biotite Granite to Granodiorite suite underlie most of the northern, central and southern portions of the Revell batholith. Rocks of this suite are typically coarse-grained, massive to weakly foliated, and white to pink in colour. The Biotite Granite to Granodiorite suite ranges compositionally from granite through granodiorite to tonalite. A distinct potassium (K)-Feldspar Megacrystic Granite phase of the Biotite Granite to Granodiorite suite occurs as an oval-shaped body in the central portion of the Revell batholith (Figure 2). One sample of coarse-grained, pink, massive K-feldspar megacrystic biotite granite produced a U-Pb age of 2694.0+/-0.9 Ma (Stone et al. 2010). The bedrock surrounding IG_BH05 is composed mainly of massive to weakly foliated felsic intrusive rocks that vary in composition between granodiorite and tonalite, and together form a relatively homogeneous intrusive complex. Bedrock identified as tonalite transitions gradationally into granodiorite and no distinct contact relationships between these two rock types are typically observed (SRK and Golder 2015; Golder and PGW 2017). Massive to weakly foliated granite is identified at the ground surface to the northwest of the feldspar-megacrystic granite. The granite is observed to intrude into the granodiorite-tonalite bedrock, indicating it is distinct from, and younger than, the intrusive complex (Golder and PGW 2017).

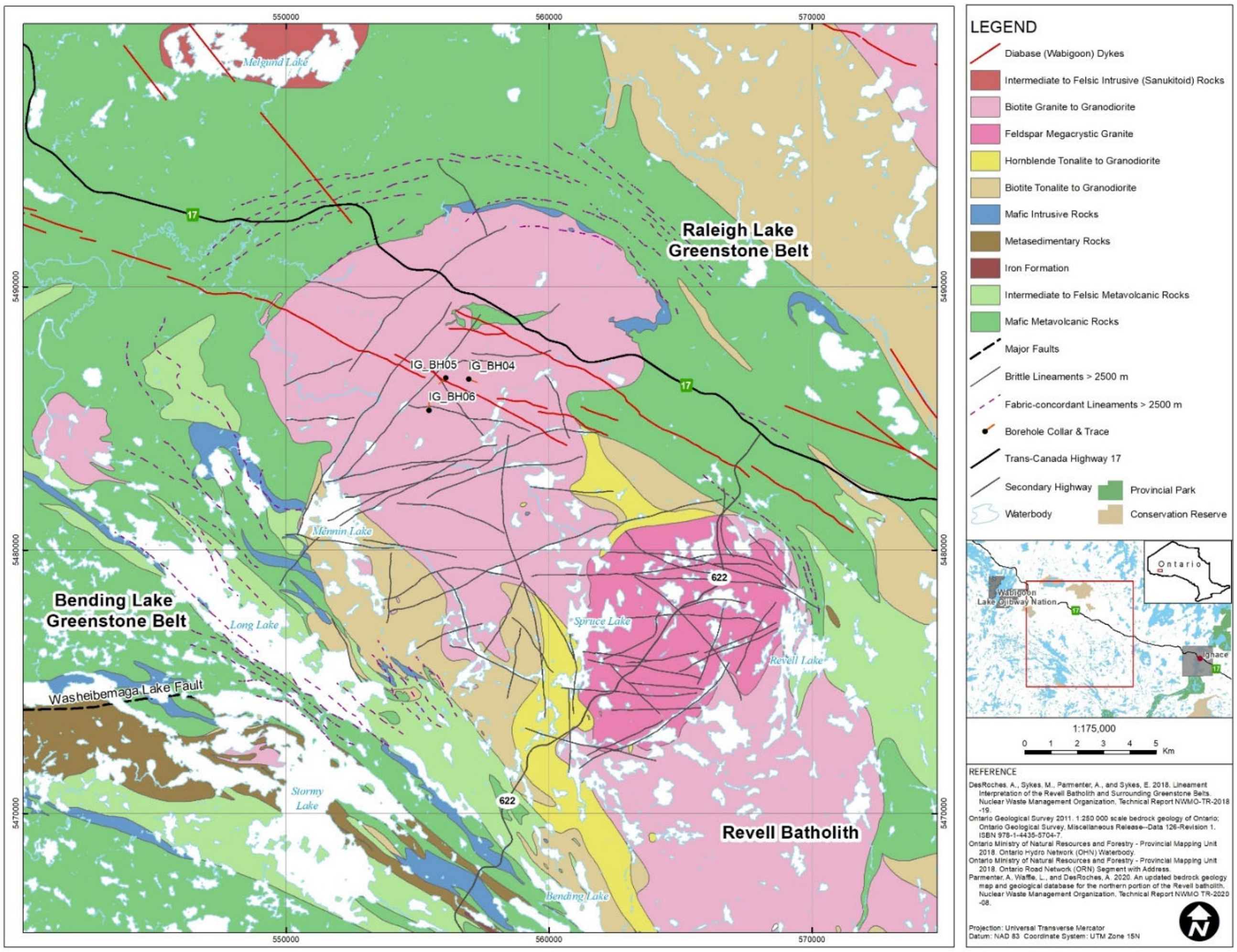


Figure 2: Geological Setting and Location of Boreholes IG_BH04, IG_BH05, and IG_BH06 in the Northern Portion of the Revell Batholith

West-northwest trending mafic dykes interpreted from aeromagnetic data extend across the northern portion of the Revell batholith and into the surrounding greenstone belts. One mafic dyke occurrence, located to the northwest of IG_BH01, is approximately 15-20 m wide (Figure 2). All of these mafic dykes have a similar character and are interpreted to be part of the Wabigoon dyke swarm. One sample from the same Wabigoon swarm produced a U-Pb age of 1887+/-13 Ma (Stone et al. 2010), indicating that these mafic dykes are Proterozoic in age. It is assumed based on surface measurements that these mafic dykes are sub-vertical (Golder and PGW 2017).

Long, narrow valleys are located along the western and southern limits of the investigation area (Figure 1). These local valleys host creeks and small lakes that drain to the southwest and may represent the surface expression of structural features that extend into the bedrock. A broad valley is located along the eastern limits of the investigation area and hosts a more continuous, un-named water body that flows to the south. The linear and segmented nature of this waterbody's shorelines may also represent the surface expression of structural features that extend into the bedrock.

Regional observations from mapping have indicated that structural features are widely spaced (typical 30 to 500 cm spacing range) and dominantly comprised of sub-vertical joints with two dominant orientations, northeast and northwest trending (Golder and PGW 2017). Interpreted bedrock lineaments generally follow these same dominant orientations in the northern portion of the Revell batholith (Figure 2; DesRoches et al. 2018). Minor sub-horizontal joints have been observed with minimal alteration, suggesting they are younger and perhaps related to glacial unloading. One mapped regional-scale fault, the Washeibemaga Lake fault, trends east and is located to the west of the Revell batholith (Figure 2). Ductile lineaments, also shown on Figure 2, follow the trend of foliation mapped in the surrounding greenstone belts. Additional details of the lithological units and structures found at surface within the investigation area are reported in Golder and PGW (2017).

1.2 Technical Objectives

Within the characterisation of the Revell site, two core samples were taken from borehole IG_BH05 for the measurement of cation exchange capacity (CEC) and specific surface area (SAA) (by BET method) at different grain size fractions. The CEC measurements were conducted by Hydroisotop GmbH (Hydroisotop). The BET SAA measurements were performed at the University of Bern. The work was carried out in accordance with the WP04F Test Plan, and the results of the experimental measurements are documented in the following sections of this report, with the analytical raw data provided in Appendix A.

2.0 SAMPLING AND SAMPLE PREPARATION

2.1 Sampling

Two core samples from borehole IG_BH05 (sample ID: IG_BH05_SA001 and IG_BH05_AR43) with a respective length of 0.49 m and 0.19 m were taken at an average depth of 300.54 mbgs and 787.89 mbgs (downhole) on June 15, 2021 and on July 21, 2021 for the determination of CEC (cation exchange capacity) and specific surface area (SAA) using the BET method (Table 1). Sampling was conducted by Golder Associates Ltd. according to the instructions provided by Hydroisotop GmbH (Hydroisotop) via personal training. After recovery from the borehole, the core samples were photographed and immediately packed in a plastic bag, evacuated and sealed airtight. This procedure was repeated for a second plastic bag and a final Al-coated plastic layer. The samples were stored in a refrigerator on site and then sent to Hydroisotop, Germany, in a cooler.

The first sample IG_BH05_SA001 was sent by Golder Associates Ltd. on June 16, 2021 and arrived at the Hydroisotop lab on July 05, 2021. The sample was well packed and arrived in the lab with preserved vacuum. At Hydroisotop the sample was stored in the fridge at 4 °C. The rock sample was identified as diabase dyke based on the mineralogy information from borehole IG_BH05.

The second sample IG_BH05_AR43 was sent by the NWMO on July 07, 2023 and arrived at the Hydroisotop lab on August 03, 2023. The sample was well packed and arrived in the lab with preserved vacuum. At Hydroisotop the sample was stored in the fridge at 4 °C. The rock sample was identified as amphibolite based on the mineralogy information from borehole IG_BH05.

2.2 Sample Preparation

The core samples were prepared for the CEC and BET SSA measurements on August 26, 2021 and on September 04, 2023, respectively. The core samples were unpacked, photographed (photos of the rock core and core slice are shown in Appendix B) and immediately wrapped into Parafilm™ and cut by dry-sawing into full-diameter sections of 1 to 2 cm thickness. After sawing the core sections were crushed using a steel mortar and the crushed rock material was sieved using a vibration sieving tower (Retsch AS 450) and analytical stainless-steel sieves with mesh sizes of 0.065, 0.15, 0.2, 0.3, 1.0, 2.0, 4.0, 10 and 20 mm. The obtained crushed rock material with grain size fractions of 10-20 mm, 2-4 mm, 1-2 mm, 0.15-0.3 mm, 0.065-0.2 mm and < 0.065 mm was stored in PE bottles. After the first step of crushing and sieving, sufficient rock material of the largest grain size fraction 10-20 mm was achieved. Crushing and sieving was repeated until sufficient rock material with a grain size fraction of 2-4 mm was obtained and than the same procedure for grain size fraction 1-2 mm. Afterwards the grain size fraction of 0.3-1 mm was milled with a zirconium oxide grinding beaker and balls (Retsch AS 450) (300 rpm, 1 min) and sieved again to obtain the smaller grain size fractions (0.15-0.3 mm and 0.065-0.2 mm) needed for CEC and BET SSA experiments.

One core section from IG_BH05_SA001 with a thickness of 3 cm and mass of 384.5 g and one core section from IG_BH05_AR43 with a thickness of 2.5 cm and mass of 227.4 g were retained for BET SSA experiments on a rock cylinder. Before sending this core slices and about 100 g of each grain size fraction to University of Bern for BET SSA measurements, the rock materials were dried at 105 °C for two weeks.

Table 1: Overview of the core samples taken from IG_BH05 for the CEC/BET specific surface area measurements

Sample description		Depth			Sampling					
Sample-ID	Hydro-isotop Lab-No.	From	To	Ave.	Length	Test Type	Date sampled	Time recovered	Date sent	Date received
		[m]	[m]	[m]	[m]			[hh:mm]		
IG_BH05_ SA001	365843	300.29	300.78	300.54	0.49	BET surface area and CEC	2021/06/15	10:38	2021/06/16	2021/07/05
IG_BH05_ AR43	403810	787.79	787.98	787.89	0.19	BET surface area and CEC	2021/07/21	17:30	2023/07/07	2023/08/03

2.3 Core Logging Depth Correction

During the core logging of borehole IG_BH05, the logged depths were not reconciled with the depths obtained by the drilling supervisor calculated from measurement of the drill string and drill rod stick-up. This resulted in the WP03 core logging depths and core sample depths to be recorded as being slightly deeper than the actual sample depths. Refer to the WP03 Report for IG_BH05 for details of the correction applied to the core logging data.

Sample depths for IG_BH05_SA001 referred to in this report and appendices are the original, uncorrected sample depths in metres below ground surface (mbgs) downhole. Sample depths for IG_BH05_AR43 (an archive sample sent for analysis later in the program) are corrected sample depths in metres below ground surface (mbgs) downhole. An Addendum to the Laboratory Report summarizing the original and corrected core depths for each sample is provided in Appendix D.

3.0 EXPERIMENTAL SET-UP AND ANALYTICAL METHODS

The specific surface areas for different grain size fractions were determined at the University of Bern. The CEC experiments were conducted at Hydroisotop. Unless otherwise specified, the analytical work was conducted at Hydroisotop GmbH, Germany.

3.1 Determination of Specific Surface Area Using the BET Method

The specific surface area (SSA) was determined on different grain size fractions (crushed rock; see Table 2) and a 9 mm diameter core approximately 25-30 mm thick drilled out of the intact cores by nitrogen adsorption isotherms at -196°C, using a BELSORP miniX surface analyser at the University of Bern (Dr. Urs Eggenberger).

A mass of 6 – 16 g of crushed rock material (Table 2; maximum volume 18 cm^3) was weighed (to an accuracy of 0.001 g) in a glass container until $^1/_3$ to maximum $^2/_3$ of the container was filled. After inserting the glass container containing the rock sample into a BELPREP vac III, the vacuum pump was started and the sample was heated up to 105 °C overnight. Hereby the rock sample was desorbed of primary adsorbed gases under vacuum before measuring the adsorption isotherm. After the glass container cools down for a minimum of six hours, the vacuum pump was stopped and the valves of the glass container were closed. To determine the weight loss, the glass container was weighed before heating and after cooling.

Table 2: Used masses of crushed rock material for the determination of specific surface area by BET method

Grain size fraction	Sent masses [g]	Used masses [g]
Core sample IG_BH05_SA001		
0.065-0.2 mm	app. 100	6.110
0.15-0.3 mm	app. 100	7.545
1-2 mm	app. 100	8.004
2-4 mm	app. 100	8.215
10-20 mm	app. 100	5.594
Core (9 mm diameter; 2.5-3 cm thickness)	384.5	15.928
Core sample IG_BH05_AR43		
0.15-0.3 mm	app. 10	6.624
1-2 mm	app. 61	7.380
2-4 mm	app. 69	8.006
Core (9 mm diameter; 2.5-3 cm thickness)	227.388	6.224

For the BET SSA measurement, the neck of the glass container was fixed in the BELSORP-miniX surface analyzer and the measurement was started using the BELSORP-miniX software. After approximately three hours the measurement was finished. The specific surface area, expressed as m^2/g, was then calculated from the amount of adsorbed N_2 and the sample weight according to the BET method (Brunauer et al. 1938) for a relative pressure of P/P_0 (measured vacuum pressure to the atmospheric pressure) from 0.05 to 0.3.

Certified standard materials (four different BET-standards with specific surface areas from 0.18 to 214 m^2/g) were used for calibration and quality checks. The reproducibility for BET surface area is < 2 % CV (Coefficient of Variation) at 1 m^2 measured area.

Raw data are included in the report in Appendix C.

3.2 Determination of Cation Exchange Capacity (CEC)

The CEC is determined by the nickel-ethylenediamine (Ni-en) method originally developed for clay-rich sedimentary rocks (Baeyens and Bradbury 1994; Bradbury and Baeyens 1997, 1998) and adapted to crystalline rocks according to Eichinger et al. (2023). This method is based on the premise that Ni, as a strong sorbent, will exclusively displace (and replace) all cations from the exchange sites in sheet silicates (the concentrations of the displaced cations will increase in solution, while the Ni concentration will accordingly decrease, allowing determination of the cation exchange capacity).

The CEC measurements were conducted on three crushed rock size fractions (0.065 - 0.2 mm, 2 – 4 mm and 10 – 20 mm) for the core sample IG_BH05_SA001 and three crushed rock size fractions (0.15 – 0.3 mm, 1 – 2 mm, 2 – 4 mm) for the core sample IG_BH05_AR43. Ni-en extractions were performed in duplicate at four different solid to liquid mass ratios (1:10, 1:4, 1:2, 1:1). In addition, a blank was carried out for each experimental run as a control. The blank sample is the experimental approach without rock material, which is treated in the same way as the cation exchange experiments with rock material. This means that this sample is prepared in the same way (solution only), shaken, decanted, filtered and measured for its elements. In this way, possible sources of error or contamination caused by the performance or handling can be checked and, ideally, excluded.

The experimental stock solution (0.0005 molar Ni-en solution) was prepared by adding ethylenediamine to a $Ni(NO_3)_2$ solution. The Ni-en solution was prepared using degassed, oxygen- and CO_2-free water that was prepared in the glove box by boiling and N_2 bubbling for 30 minutes.

For the determination of the CEC values, the batch volumes were selected according to the grain size fraction and the experiment duration. Table 3 gives an overview of the respective rock and test solution masses for the individual experiments. For the grain size fraction 0.15-0.3 mm the 1:10 experiments runs with lower rock and water amount caused by low amount of rock material of this grain size fraction.

Table 3: Overview of the experimental set-ups for CEC measurements

Rock core sample/test solution mass ratio		1:1	1:2	1:4	1:10	Blank
Experiment 0.065-0.2 mm (48 h); 1-2 mm (72h), 2-4 mm (96 h) and 2-4 mm-2 (74 h)						
rock material mass	[g]	40	20	10	10	0
test solution mass	[g]	40	40	40	100	75
Experiment 0.15-0.3 mm (74 h)						
rock material mass	[g]	40	20	10	5	0
test solution mass	[g]	40	40	40	50	50
Experiment 10-20 mm (app. 27 weeks or 184 days*)						
rock material mass	[g]	60	30	15	10	0
test solution mass	[g]	60	60	60	100	75

*until equilibration (nearly) reached

The experimental procedures were carried out in an oxygen free glove box, which was continuously flushed with nitrogen and held on slight nitrogen overpressure. Oxygen concentrations in the glove box were measured in the inner atmosphere. The oxygen concentration was lower than 5 % related to air.

The weighted rock material was added into a 100 mL polyethylene bottle. To start the experiment, the experimental solution was added to the rock material in the polyethylene bottle in the glove box using a graduated cylinder. Immediately after addition of the solution, the pH and redox potential of the experimental solution were measured with a WTW Multi 3620 IDS with a SenTix-ORP-T900 redox-electrode and a SenTix-940 pH-electrode. The bottles were closed and continuously shaken upside down.

The samples from the experiments with the smaller (0.065-0.2 mm and 0.15-0.3 mm) and the middle grain size fractions (1-2 mm and 2-4 mm) were continuously shaken end-over-end in the polyethylene bottles. The polyethylene bottles of the large grain size fraction (10-20 mm) experiments were only shaken one to two times per day, to avoid too strong erosion of the material as shown by the experiments of the IG_BH04 core sample (IG_BH04_SA001). The reaction time depended on the sizes of the crushed rock sample. The smallest grain size fraction (0.065-0.2 mm) samples were shaken for 48 h, the grain size fraction 0.15-0.3 mm samples for 74 h, the grain size fraction 1-2 mm samples for 72 h, the grain size fraction 2-4 mm samples for 96 h and the second grain size fraction 2-4 mm samples for 74 h. The largest grain size fraction (10-20 mm) samples were shaken until stable Ni-concentrations in the solution were achieved. Until nickel concentration was stable, an aliquot of 1.0 mL sub-sample was taken at 8, 16, 40, 56, 82, 101, 157 and 171 days. The experimental solutions were sampled after 8, 16, 40, 56, 82, 101, 157 and 171 days as sub-samples until the final sampling at day 184.

A 1 mL sub-sample was taken from the polyethylene bottle with a pipette and filled into a 1.5 mL reaction tube. The reaction tube was centrifuged until the solution was clear. The solution was then carefully removed with a pipette. 0.1 mL solution was directly added to a 10 mL centrifuge tube containing 9900 µL of 2 % ultrapure HNO_3 for Ni concentration measurement (1:100 dilution). The remaining solution was transferred to a clean 1.5 mL reaction tube for the cation concentration analysis by IC.

For the final sampling of all experimental set-ups, the pH value and the redox potential of the final solution were measured in the glove box. The solution was then decanted into a 50 mL centrifuge tube and centrifuged until the solution was clear. The solution was divided into 3 vials in the glove box for concentration analysis.

- For the photometer and IC measurements, a partial sample (vial 1) was filtered with a 0.45 µm and finally a 0.2 µm syringe filter and filled into a tube.
- For the total iron (Fe_{tot}) analysis, a 2nd aliquot of the sample (vial 2) was filled unfiltered (0.1 mL) into a 10 mL centrifuge tube containing 9.9 mL of 2 % HNO_3.
- For all cations measured by the AAS and Fe^{2+}, the 3rd subsample (vial 3) was filtered with a 0.45 µm and a 0.2 µm syringe filter and filled into a 50 mL tube and added concentrated HNO_3 (0.1 %).

All samples were immediately analysed after the experiment was finished.

The Ni-en solution was analysed for Ni^{2+} concentration before and after extraction by AAS (Analytic Jena contra 800) with a detection limit of 0.01 mg/L. The analytical error of the AAS is ± 10 % based on multiple measurements of high-grade, commercial check-standard solutions.

For the sub-samples, Ni^{2+}, Ca^{2+} and Mg^{2+} concentrations were determined by AAS and K^+, Na^+ and NH_4^+ concentrations by IC (Thermo Scientific Dionex Integrion HPIC).

For the final samples, Ni^{2+}, Ca^{2+}, Mg^{2+}, Sr^{2+}, Ba^{2+}, Fe^{2+}, Fe^{3+}, Al^{3+} concentrations were determined by AAS. Na^+, K^+, Cl^-, SO_4^{2-}, F^-, NO_3^- and NH_4^+ concentrations were measured by IC.

The cation exchange capacity (CEC) was then derived from the Ni consumption, i.e., the difference between the Ni concentration in the initial and the final extract solutions. The cumulative error of the entire procedure (i.e., extraction and analysis) is approximately 10 %. The cation concentrations determined before and after the experiments are used to calculate the cation exchange capacity. The exchange of cations can always take place in both directions. As long as cations (except nickel) are brought from the rock into the solution, the value is positive, meaning it is released from the rock. If cations from the solution are bound in the rock, meaning a backward reaction takes place, the exchange factor is negative.

This means that the forward reaction (from the rock into the solution) has positive values and the backward reaction (from the solution into the rock) has negative values. For nickel, the forward reaction (positive values) was defined as from the solution into rock and the backward reaction (negative values) from rock into solution.

In order to confirm the CEC value obtained by measuring the nickel concentration, major and trace cation (Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, Sr^{2+}, Ba^{2+}, Fe^{2+}, Fe^{3+}, Al^{3+}) concentrations in the final extract solution were also determined. The nickel, major and trace cation concentrations were measured in duplicate. pH was measured in the individual solutions before and after the experiments using a Schott Titroline alpha system.

All CEC experiments were conducted under anoxic conditions, so that the concentrations of redox specific ions like Fe^2, Fe^{3+} and NH_4^+ are obtained. Total iron (Fe_{tot}) and Fe^{2+} concentrations were measured by AAS, afterwards the Fe^{3+} concentration was calculated by the concentration of Fe_{tot} minus the concentration of Fe^{2+}. The redox potential of the solution was analyzed before and after the experiments for all CEC solutions using a WTW Multi 3620 IDS with a SenTix-ORP-T900 electrode.

4.0 RESULTS

The results of the BET SSA and CEC experimental measurements of the core samples (IG_BH05_SA001; IG_BH05_AR43) taken from borehole IG_BH05 are explained in the following sections.

4.1 BET Specific Surface Area

The results of the BET SSA measurements are summarized in Table 4 and Figure 3. The accuracy of the measurement for the grain size fractions (0.065-0.2 mm, 0.15-0.3 mm, 1-2 mm, 2-4 mm and 10-20 mm) and the core slice is ± 30%.

Table 4: Results of the specific surface area for the core sample IG_BH05_SA001 and the core sample IG_BH05_AR43 of IG_BH05 measured at different grain size fractions by the BET method (analytical error = ± 30 %)

Grain size fraction	Specific surface area [m^2/g]
core sample IG_BH05_SA001	
0.065-0.2 mm	0.92±0.28
0.15-0.3 mm	0.23±0.07
1-2 mm	0.08±0.02
2-4 mm	0.04±0.01
10-20 mm	0.03±0.01
Core (9 mm diameter; 2.5-3 cm thickness)	0.010±0.003

core sample IG_BH05_AR43	
0.15-0.3 mm	0.59±0.18
1-2 mm	0.27±0.08
2-4 mm	0.22±0.07
Core (9 mm diameter; 2.5-3 cm thickness)	0.04±0.01

For the core sample IG_BH05_SA001 the specific surface area of the grain size fraction 0.065-0.2 mm is 0.92 m^2/g, for the grain size fraction 0.15-0.3 mm is 0.23 m^2/g, for the grain size fraction 1-2 mm is 0.08 m^2/g, for the grain size fraction 2-4 mm is 0.04 m^2/g, for the grain size fraction 10-20 mm is 0.03 m^2/g, and for the core slice (9 mm diameter; 2.5-3 cm thickness) is 0.01 m^2/g.

For the core sample IG_BH05_AR43 the specific surface area of the grain size fraction 0.15-0.3 mm is 0.59 m^2/g, for the grain size fraction 1-2 mm is 0.27 m^2/g, for the grain size fraction 2-4 mm is 0.22 m^2/g, and for the core slice (9 mm diameter; 2.5-3 cm thickness) is 0.04 m^2/g.

Within the same sample and rock type, the specific surface area generally increases with decreasing grain size.

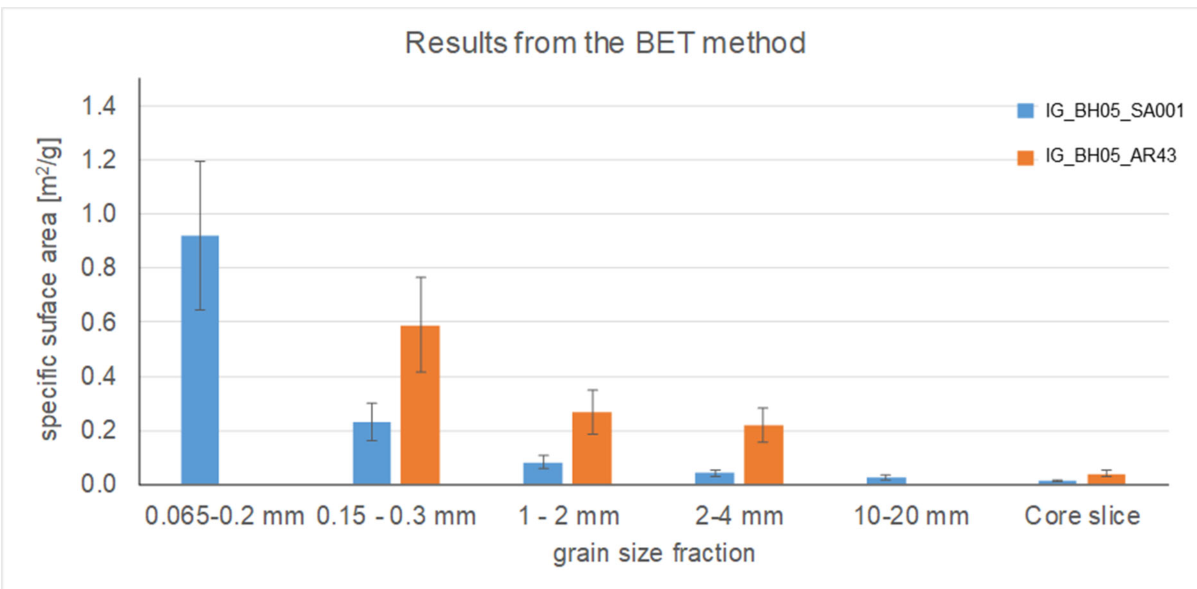


Figure 3: The specific surface area measured for the core sample IG_BH05_SA001 and the core sample IG_BH05_AR43 of IG_BH05 at different grain size fractions and at a 9 mm diameter core using the BET method

4.2 Cation Exchange Capacity

4.2.1 CEC_{Ni}

The initial Ni concentration of the Ni-en stock solution was on average for all experiments (including all start, sub and end samples of the Ni-en solution) 29.4 mg/L with a variation of ±2.9 mg/L. Each experiment was performed in duplicate indicated as No. 1 and No. 2 in the following tables and figures. Nickel concentrations of all experimental approaches were analysed for the periodically taken sub-samples. The element concentrations of the sample for the time-series CEC measurements are compiled in Appendix A, Tables A-3 to A-10.

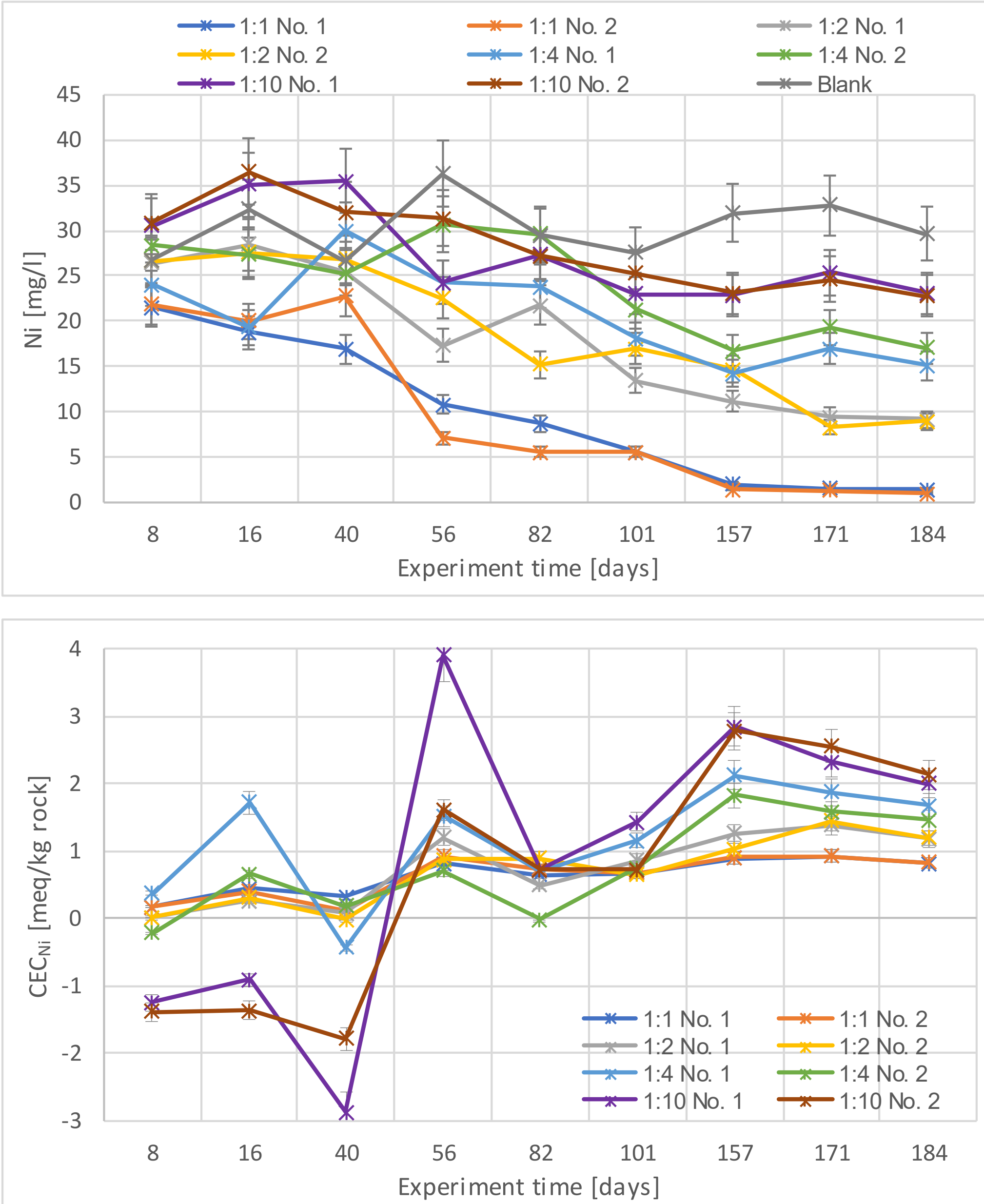


Figure 4: Nickel concentration in test solution (upper) and CEC$_{Ni}$ values (bottom) measured for the largest grain size fraction 10-20 mm over experimental time. Experiments ran for 184 days

Figure 4 shows the nickel concentrations and the resulting CEC$_{Ni}$ values during the course of the experiment for the largest grain size fraction (10-20 mm) versus experimental time. The nickel concentration in the solution decreases with the experimental time because nickel exchanges with the cations on the rock surface. As a result, the calculated CEC values increase with time. The equilibrium of Ni exchange with cations on the rock surface was defined as being reached when the nickel concentration between two subsamples did not change by more than ± 10 %. The time-series show that the time period of reaching Ni-equilibration depends on the rock core sample (solid)/ test solution (liquid) ratio. The experiments with high solid/ liquid (s/l) mass ratios (1:1, 1:2) reach Ni-equilibrium faster than those with lower s/l mass ratios (1:4, 1:10). As a result, the nickel concentration levels off at a constant lower value, confirming the cation exchange equilibrium within the experimental time (Figure 4). For all experiments cation exchange equilibrium was achieved with respect to the Ni-concentrations. The equilibrium time appears to depend on the s/l ratio. For the experiments conducted with a s/l ratio of 1:1 equilibrium was achieved after 56 days, with a s/l ratio of 1:2 after approximate 101 days, whereas for those with a s/l ratio of 1:4 and 1:10 equilibrium was nearly reached after 157 days. This can be explained by the higher availability of the exchangeable sites or reactive surface of the distinct grain size.

The results of the CEC experiments (concentrations of the final measurements when the experiment was completed) of IG_BH05_SA001 performed on the smallest grain size fraction (0.065-0.2 mm) are summarized in Table 5, the results measured for the middle grain size fraction (2-4 mm) are summarized in Table 6 and the results measured for the largest grain size fraction (10-20 mm) are summarized in Table 7.

Table 5: Element concentrations of the final CEC experiment solutions using different rock material / test solution mass ratios conducted with the smallest grain size fraction (0.065-0.2 mm) after 48 h (sample name IG_BH05_SA001 0.065-0.2 mm)

Hydro Lab.-No.		381672	381660	381661	381662	381663	381664	381665	381666	381667	381668
Sample		Ni-en solution	1:1 No. 1	1:1 No. 2	1:2 No. 1	1:2 No. 2	1:4 No. 1	1:4 No. 2	1:10 No. 1	1:10 No. 2	Blank
Rock/ test solution mass ratio (s/l ratio)	unit	-	1:1	1:1	1:2	1:2	1:4	1:4	1:10	1:10	-
Rock mass	g	-	39.997	40.007	20.000	20.013	10.000	9.995	10.000	10.015	0
Solution mass	g	-	38.975	40.044	39.894	39.231	39.824	39.372	98.019	98.858	73.759
pH value start		-	9.90	9.35	9.15	9.16	9.24	9.13	9.39	9.11	8.94
pH value end		-	9.64	9.59	9.48	9.54	9.45	9.43	9.37	9.32	8.93
Redox potential start	mV	-	16.7	-13.2	13.9	12.3	24.8	8.3	36.0	23.1	36.5
Redox potential end	mV	-	-73.4	-104.4	-70.3	-65.7	-70.7	-73.4	-28.5	-32.9	2.9
Nickel (Ni^{2+})	mg/l	31.5	2.16	3.95	1.82	2.48	6.32	6.01	20.7	20.9	29.3
Barium (Ba^{2+})	mg/l	0.051	0.307	0.472	0.139	0.177	0.038	0.021	0.014	0.021	0.043
Strontium (Sr^{2+})	mg/l	0.035	0.102	0.141	0.048	0.048	0.040	0.037	0.040	0.044	0.026
Aluminum (Al^{3+})	mg/l	< 0.02	21.0	35.1	7.19	13.38	0.587	0.482	0.089	0.434	< 0.02
Iron tot. (Fe_{tot})	mg/l	< 0.01	130	153	27.5	31.7	4.74	1.55	4.63	5.73	< 0.01
Iron-II (Fe^{2+})	mg/l	< 0.01	62.7	103	0.365	0.394	0.032	0.023	0.021	0.024	< 0.01
Iron-III (Fe^{3+})	mg/l	< 0.01	67.3	49.5	27.1	31.3	4.71	1.52	4.61	5.70	< 0.01
Sodium (Na^{+})	mg/l	< 0.2	83.5	82.3	54.0	55.4	32.4	32.8	14.8	15.0	1.33
Potassium (K^{+})	mg/l	< 0.1	4.74	3.48	2.63	2.47	1.80	1.68	1.02	1.12	1.51
Calcium (Ca^{2+})	mg/l	7.71	12.1	14.2	7.37	5.77	6.17	6.18	6.94	7.15	6.24
Magnesium (Mg^{2+})	mg/l	0.61	11.4	9.77	3.52	4.74	1.46	1.35	0.86	1.54	3.91
Ammonium (NH_4^{+})	mg/l	< 0.1	0.17	0.16	0.16	0.15	0.17	0.15	< 0.1	0.19	< 0.1

The results of the CEC experiments (concentrations of the final measurements when the experiment was completed) of IG_BH05_AR43 performed on the smallest grain size fraction (0.15-0.3 mm) are summarized in Table 8, the results measured for the middle grain size fraction (1-2 mm) are summarized in Table 9 and the results measured for the largest grain size fraction (2-4 mm) are summarized in Table 10.

Table 6: Element concentrations of the final CEC experiment solutions using different rock material / test solution mass ratios conducted with the medium grain size fraction (2-4 mm) after 96 h (sample name IG_BH05_SA001 2-4 mm)

Hydro Lab.-No.		380685	380689	380690	380691	380692	380693	380694	380695	380696	380697
Sample		Ni-en solution	1:1 No. 1	1:1 No. 2	1:2 No. 1	1:2 No. 2	1:4 No. 1	1:4 No. 2	1:10 No. 1	1:10 No. 2	Blank
Rock/ test solution mass ratio (s/l ratio)	unit	-	1:1	1:1	1:2	1:2	1:4	1:4	1:10	1:10	-
Rock mass	g	-	39.971	39.955	20.009	19.999	10.036	10.019	10.022	10.017	0
Solution mass	g	-	39.209	39.741	40.021	39.815	39.857	40.013	100.152	99.570	74.878
pH value start		-	9.18	9.20	9.09	9.07	9.05	8.99	9.00	8.97	8.92
pH value end		-	9.72	10.01	9.54	9.56	9.44	9.46	9.28	9.26	8.93
Redox potential start	mV	-	57.8	56.7	69.9	59.5	71.8	77.4	80.8	75.3	79.4

Hydro Lab.-No.		380685	380689	380690	380691	380692	380693	380694	380695	380696	380697
Redox potential end	mV	-	-224.3	-231.4	-158.0	-152.7	-78.1	-62.7	-56.1	-45.7	0.1
Nickel (Ni^{2+})	mg/l	30.4	0.680	0.020	2.01	2.12	21.5	10.4	25.5	25.2	30.9
Barium (Ba^{2+})	mg/l	0.042	0.106	0.162	0.034	0.022	0.0029	0.0024	0.0097	0.0096	0.051
Strontium (Sr^{2+})	mg/l	0.029	0.037	0.113	0.021	0.029	0.044	0.036	0.047	0.045	0.035
Aluminum (Al^{3+})	mg/l	< 0.02	10.0	42.3	1.78	1.14	0.100	< 0.02	0.124	0.112	0.022
Iron tot. (Fe_{tot})	mg/l	< 0.01	43.4	104	6.37	5.18	3.83	2.42	2.25	2.55	1.41
Iron-II (Fe^{2+})	mg/l	< 0.01	42.7	110	4.99	4.68	0.098	0.122	0.061	0.062	< 0.01
Iron-III (Fe^{3+})	mg/l	< 0.01	0.713	< 0.01	1.38	0.507	3.73	2.30	2.19	2.49	1.42
Sodium (Na^{+})	mg/l	< 0.2	57.3	48.1	35.1	37.1	21.7	18.6	8.51	8.50	1.18
Potassium (K^{+})	mg/l	1.13	3.72	1.82	3.50	3.50	3.91	3.90	1.54	1.28	1.90
Calcium (Ca^{2+})	mg/l	10.78	6.22	14.6	5.27	5.18	8.34	8.27	9.13	8.63	10.7
Magnesium (Mg^{2+})	mg/l	0.449	4.81	16.2	2.24	2.51	3.23	1.85	1.66	1.59	0.05
Ammonium (NH_4^{+})	mg/l	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1

The pH value and redox potential were measured at the beginning of the experiment right after adding the experimental solution to the grinded rock material and after the experiment (after 48 h, 72 h, 74 h, 96 h, 184 days for the grain size fractions 0.065-0.2 mm, 1-2 mm, 0.15-0.3 mm, 2-4 mm (74 h and 96 h) and 10-20 mm (184 days), respectively). During the experiments the pH values generally slightly increased or remained constant depending on the s/l ratio (Table 5 to 10).

Table 7: Element concentrations of the final CEC experiment solutions using different rock material / test solution mass ratios conducted with the largest grain size fraction (10-20 mm) after 184 days (sample name IG_BH05_SA001 10-20 mm)

Hydro Lab.-No.		380687	388014	388015	388016	388017	388018	388019	388020	388021	388022
Sample		Ni-en solution	1:1 No. 1	1:1 No. 2	1:2 No. 1	1:2 No. 2	1:4 No. 1	1:4 No. 2	1:10 No. 1	1:10 No. 2	Blank
Rock/ test solution mass ratio (s/l ratio)	unit	-	1:1	1:1	1:2	1:2	1:4	1:4	1:10	1:10	-
Rock mass	g	-	59.857	60.201	29.820	29.987	14.922	15.268	10.150	10.057	0
Solution mass	g	-	58.984	59.145	58.923	58.937	58.779	60.065	100.043	99.732	74.488
pH value start		-	9.05	9.06	9.02	9.02	9.01	8.99	9.05	9.00	8.98
pH value end		-	9.16	9.37	9.15	9.20	9.00	9.21	8.92	8.86	8.75
Redox potential start	mV	-	27.2	41.7	56.5	49.8	53.4	54.1	62.4	60.4	78.0
Redox potential end	mV	-	29.2	-2.7	42.4	32.6	59.1	52.8	77.9	87.3	108.5
Nickel (Ni^{2+})	mg/l	27.0	1.43	0.95	9.20	8.96	15.1	17.1	23.1	22.7	29.6
Barium (Ba^{2+})	mg/l	0.045	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.015	0.016	0.019
Strontium (Sr^{2+})	mg/l	0.029	0.051	0.036	0.086	0.072	0.076	0.081	0.068	0.064	0.045
Aluminum (Al^{3+})	mg/l	< 0.02	0.091	0.139	0.066	0.097	0.041	0.044	0.026	0.026	0.034
Iron tot. (Fe_{tot})	mg/l	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Iron-II (Fe^{2+})	mg/l	< 0.01	0.027	0.013	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Iron-III (Fe^{3+})	mg/l	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Sodium (Na^{+})	mg/l	0.28	44.9	43.8	26.4	27.2	17.3	14.0	6.60	7.39	1.66
Potassium (K^{+})	mg/l	< 0.1	1.89	1.67	1.93	1.79	1.94	1.51	1.11	1.18	2.80

Hydro Lab.-No.		380687	388014	388015	388016	388017	388018	388019	388020	388021	388022
Calcium (Ca^{2+})	mg/l	10.1	6.58	7.12	10.6	9.60	11.0	10.3	10.2	10.2	11.0
Magnesium (Mg^{2+})	mg/l	0.482	0.062	0.040	0.131	0.098	0.256	0.270	0.375	0.348	0.404
Ammonium (NH_4^+)	mg/l	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1

Table 8: Element concentrations of the final CEC experiment solutions using different rock material / test solution mass ratios conducted with the largest grain size fraction (0.15-0.3 mm) after 74 h (sample name IG_BH05_AR43 0.15-0.3 mm)

Hydro Lab.-No.											
Sample		Ni-en solution	1:1 No. 1	1:1 No. 2	1:2 No. 1	1:2 No. 2	1:4 No. 1	1:4 No. 2	1:10 No. 1	1:10 No. 2	Blank
Rock/ test solution mass ratio (s/l ratio)	unit	-	1:1	1:1	1:2	1:2	1:4	1:4	1:10	1:10	-
Rock mass	g	-	39.961	40.009	19.988	19.978	10.009	9.998	5.001	5.000	0
Solution mass	g	-	39.660	39.741	39.401	40.017	39.819	42.460	49.575	49.668	50.344
pH value start		-	9.10	9.03	9.01	9.04	9.02	9.02	8.95	8.58	8.18
pH value end		-	9.32	9.38	9.40	9.36	9.36	9.36	9.20	9.16	7.98
Redox potential start	mV	-	55.3	62.5	68.1	65.6	66.7	62.9	93.3	82.0	111.1
Redox potential end	mV	-	-125.3	-148.5	-73.7	-74.7	-55.1	-53.0	-14.4	-30.6	136.6
Nickel (Ni^{2+})	mg/l	26.9	< 0.0001	0.084	0.240	0.010	0.330	0.380	5.26	5.20	28.0
Barium (Ba^{2+})	mg/l	< 0.1	< 0.1	< 0.1	0.01	0.03	< 0.1	0.01	0.02	< 0.1	< 0.1
Strontium (Sr^{2+})	mg/l	< 0.1	0.09	0.09	0.08	0.07	0.07	0.08	0.04	0.03	< 0.1
Aluminum (Al^{3+})	mg/l	2.59	12.8	25.3	3.53	2.08	2.78	3.68	2.84	8.77	2.40
Iron tot. (Fe_{tot})	mg/l	< 0.01	< 0.01	2.63	0.424	< 0.01	< 0.01	< 0.01	0.62	< 0.01	< 0.01
Iron-II (Fe^{2+})	mg/l	< 0.01	< 0.01	< 0.01	0.003	< 0.01	< 0.01	< 0.01	0.01	< 0.01	< 0.01
Iron-III (Fe^{3+})	mg/l	< 0.01	< 0.01	2.63	0.421	< 0.01	< 0.01	< 0.01	0.61	< 0.01	< 0.01
Sodium (Na^+)	mg/l	0.23	22.0	20.0	15.9	12.5	8.3	13.2	4.0	5.5	2.3
Potassium (K^+)	mg/l	0.13	7.1	8.1	4.5	4.7	4.4	5.8	4.3	6.0	4.5
Calcium (Ca^{2+})	mg/l	37.9	60.6	78.9	37.7	56.2	40.2	51.6	40.0	46.9	35.0
Magnesium (Mg^{2+})	mg/l	0.01	7.1	7.0	5.8	5.9	4.9	4.9	2.7	2.5	0.04
Ammonium (NH_4^+)	mg/l	0.02	< 0.1	0.03	0.05	0.03	0.08	0.05	0.11	0.04	0.07

Table 9: Element concentrations of the final CEC experiment solutions using different rock material / test solution mass ratios conducted with the largest grain size fraction (1-2 mm) after 72 h (sample name IG_BH05_AR43 1-2 mm)

Hydro Lab.-No.											
Sample		Ni-en solution	1:1 No. 1	1:1 No. 2	1:2 No. 1	1:2 No. 2	1:4 No. 1	1:4 No. 2	1:10 No. 1	1:10 No. 2	Blank
Rock/ test solution mass ratio (s/l ratio)	unit	-	1:1	1:1	1:2	1:2	1:4	1:4	1:10	1:10	-
Rock mass	g	-	40.006	40.000	20.002	20.005	10.003	10.001	10.003	9.999	0
Solution mass	g	-	39.791	39.278	39.886	40.255	39.854	39.984	98.897	99.101	74.469
pH value start		-	8.92	8.86	8.79	9.04	8.55	8.38	8.23	8.23	8.06

Hydro Lab.-No.										
pH value end		-	9.73	9.73	9.71	9.67	9.66	9.66	9.42	9.34	8.02
Redox potential start	mV	-	50.2	59.8	61.8	56.9	75.0	63.7	90.4	82.5	113.0
Redox potential end	mV	-	-137.3	-151.3	-76.2	-112.8	-63.9	-65.4	-36.9	-42.2	34.0
Nickel (Ni^{2+})	mg/l	27.9	0.049	0.053	0.120	0.120	0.440	0.430	4.33	4.95	31.8
Barium (Ba^{2+})	mg/l	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.001	0.003	< 0.1
Strontium (Sr^{2+})	mg/l	< 0.1	0.11	0.06	0.06	0.08	0.07	0.07	0.03	0.02	< 0.1
Aluminum (Al^{3+})	mg/l	1.24	1.15	1.28	1.13	1.44	< 0.01	2.16	4.02	1.65	< 0.01
Iron tot. (Fe_{tot})	mg/l	0.290	0.470	0.620	0.530	0.610	0.570	0.250	0.910	1.30	0.600
Iron-II (Fe^{2+})	mg/l	0.034	0.011	0.09	0.40	0.10	0.054	0.019	< 0.01	0.10	0.015
Iron-III (Fe^{3+})	mg/l	0.26	0.46	0.53	0.13	0.51	0.52	0.23	0.91	1.2	0.59
Sodium (Na^{+})	mg/l	0.19	27.5	20.5	11.2	11.1	6.7	7.4	2.2	2.0	0.33
Potassium (K^{+})	mg/l	0.14	5.6	5.4	3.6	4.2	3.4	3.8	1.3	1.6	1.6
Calcium (Ca^{2+})	mg/l	9.6	20.8	24.4	35.1	28.9	34.3	23.9	113.0	41.3	8.0
Magnesium (Mg^{2+})	mg/l	0.02	3.5	3.0	3.5	3.7	4.0	3.7	3.7	3.5	0.02
Ammonium (NH_4^{+})	mg/l	0.083	0.28	0.28	0.27	0.27	0.23	0.25	0.15	0.13	0.046

Table 10: Element concentrations of the final CEC experiment solutions using different rock material / test solution mass ratios conducted with the largest grain size fraction (2-4 mm) after 74 h (sample name IG_BH05_AR43 2-4 mm)

Hydro Lab.-No.										
Sample		Ni-en solution	1:1 No. 1	1:1 No. 2	1:2 No. 1	1:2 No. 2	1:4 No. 1	1:4 No. 2	1:10 No. 1	1:10 No. 2	Blank
Rock/ test solution mass ratio (s/l ratio)	unit	-	1:1	1:1	1:2	1:2	1:4	1:4	1:10	1:10	-
Rock mass	g	-	40.011	39.997	19.994	20.005	10.000	9.998	10.004	10.005	0
Solution mass	g	-	39.834	39.816	38.797	38.937	39.08	39.751	99.056	99.632	38.839
pH value start		-	8.71	8.64	8.68	8.53	8.29	8.11	8.03	8.08	7.95
pH value end		-	10.15	10.10	9.98	9.99	9.82	9.80	9.50	9.45	8.10
Redox potential start	mV	-	100.0	109.1	108.3	102.2	63.8	77.7	85.4	94.7	98.2
Redox potential end	mV	-	-127.0	-126.3	-103.6	-99.6	-70.7	-66.8	-49.0	-43.1	107.7
Nickel (Ni^{2+})	mg/l	27.5	0.170	0.074	0.170	0.110	0.960	0.740	6.76	5.51	31.1
Barium (Ba^{2+})	mg/l	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Strontium (Sr^{2+})	mg/l	< 0.1	0.05	0.05	0.07	0.07	0.09	0.09	0.05	0.05	< 0.1
Aluminum (Al^{3+})	mg/l	2.14	1.22	< 0.01	1.79	1.33	1.78	1.42	2.05	< 0.01	6.10
Iron tot. (Fe_{tot})	mg/l	0.41	0.800	15.8	0.950	< 0.01	1.18	1.31	0.930	2.25	2.30
Iron-II (Fe^{2+})	mg/l	< 0.01	0.38	0.06	0.054	0.03	0.48	0.14	0.01	0.012	< 0.01
Iron-III (Fe^{3+})	mg/l	0.41	0.42	15.7	0.89	0.42	0.7	1.17	0.92	2.23	2.30
Sodium (Na^{+})	mg/l	0.70	37.0	38.7	27.0	31.7	14.3	13.3	7.3	5.9	42.6
Potassium (K^{+})	mg/l	0.46	5.2	6.7	6.3	8.5	3.8	3.7	2.9	2.0	7.0
Calcium (Ca^{2+})	mg/l	29.6	33.4	13.7	21.1	22.5	36.8	84.9	423.0	21.4	184.0
Magnesium (Mg^{2+})	mg/l	0.02	1.2	2.2	3.0	2.6	2.6	3.0	4.4	4.1	0.34
Ammonium (NH_4^{+})	mg/l	2.62	0.57	0.58	0.46	< 0.05	0.46	0.43	0.71	0.88	< 0.05

Table 11 and Figures 5 and 6 give an overview of the calculated mean CEC values based on the nickel concentrations. Depending on the rock material / test solution ratio (s/l ratio) and the grain size fraction, the CEC_{Ni} value varies from 0.82 to 9.25 meq/kg rock. The results of the duplicates of the individual experiments agree well with each other (Table 11). The change in the Ni concentrations was very low, in the range of the standard deviation. This shows that the experiments are comparable and reproducible. An exception is the s/l ratio of 1:4 experiment of grain size fraction 2-4 mm (core IG_BH05_SA001), where the replicates differ from each other. The reason is probably that the 10 g rock weight (in 400 g solution) corresponds to only a few rock grains and thus the reactive surface of the rock sample can differ significantly between the two replicates.

The results also show that the CEC value for each grain size fraction increases as the volume of solution increases in relation to the mass of rock. For the grain size fraction 0.065-0.2 mm (IG_BH05_SA001) the CEC_{Ni} values increase from 0.86-0.90 meq/kg rock at a s/l ration of 1:1 to 2.83-3.12 meq/kg rock at a s/l ratio of 1:10. For the grain size fraction 0.15-0.3 mm (IG_BH05_AR43) the CEC_{Ni} values increase from 0.94-0.95 meq/kg rock at a s/l ration of 1:1 to 7.68-7.72 meq/kg rock at a s/l ratio of and 1:10. For the grain size fraction 1-2 mm (IG_BH05_AR43) the CEC_{Ni} values increase from 1.06-1.08 meq/kg rock at a s/l ration of 1:1 to 9.07-9.25 meq/kg rock at a s/l ratio of 1:10. For the grain size fraction 2-4 mm (IG_BH05_AR43) the CEC_{Ni} values increase from 1.05 meq/kg rock at a s/l ration of 1:1 to 8.21-8.68 meq/kg rock at a s/l ratio of 1:10.

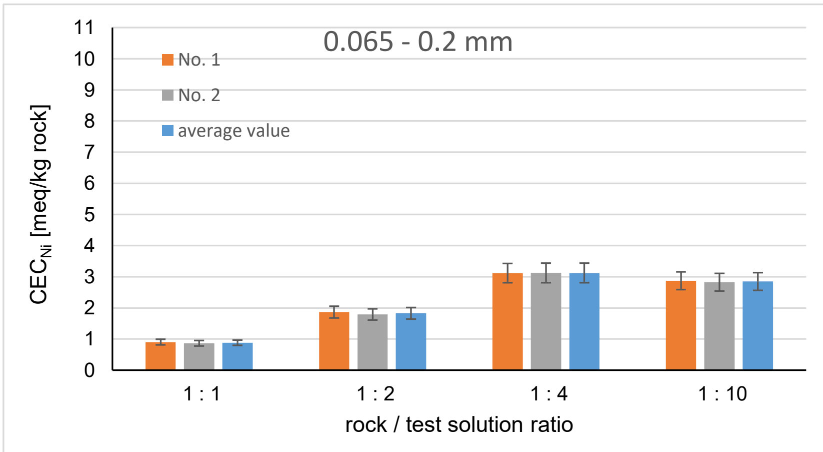
The grain size fraction 2-4 mm and 10-20 mm of the core IG_BH05_SA001 shows significantly lower trends of the CEC_{Ni} value increase with the increasing s/l ratio than the grain size fraction 0.065-0.2 mm of core IG_BH05_SA001 and the different grain size fractions for the core IG_BH05_AR43. For grain size fraction 2-4 mm (IG_BH05_SA001) at the s/l ratio 1:1 the CEC_{Ni} values increase from 1.01-1.05 meq/kg rock to 1.84-1.93 meq/kg rock at a s/l ratio of 1:10. For the grain size fraction 10-20 mm (IG_BH05_SA001) the CEC_{Ni} values goes from 0.82-0.83 meq/kg rock at a s/l ratio of 1:1 to 2.0-2.13 meq/kg rock at a s/l ratio of 1:10.

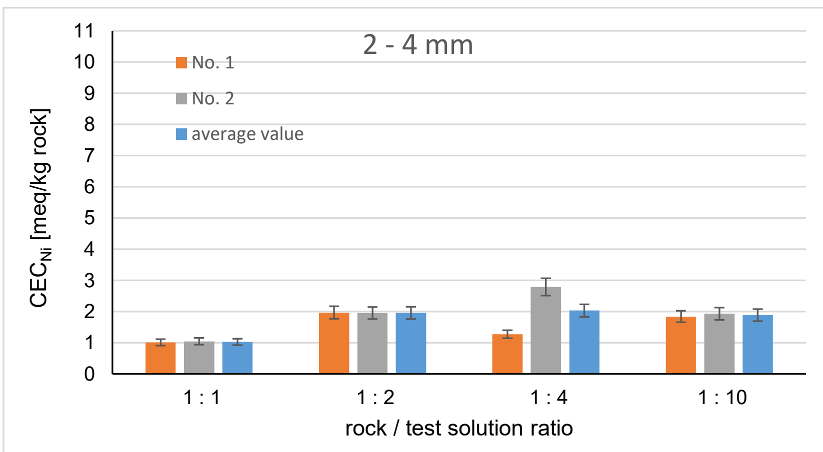
For the core IG_BH05_SA001 CEC_{Ni} values increase with decreasing grain size fraction for the experimental approaches with a s/l ratio of 1:4 and 1:10. For the experiments with a s/l ratio of 1:2 this trend is less pronounced, and for the s/l ratio 1:1 the CEC_{Ni} results are constant or vary slightly at a low level, independent of the grain size fraction (Table 11, Figure 5). For the individual grain size fraction of core IG_BH05_AR43 these trends are not observed. They show almost similar CEC_{Ni} results for the individual grain sizes at the same s/l ratios (Table 11, Figure 6)

Table 11: Calculated CEC_{Ni} values, mean CEC_{Ni} values and standard deviation from the CEC experiments with the grain size fractions 0.065-0.2 mm, 0.15-0.3 mm, 1-2 mm, 2-4 mm and 10-20 mm

Rock/test solution mass ratio		1:1	1:1	1:2	1:2	1:4	1:4	1:10	1:10
core sample IG_BH05_SA001									
0.065-0.2 mm	CEC_{Ni} (meq/kg rock)	0.90	0.86	1.87	1.79	3.12	3.13	2.87	2.83
	Mean CEC_{Ni} (meq/kg rock)	0.88±0.03		1.83±0.05		3.12±0.01		2.85±0.03	
2-4 mm	CEC_{Ni} (meq/kg rock)	1.01	1.05	1.97	1.95	1.27	2.79	1.84	1.93
	Mean CEC_{Ni} (meq/kg rock)	1.03±0.03		1.96±0.01		2.03±1.07		1.88±0.06	
10-20 mm	CEC_{Ni} (meq/kg rock)	0.82	0.83	1.19	1.19	1.68	1.45	2.00	2.13
	Mean CEC_{Ni} (meq/kg rock)	0.82±0.01		1.19±0.01		1.57±0.16		2.07±0.09	
core sample IG_BH05_AR43									
0.15-0.3 mm	CEC_{Ni} (meq/kg rock)	0.95	0.94	1.86	1.91	3.75	4.00	7.68	7.72
	Mean CEC_{Ni} (meq/kg rock)	0.95±0.002		1.89±0.03		3.87±0.17		7.70±0.03	

1-2 mm	CEC_{Ni} (meq/kg rock)	1.08	1.06	2.15	2.17	4.26	4.27	9.25	9.07
	Mean CEC_{Ni} (meq/kg rock)	1.07±0.01		2.16±0.01		4.27±0.01		9.16±0.13	
2-4 mm	CEC_{Ni} (meq/kg rock)	1.05	1.05	2.04	2.05	4.01	4.11	8.21	8.68
	Mean CEC_{Ni} (meq/kg rock)	1.05±0.002		2.05±0.01		4.06±0.07		8.44±0.33	





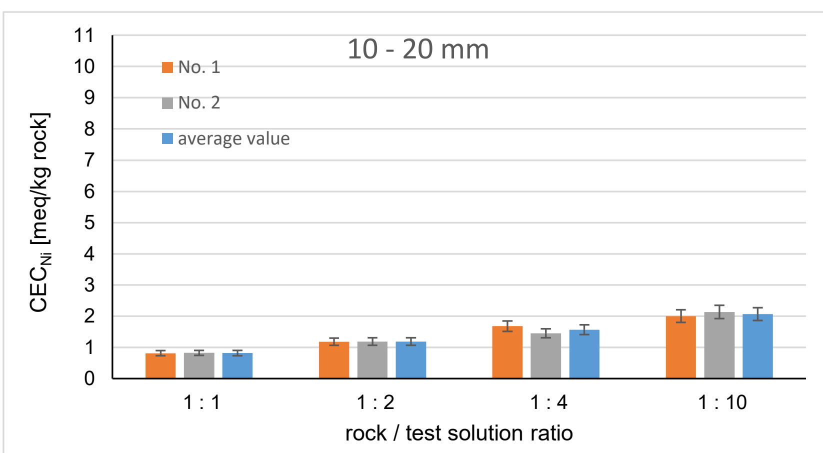


Figure 5: Results of the CEC_{Ni} values determined for the different grain size fractions (0.065-0.2 mm; 2-4 mm; 10-20 mm) of core IG_BH05_SA001 and rock material/test solution mass ratios bases on calculation by nickel concentrations

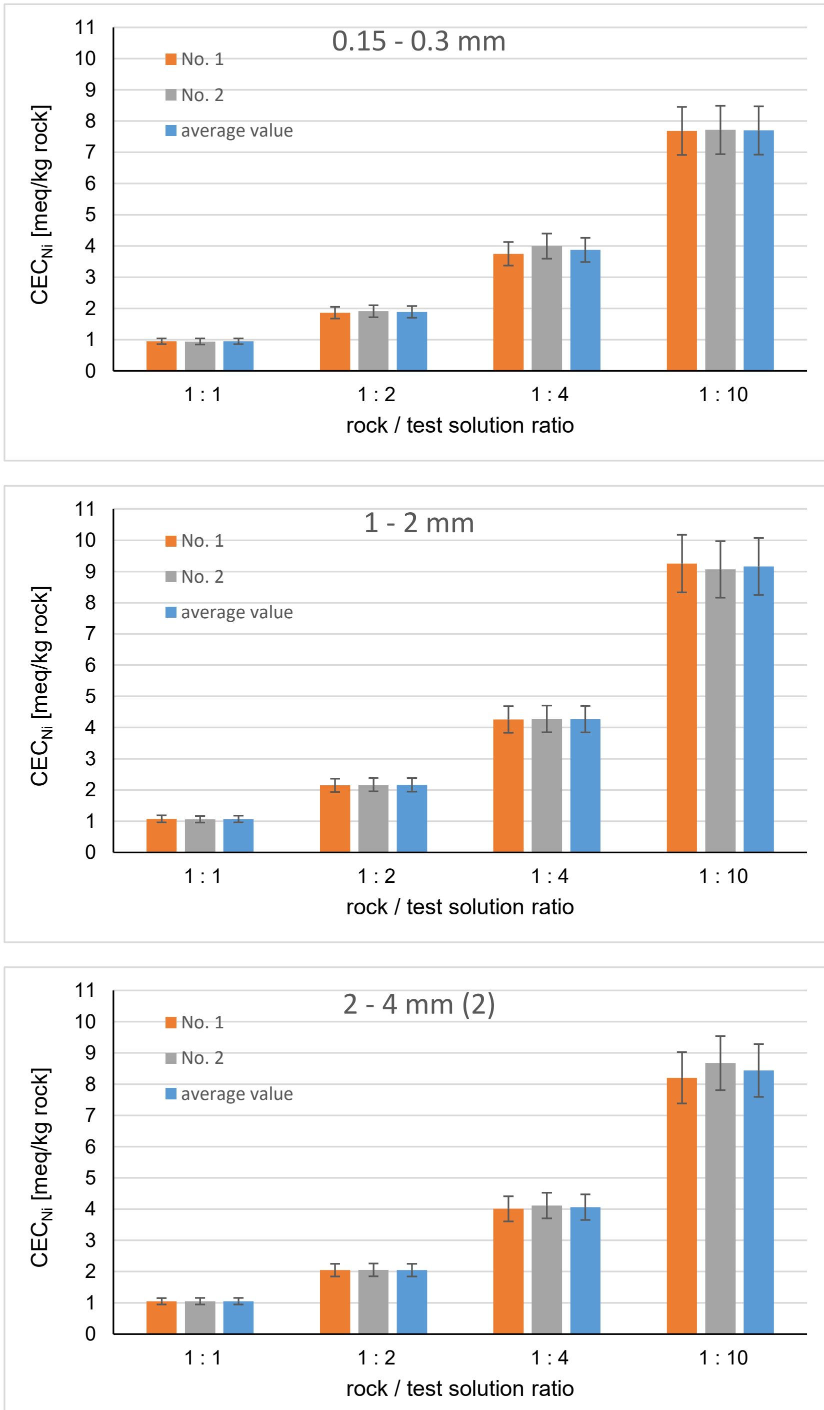


Figure 6: Results of the CEC_{Ni} values determined for the different grain size fractions (0.15-0.3 mm; 1-2 mm; 2-4 mm) of core IG_BH05_AR43 and rock material/test solution mass ratios bases on calculation by nickel concentrations

4.2.2 CEC$_{Cation}$

To verify the measured CEC$_{Ni}$ values calculated by nickel concentration measurement, the concentrations of major and trace cations (Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, Al^{3+}, Ba^{2+}, Sr^{2+}, Fe) in the final extract solutions are measured by ion chromatography and AAS. The concentrations of each cation and the CEC calculations based on the sum of cations (CEC$_{cations}$) are summarized in Table 12 to 17. The results of the CEC calculations based on the sum of all the cations are summarized in Table 18 and Figures 7 and 8. The CEC calculations based on the cation concentrations take the initial concentrations into account and are corrected for those.

Table 12: CEC values of each cation (Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, Al^{3+}, Ba^{2+}, Sr^{2+}, Fe) and CEC values of the sum of cations determined for the smallest grain size fraction (0.065-0.2 mm). Sample name IG_BH05_SA001 0.065-0.2 mm. All values in meq/kg rock

Hydro Lab.-No.	381660	381661	381662	381663	381664	381665	381666	381667
Sample	1:1 No. 1	1:1 No. 2	1:2 No. 1	1:2 No. 2	1:4 No. 1	1:4 No. 2	1:10 No. 1	1:10 No. 2
Rock/ test solution mass ratio (s/l ratio)	1:1	1:1	1:2	1:2	1:4	1:4	1:10	1:10
Nickel (Ni^{2+})	0.90	0.86	1.87	1.79	3.12	3.13	2.87	2.83
Barium (Ba^{2+})	3.74×10^{-3}	6.25×10^{-3}	2.77×10^{-3}	3.80×10^{-3}	-3.37×10^{-4}	-1.31×10^{-3}	-4.20×10^{-3}	-3.29×10^{-3}
Strontium (Sr^{2+})	1.69×10^{-3}	2.63×10^{-3}	9.90×10^{-4}	9.73×10^{-4}	1.29×10^{-3}	1.04×10^{-3}	3.18×10^{-3}	4.11×10^{-3}
Aluminum (Al^{3+})	1.81	3.12	1.27	2.32	0.21	0.17	0.09	0.44
Iron tot. (Fe_{tot})	4.53	5.47	1.96	2.22	0.68	0.22	1.63	2.02
Iron-II (Fe^{2+})	2.19	3.69	0.03	0.03	4.58×10^{-3}	3.17×10^{-3}	0.01	0.01
Iron-III (Fe^{3+})	3.52	2.66	2.90	3.29	1.01	0.32	2.43	3.02
Sodium (Na^+)	3.48	3.53	4.57	4.61	5.38	5.39	5.74	5.87
Potassium (K^+)	0.08	0.05	0.06	0.05	0.03	0.02	-0.12	-0.10
Calcium (Ca^{2+})	0.28	0.40	0.11	-0.05	-0.02	-0.01	0.34	0.44
Magnesium (Mg^{2+})	0.60	0.48	-0.06	0.13	-0.80	-0.83	-2.46	-1.93
Ammonium (NH_4^+)	0.01	0.01	0.02	0.02	0.04	0.03	< 0.1	0.10
CEC$_{cations}$ (all cation/sum)	10.80	13.06	7.93	9.31	5.52	4.99	5.22	6.86
CEC$_{main-cations}$ (Na^+, K^+, Ca^{2+}, Mg^{2+})	4.45	4.45	4.68	4.75	4.59	4.57	3.50	4.29

Note: Negative CEC values of some elements mean that their initial concentrations are higher than the final after the experiments.

Table 13: CEC values of each cation (Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, Al^{3+}, Ba^{2+}, Sr^{2+}, Fe) and CEC values of the sum of cations determined for the medium grain size fraction (2-4 mm). Sample name IG_BH05_SA001 2-4 mm. All values in meq/kg rock

Hydro Lab.-No.	380689	380690	380691	380692	380693	380694	380695	380696
Sample	1:1 No. 1	1:1 No. 2	1:2 No. 1	1:2 No. 2	1:4 No. 1	1:4 No. 2	1:10 No. 1	1:10 No. 2
Rock/ test solution mass ratio (s/l ratio)	1:1	1:1	1:2	1:2	1:4	1:4	1:10	1:10
Nickel (Ni^{2+})	1.01	1.05	1.97	1.95	1.27	2.79	1.84	1.93

Hydro Lab.-No.	380689	380690	380691	380692	380693	380694	380695	380696
Sample	1:1 No. 1	1:1 No. 2	1:2 No. 1	1:2 No. 2	1:4 No. 1	1:4 No. 2	1:10 No. 1	1:10 No. 2
Rock/ test solution mass ratio (s/l ratio)	1:1	1:1	1:2	1:2	1:4	1:4	1:10	1:10
Barium (Ba^{2+})	7.75×10^{-4}	1.60×10^{-3}	-5.08×10^{-4}	-8.60×10^{-4}	-2.80×10^{-3}	-2.85×10^{-3}	-6.06×10^{-3}	-6.04×10^{-3}
Strontium (Sr^{2+})	5.51×10^{-5}	1.77×10^{-3}	-6.42×10^{-4}	-2.65×10^{-4}	8.56×10^{-4}	6.93×10^{-5}	2.66×10^{-3}	2.16×10^{-3}
Aluminum (Al^{3+})	0.87	3.74	0.31	0.20	0.03	< 0.02	0.10	0.09
Iron tot. (Fe_{tot})	1.47	3.64	0.36	0.27	0.34	0.15	0.30	0.41
Iron-II (Fe^{2+})	1.50	3.90	0.36	0.33	0.01	0.02	0.02	0.02
Iron-III (Fe^{3+})	-0.04	< 0.01	-3.65×10^{-3}	-0.10	0.49	0.19	0.41	0.57
Sodium (Na^{+})	2.39	2.03	2.95	3.11	3.54	3.03	3.19	3.16
Potassium (K^{+})	0.05	-2.04×10^{-3}	0.08	0.08	0.20	0.20	-0.09	-0.16
Calcium (Ca^{2+})	-0.22	0.19	-0.54	-0.55	-0.47	-0.48	-0.78	-1.03
Magnesium (Mg^{2+})	0.38	1.32	0.36	0.40	1.04	0.59	1.32	1.26
Ammonium (NH_4^{+})	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
$CEC_{cations}$ (all cation/sum)	4.95	10.92	3.52	3.51	4.69	3.48	4.04	3.74
$CEC_{main\text{-}cations}$ (Na^{+}, K^{+}, Ca^{2+}, Mg^{2+})	2.61	3.54	2.85	3.05	4.32	3.34	3.64	3.24

Note: Negative CEC values of some elements mean that their initial concentrations are higher than the final after the experiments.

Table 14: CEC values of each cation (Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, NH_4^{+}, Al^{3+}, Ba^{2+}, Sr^{2+}, Fe) and CEC values of the sum of cations of the largest grain size fraction (10-20 mm). Sample name IG_BH05_SA001 10-20 mm. All values in meq/kg rock

Hydro Lab.-No.	388014	388015	388016	388017	388018	388019	388020	388021
Sample	1:1 No. 1	1:1 No. 2	1:2 No. 1	1:2 No. 2	1:4 No. 1	1:4 No. 2	1:10 No. 1	1:10 No. 2
Rock/ test solution mass ratio (s/l ratio)	1:1	1:1	1:2	1:2	1:4	1:4	1:10	1:10
Nickel (Ni^{2+})	0.82	0.83	1.19	1.19	1.68	1.45	2.00	2.13
Barium (Ba^{2+})	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	-5.93×10^{-4}	-5.17×10^{-4}
Strontium (Sr^{2+})	1.18×10^{-4}	-1.67×10^{-4}	1.59×10^{-3}	1.04×10^{-3}	2.40×10^{-3}	2.83×10^{-3}	4.72×10^{-3}	3.95×10^{-3}
Aluminum (Al^{3+})	5.39×10^{-3}	9.92×10^{-3}	6.07×10^{-3}	1.18×10^{-2}	2.38×10^{-3}	3.66×10^{-3}	-8.52×10^{-3}	-8.48×10^{-3}
Iron tot. (Fe_{tot})	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Iron-II (Fe^{2+})	8.14×10^{-4}	3.93×10^{-4}	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Iron-III (Fe^{3+})	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Sodium (Na^{+})	1.60	1.56	1.84	1.89	2.32	1.83	1.95	2.27
Potassium (K^{+})	-0.02	-0.02	-0.04	-0.04	-0.07	-0.11	-0.39	-0.38
Calcium (Ca^{2+})	-0.19	-0.16	-0.03	-0.12	4.42×10^{-3}	-0.11	-0.30	-0.34
Magnesium (Mg^{2+})	-0.02	-0.03	-0.04	-0.04	-0.04	-0.04	-0.02	-0.04
Ammonium (NH_4^{+})	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
$CEC_{cations}$ (all cation/sum)	1.38	1.35	1.74	1.70	2.21	1.57	1.23	1.50
$CEC_{main\text{-}cations}$ (Na^{+}, K^{+}, Ca^{2+}, Mg^{2+})	1.37	1.34	1.73	1.69	2.20	1.57	1.24	1.51

Note: Negative CEC values of some elements mean that their initial concentrations are higher than the final after the experiments.

Table 15: CEC values of each cation (Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, Al^{3+}, Ba^{2+}, Sr^{2+}, Fe) and CEC values of the sum of cations of the largest grain size fraction (0.15-0.3 mm). Sample name IG_BH05_AR43 0.15-0.3 mm. All values in meq/kg rock

Hydro Lab.-No.								
Sample	1:1 No. 1	1:1 No. 2	1:2 No. 1	1:2 No. 2	1:4 No. 1	1:4 No. 2	1:10 No. 1	1:10 No. 2
Rock/ test solution mass ratio (s/l ratio)	1:1	1:1	1:2	1:2	1:4	1:4	1:10	1:10
Nickel (Ni^{2+})	0.95	0.94	1.86	1.91	3.75	4.00	7.68	7.72
Barium (Ba^{2+})	< 0.01	< 0.01	2.87×10^{-4}	8.75×10^{-4}	< 0.01	6.18×10^{-4}	2.89×10^{-3}	< 0.01
Strontium (Sr^{2+})	2.04×10^{-3}	2.04×10^{-3}	3.60×10^{-3}	3.20×10^{-3}	6.36×10^{-3}	7.76×10^{-3}	9.05×10^{-3}	6.80×10^{-3}
Aluminum (Al^{3+})	0.77	1.69	0.17	-0.05	0.11	0.40	0.32	4.69
Iron tot. (Fe_{tot})	< 0.01	9.36×10^{-2}	2.99×10^{-2}	< 0.01	< 0.01	< 0.01	0.22	< 0.01
Iron-II (Fe^{2+})	< 0.01	< 0.01	2.12×10^{-4}	< 0.01	< 0.01	< 0.01	3.55×10^{-3}	< 0.01
Iron-III (Fe^{3+})	< 0.01	1.40×10^{-1}	4.46×10^{-2}	< 0.01	< 0.01	< 0.01	0.32	< 0.01
Sodium (Na^+)	0.85	0.76	1.17	0.89	1.04	2.01	0.73	1.38
Potassium (K^+)	0.066	0.091	0.000	0.010	-0.010	0.141	-0.051	0.38
Calcium (Ca^{2+})	1.27	2.18	0.27	2.12	1.03	3.52	2.47	5.90
Magnesium (Mg^{2+})	0.58	0.57	0.93	0.97	1.59	1.70	2.17	2.01
Ammonium (NH_4^+)	< 0.1	-2.20×10^{-3}	-2.19×10^{-3}	-4.44×10^{-3}	2.21×10^{-3}	-4.71×10^{-3}	2.20×10^{-2}	-1.65×10^{-2}
$CEC_{cations}$ (all cation/sum)	3.53	5.38	2.56	3.94	3.77	7.78	5.90	14.35
$CEC_{main-cations}$ (Na^+, K^+, Ca^{2+}, Mg^{2+})	2.76	3.60	2.37	3.98	3.65	7.37	5.33	9.67

Note: Negative CEC values of some elements mean that their initial concentrations are higher than the final after the experiments.

Table 16: CEC values of each cation (Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, Al^{3+}, Ba^{2+}, Sr^{2+}, Fe) and CEC values of the sum of cations of the largest grain size fraction (1-2 mm). Sample name IG_BH05_AR43 1-2 mm. All values in meq/kg rock

Hydro Lab.-No.								
Sample	1:1 No. 1	1:1 No. 2	1:2 No. 1	1:2 No. 2	1:4 No. 1	1:4 No. 2	1:10 No. 1	1:10 No. 2
Rock/ test solution mass ratio (s/l ratio)	1:1	1:1	1:2	1:2	1:4	1:4	1:10	1:10
Nickel (Ni^{2+})	1.08	1.06	2.15	2.17	4.26	4.27	9.25	9.07
Barium (Ba^{2+})	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	1.44×10^{-4}	4.33×10^{-4}
Strontium (Sr^{2+})	2.50×10^{-3}	1.34×10^{-3}	2.73×10^{-3}	3.67×10^{-3}	6.37×10^{-3}	6.39×10^{-3}	6.77×10^{-3}	4.52×10^{-3}
Aluminum (Al^{3+})	0.08	0.09	0.17	0.21	< 0.01	0.64	2.95	1.21
Iron tot. (Fe_{tot})	-4.63×10^{-3}	7.03×10^{-4}	-5.00×10^{-3}	7.21×10^{-4}	-4.28×10^{-3}	-5.01×10^{-2}	1.10×10^{-1}	2.48×10^{-1}
Iron-II (Fe^{2+})	-1.42×10^{-4}	2.64×10^{-3}	2.75×10^{-2}	6.13×10^{-3}	5.56×10^{-3}	5.73×10^{-4}	< 0.01	3.02×10^{-2}
Iron-III (Fe^{3+})	-6.95×10^{-3}	-3.17×10^{-3}	-4.93×10^{-2}	-8.65×10^{-3}	-1.50×10^{-2}	-7.73×10^{-2}	1.70×10^{-1}	3.25×10^{-1}
Sodium (Na^+)	1.18	0.86	0.94	0.94	1.10	1.23	0.80	0.72

Hydro Lab.-No.								
Sample	**1:1 No. 1**	**1:1 No. 2**	**1:2 No. 1**	**1:2 No. 2**	**1:4 No. 1**	**1:4 No. 2**	**1:10 No. 1**	**1:10 No. 2**
Rock/ test solution mass ratio (s/l ratio)	**1:1**	**1:1**	**1:2**	**1:2**	**1:4**	**1:4**	**1:10**	**1:10**
Potassium (K^+)	0.10	0.10	0.10	0.13	0.18	0.22	-0.08	0.00
Calcium (Ca^{2+})	0.64	0.80	2.70	2.10	5.23	3.17	51.80	16.47
Magnesium (Mg^{2+})	0.28	0.24	0.57	0.61	1.30	1.21	2.99	2.84
Ammonium (NH_4^+)	0.013	0.013	0.025	0.025	0.041	0.045	0.057	0.046
$CEC_{cations}$ (all cation/sum)	2.29	2.11	4.50	4.03	7.86	6.48	58.65	21.54
$CEC_{main\text{-}cations}$ (Na^+, K^+, Ca^{2+}, Mg^{2+})	2.20	2.00	4.31	3.78	7.82	5.84	55.53	20.03

Note: Negative CEC values of some elements mean that their initial concentrations are higher than the final after the experiments.

Table 17: CEC values of each cation (Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, Al^{3+}, Ba^{2+}, Sr^{2+}, Fe) and CEC values of the sum of cations of the largest grain size fraction (2-4 mm). Sample name IG_BH05_AR43 2-4 mm. All values in meq/kg rock

Hydro Lab.-No.								
Sample	**1:1 No. 1**	**1:1 No. 2**	**1:2 No. 1**	**1:2 No. 2**	**1:4 No. 1**	**1:4 No. 2**	**1:10 No. 1**	**1:10 No. 2**
Rock/ test solution mass ratio (s/l ratio)	**1:1**	**1:1**	**1:2**	**1:2**	**1:4**	**1:4**	**1:10**	**1:10**
Nickel (Ni^{2+})	1.05	1.05	2.04	2.05	4.01	4.11	8.21	8.68
Barium (Ba^{2+})	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Strontium (Sr^{2+})	1.14×10^{-3}	1.14×10^{-3}	3.10×10^{-3}	3.11×10^{-3}	8.03×10^{-3}	8.17×10^{-3}	1.13×10^{-2}	1.14×10^{-2}
Aluminum (Al^{3+})	-0.36	< 0.01	-0.62	-0.69	-1.25	-1.38	-2.97	< 0.01
Iron tot. (Fe_{tot})	-0.05	0.48	-0.09	-0.13	-0.16	-0.14	-0.49	-0.02
Iron-II (Fe^{2+})	1.35×10^{-2}	2.14×10^{-3}	3.75×10^{-3}	2.09×10^{-3}	6.72×10^{-2}	1.99×10^{-2}	3.55×10^{-3}	4.28×10^{-3}
Iron-III (Fe^{3+})	-0.10	0.72	-0.15	-0.20	-0.34	-0.24	-0.73	-0.04
Sodium (Na^+)	-0.24	-0.17	-1.32	-0.92	-4.81	-5.07	-15.20	-15.90
Potassium (K^+)	-0.05	-0.01	-0.03	0.07	-0.32	-0.34	-1.04	-1.27
Calcium (Ca^{2+})	-7.48	-8.46	-15.77	-15.69	-28.71	-19.66	118.09	-80.80
Magnesium (Mg^{2+})	0.07	0.15	0.42	0.36	0.73	0.87	3.31	3.08
Ammonium (NH_4^+)	0.03	0.03	0.05	< 0.1	0.10	0.09	0.39	0.49
$CEC_{cations}$ (all cation/sum)	-8.08	-7.97	-17.36	-16.99	-34.41	-25.61	102.10	-94.41
$CEC_{main\text{-}cations}$ (Na^+, K^+, Ca^{2+}, Mg^{2+})	-7.70	-8.48	-16.70	-16.17	-33.11	-24.19	105.16	-94.89

Note: Negative CEC values of some elements mean that their initial concentrations are higher than the final after the experiments.

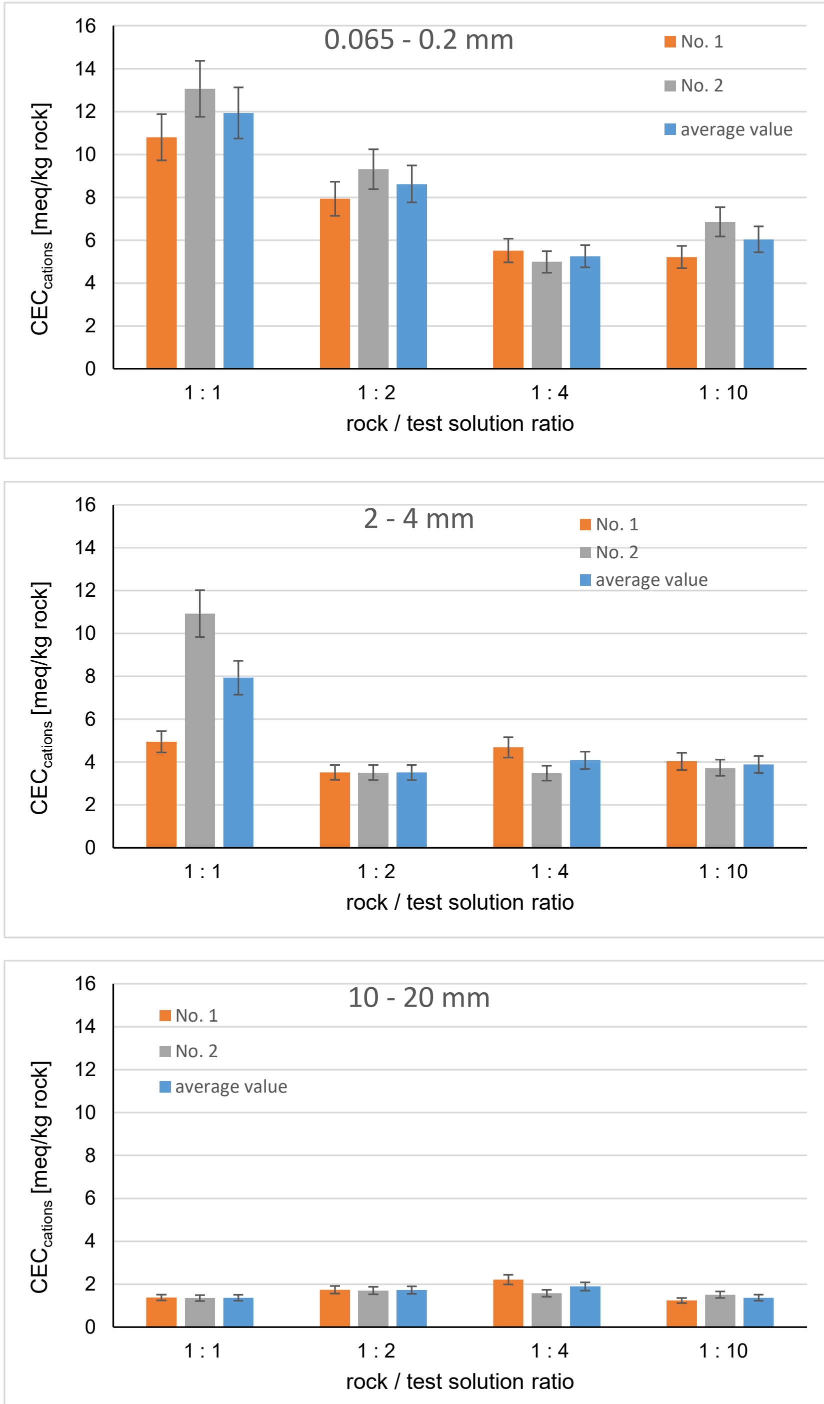


Figure 7: Results of the $CEC_{Cations}$ values determined for the different grain size fractions (0.065-0.2 mm, 2-4 mm, 10-20 mm) of core IG_BH05_SA001 and rock material / test solution mass ratios based on calculation by the sum of concentrations of all the cations in the solution

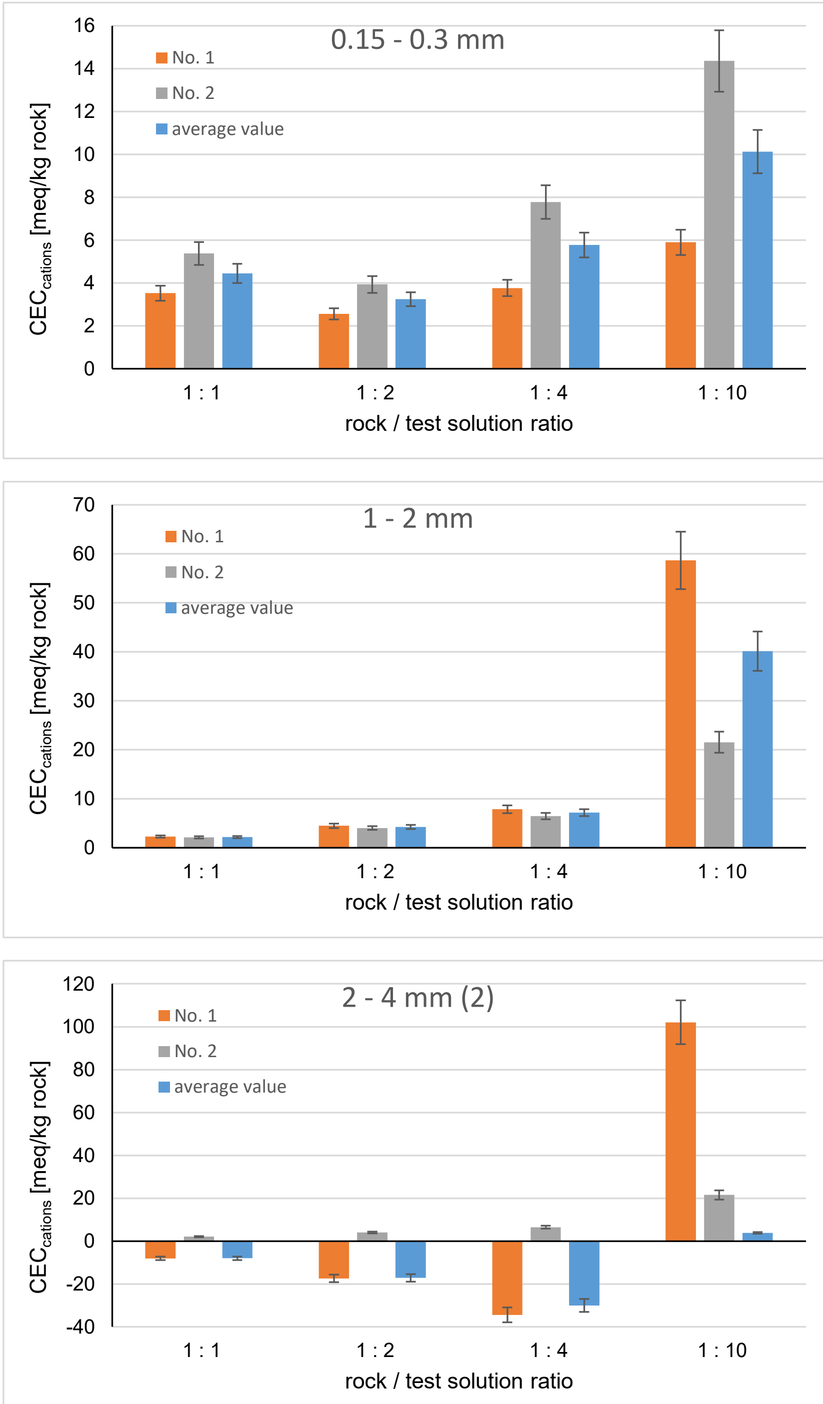


Figure 8: Results of the $CEC_{Cations}$ values determined for the different grain size fractions (0.15-0.3 mm, 1-2 mm, 2-4 mm) of core IG_BH05_AR43 and rock material / test solution mass ratios based on calculation by the sum of concentrations of all the cations in the solution

Table 18: Calculated $CEC_{Cations}$ values, mean $CEC_{Cations}$ values and standard deviation from the CEC experiments with the grain size fractions 0.065-0.2 mm, 0.15-0.3 mm, 1-2 mm, 2-4 mm and 10-20 mm

Rock/test solution mass ratio		1:1	1:1	1:2	1:2	1:4	1:4	1:10	1:10
core sample IG_BH05_SA001									
0.065-0.2 mm	$CEC_{Cations}$ (meq/kg rock)	10.80	13.06	7.93	9.31	5.52	4.99	5.22	6.86
	Mean $CEC_{Cations}$ (meq/kg rock)	11.93±1.60		8.62±0.98		5.25±0.37		6.04±1.16	
2-4 mm	$CEC_{Cations}$ (meq/kg rock)	4.95	10.92	3.52	3.51	4.69	3.48	4.04	3.74
	Mean $CEC_{cations}$ (meq/kg rock)	7.93±4.22		3.52±0.01		4.08±0.86		3.89±0.21	
10-20 mm	$CEC_{Cations}$ (meq/kg rock)	1.38	1.35	1.74	1.70	2.21	1.57	1.23	1.50
	Mean $CEC_{cations}$ (meq/kg rock)	1.37±0.02		1.72±0.03		1.89±0.45		1.37±0.19	
core sample IG_BH05_AR43									
0.15-0.3 mm	$CEC_{Cations}$ (meq/kg rock)	3.53	5.38	2.56	3.94	3.77	7.78	5.90	14.35
	Mean $CEC_{Cations}$ (meq/kg rock)	4.45±1.31		3.25±0.97		5.77±2.83		10.13±5.98	
1-2 mm	$CEC_{Cations}$ (meq/kg rock)	2.29	2.11	4.50	4.03	7.86	6.48	58.65	21.54
	Mean $CEC_{Cations}$ (meq/kg rock)	2.20±0.13		4.27±0.33		7.17±0.98		40.09±26.24	
2-4 mm	$CEC_{Cations}$ (meq/kg rock)	-8.08	-7.97	-17.36	-16.99	-34.41	-25.61	102.10	-94.41
	Mean $CEC_{Cations}$ (meq/kg rock)	-8.03±0.08		-17.17±0.33		-30.01±0.98		3.85±138.96	

The measured CEC_{cation} values significantly increased during the experiment time for the largest grain size fraction (10-20 mm) (Appendix A, Tables A-3 to A-11).

The results of the experiment duplicates (No. 1 and No. 2) show that the CEC_{cation} values calculated by the sum of all cations are relatively comparable (Table 12). Only the 1:1 experiment at the middle grain size fraction (2-4 mm; IG_BH05_SA001) shows larger differences. Also, some duplicates of the grain size fractions of core IG_BH05_AR43 shows larger differences, mainly by the high s/l ratios: 0.15-0.3 mm 1:4 and 1:10; 1-2 mm 1:10 and 2-4 mm 1:4. Due to less available reactive surface area for cation adsorption in relation to the volume of solution, this trend can be observed.

As the grain size increases, the surface area of the rock samples decreases in relation to the solution. This is reflected in a decrease of the CEC_{cation} values with increasing grain size. At the largest grain size fraction, the difference of the determined CEC_{cation} values between the individual rock to test solution ratios is very small as shown by the s/l ratios 1:1, 1:2 and 1:4. As shown by the s/l ratio 1:10 the variations between the replicates were large and so the CEC values are shown also high variations, this is reasoned probably that the 10 g rock weight (in 100 g solution) corresponds to only a few rock grains and thus the reactive surface of the rock sample can differ significantly between the two replicates.

The results show that for the core IG_BH05_SA001 the CEC_{cation} values calculated by the sum of all the cations (measured by the s/l = 1:1, 1:2 and 1:4 experiments), except the 2nd 2-4 mm experiment, (1.37-11.93 meq/kg rock) are 1.2 to 13.5 times higher than the CEC_{Ni} values (0.82-3.12 meq/kg rock) calculated from the nickel concentrations. The same trend can be observed for the grain size fractions 0.15-0.3 mm and 1-2 mm of the core IG_BH05_AR43 where the CEC_{cation} values calculated by the sum of all the cations (measured by the s/l = 1:1, 1:2 and 1:4 experiments), (2.20-7.19 meq/kg rock) are 1.7 to 2.1 times higher than the CEC_{Ni} values (1.07-4.27 meq/kg rock) calculated from the nickel concentrations. Only for the s/l ratio 1:10 experiments of the largest grain size fraction (10-20 mm) of the core IG_BH05_SA001 the CEC_{cation} values are clearly lower than the CEC_{Ni} values. An exception is the experiment with the grain size fraction 2-4 mm of the core IG_BH05_AR43, where all s/l ratios show lower CEC_{cation} values (-30.01-3.85 meq/kg rock) than the CEC_{Ni} values (1.05-8.44 meq/kg rock). This is due to very low and widely varying cation concentrations.

Some elements (Al, Ba, Sr, Fe, Na, K, Ca, Mg) show slight negative CEC values. This means that the initial concentrations are higher than the final after the experiments. This can be caused by an oversaturation of the individual elements in the experimental solution and a precipitation of those elements. The negative concentrations are taken into account for the sum of concentrations. This leads to a negative CEC_{cation} sum value for the s/l ratio 1:1, 1:2 and 1:4 by the grain size fraction 2-4 mm of the core IG_BH05_AR43. Due to the general low cation exchange capacity of the rock and the larger grain size fractions, especially, the effects of the cation decrease during the experiments is pronounced.

The experiment solutions at the end of the experiments did not show as high cation concentrations as that for the CEC measurements for the core sample IG_BH04_SA001 (also biotite granodiorite tonalite, APM-RP-01332-0355), because possible abrasion and erosion caused by end-over-end shaking of the previous experiments was avoided by normal daily shaking of the large grain size fraction experiments and so an overestimation of the calculated CEC_{cation} values was avoided.

4.2.3 "Zero Exchange Experiment"

To evaluate the influence of possible disturbing effects, resulting in the overestimation of exchanged cations, aqueous extraction experiments, following the same procedures as the Ni-exchange experiments were conducted without addition of Ni-en.

The mineralization of a leach solution is the sum of: (i) the constituents originally dissolved in the porewater, (ii) the constituents present in fluid inclusions, and (iii) elements brought in by water-rock interactions during the leaching process. Thus, the aqueous leach solution represents a complex composition in rocks with abundant fluid inclusions, porewater components and reacting mineral phases.

Fluid inclusions, a high salt content in porewater and the presence of carbonates, such as calcite and dolomite (Ca^{2+} and Mg^{2+}) and other minerals, for example, feldspars (K^+, Na^+ and Ca^{2+}) in the rock material can induce an overestimated $CEC_{cations}$ value. Carbonates with concentrations > 1 wt.% are not expected in crystalline rocks from the Revell site.

K^+ and Na^+ cations might originate from porewater in the Ni-en complex solution. Hence, the measured cation concentration has to be corrected for the porewater composition (Waber et al., 2003). Therefore, a blank experiment has to be realized parallel to the CEC experiments. Exchangeable cations that are not analyzed also may lead to an underestimated CEC value (e.g. NH_4^+, H^+) (Waber et al., 2003).

To evaluate these effects, a "zero exchange experiment" was conducted. The aim was to determine the basic dissolution of elements from the rock by rock-water interaction processes during the experiments and to use this as a basic value for the CEC calculation ($CEC_{cation\ corr.} = CEC_{cation} - CEC_{cation\ zero}$; $CEC_{cation\ zero}$ is the CEC measured by the "zero exchange experiment", $CEC_{cation\ corr.}$ is the CEC after the correction). For this purpose, rock material was added to ultrapure water following the procedures for the normal CEC-experiment (same grain size fraction for a certain period of time: IG_BH05_SA001: 0.065-0.2 mm for 48 h, 2-4 mm for 96 h, 10-20 mm for app. 184 d; IG_BH05_AR43: 0.15-0.3 mm for 74 h, 1-2 mm for 72 h, 2-4 mm for 74 h) for one rock material / test solution ratio (see Table 19). Therefore, the highest s/l ratio (1:1) was taken, since by the largest reactive surface area and thus the maximum cation exchange was to be expected with this ratio. The "zero exchange experiments" run parallel to the CEC experiments under the same conditions and time period. All “zero exchange experiments” were sampled and analyzed followed the same protocols as the CEC experiments.

Table 19: Overview of the experimental set-ups of the “zero exchange experiment”

Grain size fraction	Rock/test solution mass ratio	Reaction time	Mass (rock material) [g]	Mass (solution) [g]
core sample IG_BH05_SA001				
0.065-0.2 mm	1:1	48 h	40	40
0.065-0.2 mm Blank	-	48 h	0	75
2-4 mm	1:1	96 h	40	40
2-4 mm Blank	-	96 h	0	75
10-20 mm	1:1	184 days	60	60
10-20 mm Blank	-	184 days	0	75
core sample IG_BH05_AR43				
0.15-0.3 mm	1:1	74 h	16.5	16.5
0.15-0.3 mm Blank	-	74 h	0	50
1-2 mm	1:1	72 h	40	40
1-2 mm Blank	-	72 h	0	75
2-4 mm	1:1	74 h	40	40
2-4 mm Blank	-	74 h	0	40

The cation concentration and so also the $CEC_{cation\ zero}$ values slightly increased during the experiment time of the largest grain size fraction (10-20 mm) (Appendix A, Tables A-3 to A-11).

The sum of cation concentration of the “Zero Exchange Experiments” of the core IG_BH05_SA001 are 185 mg/l (0.065-0.2 mm), 144 mg/l (2-4 mm) and 42 mg/l (10-20 mm). In contrast at the normal experiments (1:1) the cation sum concentrations were 284 mg/l (0.065-0.2 mm), 177 mg/l (2-4 mm) and 54 mg/l (10-20 mm).

The sum of cation concentration of the “Zero Exchange Experiments” of the core IG_BH05_AR43 are 112 mg/l (0.15-0.3 mm), 54 mg/l (1-2 mm) and 233 mg/l (2-4 mm). In contrast at the normal experiments (1:1) the cation sum concentrations were 129 mg/l (0.15-0.3 mm), 60 mg/l (1-2 mm) and 87 mg/l (2-4 mm).

The results of the experiment duplicates (No. 1 and No. 2) show that the $CEC_{cation\ zero}$ values calculated by the sum of all cations are comparable (Table 20).

It can be seen that the highest $CEC_{cation\ zero}$ values were observed by the smallest grain size fraction (0.065-0.2 mm) for the core IG_BH05_SA001. In contrast by the core IG_BH01_AR43 the highest $CEC_{cation\ zero}$ values were observed for the largest grain size fraction (2-4 mm).

Normally if the grain size fraction increases, the $CEC_{cation\ zero}$ values will decrease, since less reactive surface area of the rock sample is available for cation exchange in relation to the volume of solution. This is shown by the results of the core IG_BH01_SA001. The $CEC_{cation\ zero}$ value determined by the largest grain size is lower than that of the other two smaller grain size fractions. For the core IG_BH05_AR43 the $CEC_{cation\ zero}$ values show the opposite trend that the grain size fractions 1-2 mm and 2-4 mm have similar $CEC_{cation\ zero}$ values and the grain size fraction 0.15 – 0.3 mm has a significant lower, even negative $CEC_{cation\ zero}$ value. This may be due to the small grain size difference between the grain size fractions used for the experiments; and a potential different rock composition (reactivity) of the two cores and the low concentrations of the individual cations in solution, which show only very small differences compared to the blank sample, some of which are within the measurement accuracy.

Table 20: Calculated $CEC_{cation\ zero}$ values (mean CEC-cation values) based on all cation concentrations from the zero exchange experiments with the grain size fractions 0.065-0.2 mm, 0.15-0.3 mm, 1-2 mm, 2-4 mm and 10-20 mm at the end of the experiments. The CEC_{cation} values and the $CEC_{cation\ coor.}$ values after correction with the $CEC_{cation\ zero}$ values

		$CEC_{cation\ zero}$ (zero exchange experiment)		CEC_{cation}		$CEC_{cation\ corr.}$
Rock/test solution mass ratio		1:1	1:1	1:1	1:1	1:1
core sample IG_BH05_SA001						
0.065-0.2 mm	(meq/kg rock)	8.17	8.53	10.80	13.06	-
	Mean (meq/kg rock)	8.35±0.25		11.93±1.60		3.58±1.60
2-4 mm	(meq/kg rock)	7.66	4.80	4.95	10.92	-
	Mean (meq/kg rock)	6.23±2.02		7.93±4.22		1.70±4.22
10-20 mm	(meq/kg rock)	1.36	1.50	1.38	1.35	-
	Mean (meq/kg rock)	1.43±0.10		1.37±0.02		-0.06±0.10
core sample IG_BH05_AR43						
0.15-0.3 mm	(meq/kg rock)	-2.05	-1.76	3.53	5.38	
	Mean (meq/kg rock)	-1.91±0.20		4.45±1.31		6.36±1.31
1-2 mm	(meq/kg rock)	0.87	1.52	2.29	2.11	
	Mean (meq/kg rock)	1.20±0.46		2.20±0.13		1.00±0.46
2-4 mm	(meq/kg rock)	1.30	1.36	-8.08	-7.97	
	Mean (meq/kg rock)	1.33±0.04		-8.03±0.08		-9.35±0.08

The results show that the $CEC_{cation\ zero}$ values without any Ni-cation-exchange calculated by the sum of all the cations range from 1.36 to 8.53 meq/kg rock for the core sample IG_BH05_SA001 and from -2.05 to 1.52 meq/kg rock for the core sample IG_BH05_AR43, respectively (Table 20).The $CEC_{cation\ zero}$ values of the grain size fraction 0.15-0.3 mm of the core IG_BH05_AR43 are negative, which means that their initial concentrations in the solution are higher than the final concentrations in the solution after the experiments.

For the grain size fractions 10-20 mm (IG_BH05_SA001) and 2-4 mm (IG_BH05_AR43) the corrected CEC_{cation} values are negative, which means that the $CEC_{cation,zero}$ (zero exchange experiments) are higher than the CEC_{cation} (Ni-en experiment) values. This is caused by the generally low cation exchange capacity of the rocks and the low concentrations of ions brought in solution. For the grain size fraction 10-20 mm (IG_BH05_SA001) both values are within the determined error ranges (Table 20). For the grain size fraction 2-4 mm (IG_BH05_AR43) the $CEC_{cation,zero}$ value is six times as high as the CEC_{cation} value. This can be caused by heterogeneities in the sample scale and the influence of nickel in the CEC experiment.

The experiment solutions at the end of the experiments did not show as high cation concentrations as that for the CEC measurements for the core sample IG_BH04_SA001 (biotite granodiorite tonalite, APM-RP-01332-0355), because possible abrasion and erosion caused by end-over-end shaking during the previous experiments was avoided by normal daily shaking of the large grain size fraction experiments and so an overestimation of the calculated CEC_{cation} values was avoided.

4.2.4 Comparison of Determined CEC Results

The comparison of the $CEC_{cations}$ and the $CEC_{cations\ zero}$ values (Figure 9) shows that the largest part of the cation concentration in the test solution is not by an exchange with nickel from the solution, but by the above-described processes (e.g. mineralization of leach solution, fluid conclusions, porewater; see chapter 4.2.3). Therefore, it is absolutely necessary to determine the $CEC_{cation\ zero}$ value and to correct the CEC_{cation} value with it.

It can be seen that the highest CEC_{Ni} and CEC_{cation} values were determined at a rock material to test solution ratio (s/l) of 1:10 for IG_BH05_SA001 and IG_BH05_AR43. If the rock to test solution ratio increases, the CEC_{Ni} and CEC_{cation} values decrease significantly, since less reactive surface area of the rock sample is available in relation to the volume of solution for cation exchange. Also, as the grain size increases the surface area of the rock sample decreases in relation to the solution. This is also reflected in a decrease of the CEC_{Ni} and CEC_{cation} values with increasing grain size fraction. At the largest grain size fraction (10-20 mm), the difference of the CEC_{Ni} and CEC_{cation} values measured at the individual rock sample to test solution mass ratios is very small.

After the correction, the CEC_{cation} values are higher than (0.065-0.2 mm; 0.15-0.3mm), similar to (1-2mm, 2-4 mm IG_BH05_SA001) or even lower than (10-20 mm, 2-4 mm IG_BH05_AR43) the CEC_{Ni} values (Figure 9). This could be caused by different rock-solution interactions or by an individual variation of the used rock particles (porewater, reactive surface) in the experiments.

The core sample IG_BH05_AR43 (amphibolite) shows significantly higher CEC_{Ni} values than the core sample IG_BH05_SA001 (diabase dyke), which could indicate a different mineralogical composition of the core sample, causing a higher reactivity of the material.

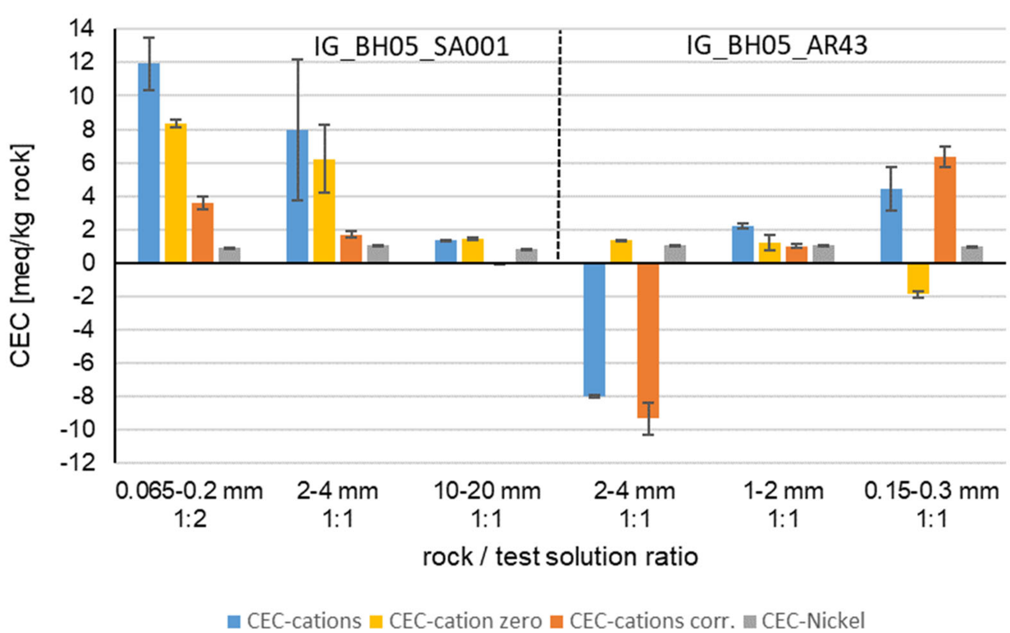


Figure 9: Results of the CEC values of the different grain size fractions and rock / test solution ratios calculated by the Ni-concentration (CEC_{Nickel}; grey bar), the sum of all cations in the solution (CEC_{cation}; blue bar), the sum of all cations in the zero solution ($CEC_{cation\ zero}$; yellow bar) and corrected with the zero exchange experiment values ($CEC_{cation\ corr.}$; orange bar) for the core samples IG_BH05_SA001 and IG_BH05_AR43.

5.0 SUMMARY

The investigations of the surface area by the BET method and the cation exchange capacity conducted on two crystalline core samples IG_BH05_SA001 (diabase dyke) and IG_BH05_AR43 (amphibolite) from borehole IG_BH05 can be summarized as follows:

- In general, the specific surface area increases with decreasing particle size.
- The specific surface area of the grain size fraction 0.065-0.2 mm for the core sample IG_BH05_SA001 is 0.92±0.28 m^2/g.
- The specific surface area of the grain size fraction 0.15-0.3 mm for the core sample IG_BH05_SA001 is 0.23±0.07 m^2/g.
- The specific surface area of the grain size fraction 1-2 mm for the core sample IG_BH05_SA001 is 0.08±0.02 m^2/g.
- The specific surface area of the grain size fraction 2-4 mm for the core sample IG_BH05_SA001 is 0.04±0.01 m^2/g.
- The specific surface area of the grain size fraction 10-20 mm for the core sample IG_BH05_SA001 is 0.03±0.01 m^2/g.
- The specific surface area of the core slice (9 mm diameter and about 2.5-3.0 cm thickness) for the core sample IG_BH05_SA001 is 0.013±0.004 m^2/g.
- The specific surface area of the grain size fraction 0.15-0.3 mm for the core sample IG_BH05_AR43 is 0.59±0.18 m^2/g.
- The specific surface area of the grain size fraction 1-2 mm for the core sample IG_BH05_AR43 is 0.27±0.08 m^2/g.
- The specific surface area of the grain size fraction 2-4 mm for the core sample IG_BH05_AR43 is 0.22±0.07 m^2/g.
- The specific surface area of the core slice (9 mm diameter and about 2.5-3.0 cm thickness) for the core sample IG_BH05_AR43 is 0.04±0.012 m^2/g.
- Depending on the rock material / test solution mass ratio and the grain size fraction, the CEC_{Ni} values for the diabase core sample IG_BH05_SA001 vary from 0.82 to 3.12 meq/kg rock.
- Depending on the rock material / test solution mass ratio and the grain size fraction, the CEC_{Ni} values for the amphibolite core sample IG_BH05_AR43 vary from 0.95 to 9.16 meq/kg rock.
- The results also show that the CEC_{Ni} value increases as the volume of test solution increases in relation to the mass of rock.
- The CEC_{cation} values calculated from the sum of all cations (Na^+, K^+, Mg^{2+}, Ca^{2+}, NH_4^+, Al^{3+}, Ba^{2+}, Sr^{2+}, Fe_{tot}) for the diabase dyke core sample IG_BH05_SA001 vary between 1.37 and 11.93 meq/kg rock depending on

the rock material / test solution ratio and are higher than the CEC_{Ni} values calculated from the nickel concentrations.

- The CEC_{cation} values calculated from the sum of all cations (Na^+, K^+, Mg^{2+}, Ca^{2+}, NH_4^+, Al^{3+}, Ba^{2+}, Sr^{2+}, Fe_{tot}) for the amphibolite core sample IG_BH05_AR47 vary between 2.20 and 40.09 meq/kg rock depending on the rock material / test solution ratio and are higher than the CEC_{Ni} values calculated from the nickel concentrations. The gran size fraction 2-4 mm shows negative values for the s/l ratios 1:1, 1:2 to 1:4.
- The CEC_{cation} values of the largest grain size fraction (10-20 mm) significantly increased over the experiment time.

It can be summarized that the measured CEC_{Ni} value depends on or is affected by various factors and processes, which include the particle size of rock sample (reactive surface), the rock sample / test solution ratio, mineralogical heterogeneities at the sample scale and the experimental setup (e.g. over head shaking caused abrasion).

On the other hand, the $CEC_{Cations}$ value also depends on or is affected by various factors and processes, which include the release of porewater, the opening of fluid inclusions, the particle size of rock sample (reactive surface), the rock sample / test solution ratio, mineralogical heterogeneities at the sample scale and the experimental set-up (e.g. over head shaking caused abrasion).

In addition to the calculation of the CEC value from the nickel concentration, the calculation from the sum of the cations ($CEC_{cations}$) is used to check the CEC_{Ni} values. Here it is important to note which cations (elements) are included in the calculation, as this can change the CEC value significantly.

It was also shown that the grain size fraction and consequently the reactive surface of rock sample as well as the rock sample / test solution ratio have a large influence on the measured CEC value.

Consequently, the CEC_{Ni} values should be used, but always taking into account the previously discussed factors and checking the CEC_{cation} values in order to know all possible influencing factors and to take them into account if relevant.

6.0 REFERENCES

Bayens, B., Bradbury, M.H., 1994. Physico-Chemical Characterization and Calculated In Situ Porewater Chemistry for a Low Permeability Palfris Marl Sample from Wellenberg. Technical report 94-22, Nagra, PSI, Würenlingen and Villigen.

Blackburn, C.E. and Hinz, P., 1996. Gold and base metal potential of the northwest part of the Raleigh Lake greenstone belt, northwestern Ontario-Kenora Resident Geologist's District; in Summary of Field Work and Other Activities 1996, Ontario Geological Survey, Miscellaneous Paper 166, p.113-115.

Bradbury, M.H., Baeyens, B., 1997. Derivation of In Situ Opalinus Clay Porewater Compositions from Experimental and Geochemical Modelling Studies. Technical report 97-07, Nagra, PSI, Würenlingen and Villigen.

Bradbury. M.H., Baeyens. B., 1998. N2-BET Surface Area Measurements on Crushed and Intact Minerals and Rocks: A Proposal for Estimating Sorption Transfer Factors. Nuclear Technology, 122.

Brunauer, S., Emmett, P. H., Teller, E, 1938. Adsorption of gases in multimolecular layers. J. Am. Chem. Soc. 60, 309-319.

DesRoches, A., Sykes, M., Parmenter, A. and Sykes, E., 2018. Lineament Interpretation of the Revell Batholith and Surrounding Greenstone Belts (Nuclear Waste Management Organization. No. NWMO-TR-2018-19.

Eichinger, F. Voutilainen, M., Siitari-Kauppi, M., Sammaljärvi, J., Ikonen, J., Joutsen, A., Van den Heuvel, D., Wersin,, P., 2023. Transport Properties and Petrography of Rock Samples from Drillhole ONK-PH28 – a Method Comparison. Posiva Working Report, 2023-06, Posiva Oy, Olkiluoto, Finland.

Golder and PGW (Paterson Grant and Watson Ltd.), 2017. Phase 2 Geoscientific Preliminary Assessment, Geological Mapping, Township of Ignace and Area, Ontario. NWMO Report Number: APM-REP-01332-0225.

OGS (Ontario Geological Survey), 2011. 1:250 000 scale bedrock geology of Ontario, Ontario Geological Survey, Miscellaneous Release Data 126 - Revision 1.

Parmenter, A., Waffle, L. and DesRoches, A., 2020. An updated bedrock geology map and geological database for the northern portion of the Revell batholith (No. NWMO-TR-2020-08). Nuclear Waste Management Organization.

SGL (Sander Geophysics Limited), 2015. Phase 2 Geoscientific Preliminary Assessment, Acquisition, Processing and Interpretation of High-Resolution Airborne Geophysical Data, Township of Ignace, Ontario. Prepared for Nuclear Waste Management Organization (NWMO). NWMO Report Number: APM-REP-06145-0002.

SRK (SRK Consulting, Inc.) and Golder, 2015. Phase 2 Geoscientific Preliminary Assessment, Observation of General Geological Features, Township of Ignace, Ontario. Prepared for Nuclear Waste Management Organization. NWMO Report Number: APM-REP-06145-0004.

Stone, D., 2009. Geology of the Bending Lake Area, Northwestern Ontario; *in* Summary of Field Work and Other Activities 2009. Ontario Geological Survey. Open File Report 6240.

Stone, D., 2010a. Geology of the Stormy Lake Area, Northwestern Ontario; *in* Summary of Field Work and Other Activities 2010. Ontario Geological Survey, Open File Report 6260.

Stone, D., 2010b. Precambrian geology of the central Wabigoon Subprovince area, northwestern Ontario. Ontario Geological Survey, Open File Report 5422.

Stone, D., Halle, J. and Chaloux, E., 1998. Geology of the Ignace and Pekagoning Lake Areas, Central Wabigoon Subprovince; *in* Summary of Field Work and Other Activities 1998, Ontario Geological Survey, Misc. Paper 169.

Stone, D., Davis, D.W., Hamilton, M.A. and Falcon, A., 2010. Interpretation of 2009 Geochronology in the Central Wabigoon Subprovince and Bending Lake Areas, Northwestern Ontario, *in* Summary of Field Work and Other Activities 2010, Ontario Geological Survey, Open File Report 6260.

Waber, H.N., Gaucher, E., Fernadez, A.M., Bath, A., 2003. Annex 3: Aqueous Leachates and Cation Exchange Properties of Mont Terri Claystones. Mont-Terri Project-Geochemistry of Water in the Opalinus Clay Formation at the Mont Terri Rock Laboratory. Reports of the FOWG, Geology Series, 2003-5, Nagra, Bern.

Waber, H.N., Eichinger, F., Voutilainen, M., Siitari-Kauppi, M., Sammaljärvi, J., Ikonen, J., Van den Heuvel, D., Wersin, P., in progress. Transport properties and petrography of rock samples from drill core ONK-PH28 – A method comparison. Posiva Working report, Posiva Oy, Olkiluoto, Finland.

APPENDIX A

Analytical Raw Data

CEC experiment 0.065-0.2 mm IG_BH05_SA001

Appendix Table A-1: Element concentrations of the final CEC experiment solutions with the smallest grain size fraction (0.065-0.2 mm) after 48 h. Sample name IG_BH05_SA001 0.065-0.2 mm.

Hydro Lab.-No.		381672	381660	381661	381662	381663	381664	381665	381666	381667	381668
Sample		Ni-en solution	1:1 No. 1	1:1 No. 2	1:2 No. 1	1:2 No. 2	1:4 No. 1	1:4 No. 2	1:10 No. 1	1:10 No. 2	Blank
Rock/ test solution Mass ratio		-	1:1	1:1	1:2	1:2	1:4	1:4	1:10	1:10	-
Rock mass	g	-	39.997	40.007	20.000	20.013	10.000	9.995	10.000	10.015	0
Solution mass	g	-	38.975	40.044	39.894	39.231	39.824	39.372	98.019	98.858	73.759
pH value start		-	9.90	9.35	9.15	9.16	9.24	9.13	9.39	9.11	8.94
pH value end		-	9.64	9.59	9.48	9.54	9.45	9.43	9.37	9.32	8.93
Redox potential start	mV	-	16.7	-13.2	13.9	12.3	24.8	8.3	36.0	23.1	36.5
Redox potential end	mV	-	-73.4	-104.4	-70.3	-65.7	-70.7	-73.4	-28.5	-32.9	2.9
Nickel (Ni^{2+})	mg/l	31.5	2.16	3.95	1.82	2.48	6.32	6.01	20.7	20.9	29.3
Barium (Ba^{2+})	mg/l	0.051	0.307	0.472	0.139	0.177	0.038	0.021	0.014	0.021	0.043
Strontium (Sr^{2+})	mg/l	0.035	0.102	0.141	0.048	0.048	0.040	0.037	0.040	0.044	0.026
Aluminum (Al^{3+})	mg/l	< 0.02	21.0	35.1	7.19	13.38	0.587	0.482	0.089	0.434	< 0.02
Iron tot. (Fe_{tot})	mg/l	< 0.01	130	153	27.5	31.7	4.74	1.55	4.63	5.73	< 0.01
Iron-II (Fe^{2+})	mg/l	< 0.01	62.7	103	0.365	0.394	0.032	0.023	0.021	0.024	< 0.01
Iron-III (Fe^{3+})	mg/l	< 0.01	67.3	49.5	27.1	31.3	4.71	1.52	4.61	5.70	< 0.01
Sodium (Na^{+})	mg/l	< 0.2	83.5	82.3	54.0	55.4	32.4	32.8	14.8	15.0	1.33
Potassium (K^{+})	mg/l	< 0.1	4.74	3.48	2.63	2.47	1.80	1.68	1.02	1.12	1.51
Calcium (Ca^{2+})	mg/l	7.71	12.1	14.2	7.37	5.77	6.17	6.18	6.94	7.15	6.24
Magnesium (Mg^{2+})	mg/l	0.61	11.4	9.77	3.52	4.74	1.46	1.35	0.86	1.54	3.91
Ammonium (NH_4^{+})	mg/l	< 0.1	0.17	0.16	0.16	0.15	0.17	0.15	< 0.1	0.19	< 0.1
Hydrogen-carbonate (HCO_3^{-})	mg/l	29.9	109	103	66.5	68.9	45.2	45.2	35.4	34.8	30.5
Chloride (Cl^{-})	mg/l	< 0.2	25.7	26.5	15.1	15.3	9.27	9.48	4.01	4.34	2.76
Sulfate (SO_4^{2-})	mg/l	< 0.5	19.8	18.7	9.35	9.7	5.01	4.97	2.47	2.25	0.58
Nitrate (NO_3^{-})	mg/l	66.7	66.8	67.6	66.9	66.9	66.7	67.3	67.2	67.1	66.9
Fluoride (F^{-})	mg/l	< 0.1	0.79	0.81	0.48	0.52	0.28	0.32	0.17	0.19	0.13

CEC experiment 2-4 mm IG_BH05_SA001

Appendix Table A-2: Element concentrations of the final CEC experiment solutions with the middle grain size fraction (2-4 mm) after 96 h. Sample name IG_BH05_SA001 2-4 mm.

Hydro Lab.-No.		380685	380689	380690	380691	380692	380693	380694	380695	380696	380697
Sample		Ni-en solution	1:1 No. 1	1:1 No. 2	1:2 No. 1	1:2 No. 2	1:4 No. 1	1:4 No. 2	1:10 No. 1	1:10 No. 2	Blank
Rock/ test solution Mass ratio		-	1:1	1:1	1:2	1:2	1:4	1:4	1:10	1:10	-
Rock mass	g	-	39.971	39.955	20.009	19.999	10.036	10.019	10.022	10.017	0
Solution mass	g	-	39.209	39.741	40.021	39.815	39.857	40.013	100.152	99.570	74.878
pH value start		-	9.18	9.20	9.09	9.07	9.05	8.99	9.00	8.97	8.92
pH value end		-	9.72	10.01	9.54	9.56	9.44	9.46	9.28	9.26	8.93
Redox potential start	mV	-	57.8	56.7	69.9	59.5	71.8	77.4	80.8	75.3	79.4
Redox potential end	mV	-	-224.3	-231.4	-158.0	-152.7	-78.1	-62.7	-56.1	-45.7	0.1
Nickel (Ni^{2+})	mg/l	30.4	0.680	0.020	2.01	2.12	21.5	10.4	25.5	25.2	30.9
Barium (Ba^{2+})	mg/l	0.042	0.106	0.162	0.034	0.022	0.0029	0.0024	0.0097	0.0096	0.051
Strontium (Sr^{2+})	mg/l	0.029	0.037	0.113	0.021	0.029	0.044	0.036	0.047	0.045	0.035
Aluminum (Al^{3+})	mg/l	< 0.02	10.0	42.3	1.78	1.14	0.100	< 0.02	0.124	0.112	0.022
Iron tot. (Fe_{tot})	mg/l	< 0.01	43.4	104	6.37	5.18	3.83	2.42	2.25	2.55	1.41
Iron-II (Fe^{2+})	mg/l	< 0.01	42.7	110	4.99	4.68	0.098	0.122	0.061	0.062	< 0.01
Iron-III (Fe^{3+})	mg/l	< 0.01	0.713	< 0.01	1.38	0.507	3.73	2.30	2.19	2.49	1.42
Sodium (Na^{+})	mg/l	< 0.2	57.3	48.1	35.1	37.1	21.7	18.6	8.51	8.50	1.18
Potassium (K^{+})	mg/l	1.13	3.72	1.82	3.50	3.50	3.91	3.90	1.54	1.28	1.90
Calcium (Ca^{2+})	mg/l	10.8	6.22	14.6	5.27	5.18	8.34	8.27	9.13	8.63	10.7
Magnesium (Mg^{2+})	mg/l	0.45	4.81	16.2	2.24	2.51	3.23	1.85	1.66	1.59	0.05
Ammonium (NH_4^{+})	mg/l	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Hydrogen-carbonate (HCO_3^{-})	mg/l	33.0	86.0	73.8	58.6	59.8	48.2	55.5	42.1	48.2	45.2
Chloride (Cl^{-})	mg/l	< 0.2	6.35	13.1	3.07	3.85	5.12	3.66	1.42	1.15	1.88
Sulfate (SO_4^{2-})	mg/l	< 0.5	5.23	6.83	3.37	2.81	1.57	1.36	0.95	0.83	< 0.1
Nitrate (NO_3^{-})	mg/l	58.4	64.5	< 0.2	65.6	70.3	68.7	71.6	73.9	73.7	72.9
Fluoride (F^{-})	mg/l	< 0.1	0.85	0.81	0.38	0.39	0.20	0.18	< 0.1	< 0.1	< 0.1

CEC experiment 10-20 mm IG_BH05_SA001

Appendix Table A-3: Element concentrations of the CEC experiment solution with the largest grain size fraction (10-20 mm) after 8 days. Sample name IG_BH05_SA001 10-20 mm.

Hydro Lab.-No.	Sample	Nickel (Ni^{2+})	Sodium (Na^{+})	Potassium (K^{+})	Calcium (Ca^{2+})	Magnesium (Mg^{2+})
		mg/l	mg/l	mg/l	mg/l	mg/l
380951	1:1 No. 1	21.5	14.4	0.75	11.1	< 0.01
380952	1:1. No. 2	21.8	14.9	0.69	10.5	< 0.01
380953	1:2 No. 1	26.5	7.87	0.54	11.1	< 0.01
380954	1:2 No.2	26.6	7.81	0.49	13.4	< 0.01
380955	1:4 No. 1	24.0	4.98	0.50	11.1	< 0.01
380956	1:4 No 2	28.4	3.95	0.47	10.6	< 0.01
380957	1:10 No. 1	30.5	1.83	0.71	21.1	< 0.01
380958	1:10 No. 2	30.9	2.00	0.64	12.7	< 0.01
380959	Blank	26.8	0.15	1.30	11.5	< 0.01
380960	Zero 1:1 No. 1	< 0.001	14.8	0.54	< 0.05	< 0.01
380961	Zero 1:1. No. 2	< 0.001	16.1	0.60	< 0.05	< 0.01
380962	Zero-Blank	< 0.001	0.12	0.98	< 0.05	< 0.01

Appendix Table A-4: Element concentrations of the CEC experiment solution with the largest grain size fraction (10-20 mm) after 16 days. Sample name IG_BH05_SA001 10-20 mm.

Hydro Lab.-No.	Sample	Nickel (Ni^{2+})	Sodium (Na^{+})	Potassium (K^{+})	Calcium (Ca^{2+})	Magnesium (Mg^{2+})
		mg/l	mg/l	mg/l	mg/l	mg/l
381636	1:1 No. 1	18.7	17.8	0.81	11.5	0.527
381637	1:1. No. 2	20.0	18.2	0.71	9.00	< 0.01
381638	1:2 No. 1	28.5	9.85	0.56	9.58	< 0.01
381639	1:2 No.2	27.6	10.2	0.59	9.91	< 0.01
381640	1:4 No. 1	19.3	6.55	0.66	5.92	0.416
381641	1:4 No 2	27.4	4.98	0.52	8.78	< 0.01
381642	1:10 No. 1	35.1	2.55	0.84	9.87	< 0.01
381643	1:10 No. 2	36.5	2.67	0.66	7.82	< 0.01
381644	Blank	32.4	1.32	2.01	5.59	0.332
381645	Zero 1:1 No. 1	< 0.001	16.9	0.43	< 0.05	< 0.01
381646	Zero 1:1. No. 2	< 0.001	18.5	0.65	< 0.05	< 0.01
381647	Zero-Blank	< 0.001	< 0.5	0.94	< 0.05	< 0.01

Appendix Table A-5: Element concentrations of the CEC experiment solution with the largest grain size fraction (10-20 mm) after 40 days. Sample name IG_BH05_SA001 10-20 mm.

Hydro Lab.-No.	Sample	Nickel (Ni^{2+})	Sodium (Na^{+})	Potassium (K^{+})	Calcium (Ca^{2+})	Magnesium (Mg^{2+})
		mg/l	mg/l	mg/l	mg/l	mg/l
382224	1:1 No. 1	16.9	22.6	0.84	11.0	< 0.01
382225	1:1. No. 2	22.7	23.1	0.74	19.2	< 0.01
382226	1:2 No. 1	25.4	12.4	0.58	9.93	< 0.01
382227	1:2 No.2	26.9	12.7	0.56	12.4	< 0.01
382228	1:4 No. 1	30.0	7.92	0.52	14.6	< 0.01
382229	1:4 No 2	25.3	6.01	0.46	10.8	< 0.01
382230	1:10 No. 1	35.4	2.74	0.61	10.4	< 0.01
382231	1:10 No. 2	32.1	3.10	0.56	9.07	< 0.01
382232	Blank	26.7	< 0.2	1.39	9.68	< 0.01
382233	Zero 1:1 No. 1	< 0.001	19.7	0.44	< 0.05	< 0.01
382234	Zero 1:1. No. 2	< 0.001	22.8	0.55	< 0.05	0.594
382235	Zero-Blank	< 0.001	< 0.2	0.93	< 0.05	< 0.01

Appendix Table A-6: Element concentrations of the CEC experiment solution with the largest grain size fraction (10-20 mm) after 56 days. Sample name IG_BH05_SA001 10-20 mm.

Hydro Lab.-No.	Sample	Nickel (Ni^{2+})	Sodium (Na^{+})	Potassium (K^{+})	Calcium (Ca^{2+})	Magnesium (Mg^{2+})
		mg/l	mg/l	mg/l	mg/l	mg/l
382940	1:1 No. 1	10.8	25.6	1.03	11.0	< 0.01
382941	1:1. No. 2	7.07	25.6	1.04	14.7	< 0.01
382942	1:2 No. 1	17.3	14.4	0.82	12.3	< 0.01
382943	1:2 No.2	22.5	15.1	0.75	10.8	< 0.01
382944	1:4 No. 1	24.2	9.08	0.82	12.9	< 0.01
382945	1:4 No 2	30.7	7.33	0.72	15.3	< 0.01
382946	1:10 No. 1	24.2	3.18	0.70	10.8	< 0.01
382947	1:10 No. 2	31.3	3.67	0.63	9.80	< 0.01
382948	Blank	36.2	0.21	1.53	11.1	< 0.01
382949	Zero 1:1 No. 1	< 0.001	23.2	0.76	< 0.05	< 0.01
382950	Zero 1:1. No. 2	< 0.001	-	-	< 0.05	< 0.01
382951	Zero-Blank	< 0.001	< 0.2	1.03	< 0.05	< 0.01

Appendix Table A-7: Element concentrations of the CEC experiment solution with the largest grain size fraction (10-20 mm) after 82 days. Sample name IG_BH05_SA001 10-20 mm.

Hydro Lab.-No.	Sample	Nickel (Ni^{2+})	Sodium (Na^{+})	Potassium (K^{+})	Calcium (Ca^{2+})	Magnesium (Mg^{2+})
		mg/l	mg/l	mg/l	mg/l	mg/l
383747	1:1 No. 1	8.66	30.3	1.80	17.8	< 0.01
383748	1:1. No. 2	5.57	30.6	1.21	11.3	< 0.01
383749	1:2 No. 1	21.7	16.9	0.88	11.8	< 0.01
383750	1:2 No.2	15.2	17.5	1.28	14.9	< 0.01
383751	1:4 No. 1	23.8	11.0	1.01	11.0	< 0.01
383752	1:4 No 2	29.6	8.50	0.65	10.7	< 0.01
383753	1:10 No. 1	27.3	3.90	0.78	12.9	< 0.01
383754	1:10 No. 2	27.3	4.39	0.77	18.3	< 0.01
383755	Blank	29.5	0.24	1.79	9.99	< 0.01
383756	Zero 1:1 No. 1	< 0.001	24.8	0.73	< 0.05	< 0.01
383757	Zero 1:1. No. 2	< 0.001	26.2	1.00	< 0.05	< 0.01
383758	Zero-Blank	< 0.001	< 0.2	1.13	< 0.05	< 0.01

Appendix Table A-8: Element concentrations of the CEC experiment solution with the largest grain size fraction (10-20 mm) after 101 days. Sample name IG_BH05_SA001 10-20 mm.

Hydro Lab.-No.	Sample	Nickel (Ni^{2+})	Sodium (Na^{+})	Potassium (K^{+})	Calcium (Ca^{2+})	Magnesium (Mg^{2+})
		mg/l	mg/l	mg/l	mg/l	mg/l
384318	1:1 No. 1	5.49	33.5	1.46	11.4	< 0.01
384319	1:1. No. 2	5.56	32.7	1.15	6.52	< 0.01
384320	1:2 No. 1	13.4	19.5	1.01	11.8	< 0.01
384321	1:2 No.2	17.0	19.1	0.78	6.36	< 0.01
384322	1:4 No. 1	18.1	11.8	0.75	9.20	< 0.01
384323	1:4 No 2	21.3	9.76	1.22	10.6	< 0.01
384324	1:10 No. 1	23.0	4.47	0.74	7.84	< 0.01
384325	1:10 No. 2	25.3	4.77	0.77	7.11	< 0.01
384326	Blank	27.5	0.40	1.64	6.25	< 0.01
384327	Zero 1:1 No. 1	< 0.001	27.3	0.78	< 0.05	< 0.01
384328	Zero 1:1. No. 2	< 0.001	28.6	0.92	< 0.05	< 0.01
384329	Zero-Blank	< 0.001	< 0.2	1.13	< 0.05	< 0.01

Appendix Table A-9: Element concentrations of the CEC experiment solution with the largest grain size fraction (10-20 mm) after 157 days. Sample name IG_BH05_SA001 10-20 mm.

Hydro Lab.-No.	Sample	Nickel (Ni^{2+})	Sodium (Na^{+})	Potassium (K^{+})	Calcium (Ca^{2+})	Magnesium (Mg^{2+})
		mg/l	mg/l	mg/l	mg/l	mg/l
386994	1:1 No. 1	2.03	39.3	1.30	11.4	< 0.01
386995	1:1. No. 2	1.45	37.6	0.87	10.1	< 0.01
386996	1:2 No. 1	11.1	21.8	0.77	15.0	< 0.01
386997	1:2 No.2	14.7	22.9	0.72	14.0	< 0.01
386998	1:4 No. 1	14.2	13.8	0.69	15.8	< 0.01
386999	1:4 No 2	16.8	11.0	0.72	15.8	< 0.01
387000	1:10 No. 1	22.9	4.85	0.55	16.3	< 0.01
387001	1:10 No. 2	23.1	5.48	0.74	15.2	< 0.01
387002	Blank	31.9	< 0.2	1.45	14.6	< 0.01
387003	Zero 1:1 No. 1	< 0.001	29.3	0.51	< 0.05	< 0.01
387004	Zero 1:1. No. 2	< 0.001	30.8	0.64	< 0.05	< 0.01
387005	Zero-Blank	< 0.001	< 0.2	0.93	< 0.05	< 0.01

Appendix Table A-10: Element concentrations of the CEC experiment solution with the largest grain size fraction (10-20 mm) after 171 days. Sample name IG_BH05_SA001 10-20 mm.

Hydro Lab.-No.	Sample	Nickel (Ni^{2+})	Sodium (Na^{+})	Potassium (K^{+})	Calcium (Ca^{2+})	Magnesium (Mg^{2+})
		mg/l	mg/l	mg/l	mg/l	mg/l
387313	1:1 No. 1	1.57	40.4	1.09	9.96	< 0.01
387314	1:1. No. 2	1.33	39.5	0.99	7.87	< 0.01
387315	1:2 No. 1	9.44	23.0	0.83	10.6	< 0.01
387316	1:2 No.2	8.26	23.5	0.81	10.3	< 0.01
387317	1:4 No. 1	17.0	14.7	0.69	12.1	< 0.01
387318	1:4 No 2	19.4	11.6	0.61	11.9	< 0.01
387319	1:10 No. 1	25.3	5.06	0.54	10.9	< 0.01
387320	1:10 No. 2	24.6	5.66	0.58	12.2	< 0.01
387321	Blank	32.8	< 0.2	1.41	12.8	< 0.01
387322	Zero 1:1 No. 1	< 0.001	30.6	0.47	< 0.05	< 0.01
387323	Zero 1:1. No. 2	< 0.001	32.5	0.60	< 0.05	< 0.01
387324	Zero-Blank	< 0.001	< 0.2	0.94	< 0.05	< 0.01

Appendix Table A-11: Element concentrations of the final CEC experiment solution with the largest grain size fraction (10-20 mm) after 184 days. Sample name IG_BH05_SA001 10-20 mm.

Hydro Lab.-No.		380687	388014	388015	388016	388017	388018	388019	388020	388021	388022
Sample		Ni-en solution	1:1 No. 1	1:1 No. 2	1:2 No. 1	1:2 No. 2	1:4 No. 1	1:4 No. 2	1:10 No. 1	1:10 No. 2	Blank
Rock/ test solution Mass ratio		-	1:1	1:1	1:2	1:2	1:4	1:4	1:10	1:10	-
Rock mass	g	-	59.857	60.201	29.820	29.987	14.922	15.268	10.150	10.057	0
Solution mass	g	-	58.984	59.145	58.923	58.937	58.779	60.065	100.043	99.732	74.488
pH value start		-	9.05	9.06	9.02	9.02	9.01	8.99	9.05	9.00	8.98
pH value end		-	9.16	9.37	9.15	9.20	9.00	9.21	8.92	8.86	8.75
Redox potential start	mV	-	27.2	41.7	56.5	49.8	53.4	54.1	62.4	60.4	78.0
Redox potential end	mV	-	29.2	-2.7	42.4	32.6	59.1	52.8	77.9	87.3	108.5
Nickel (Ni^{2+})	mg/l	27.0	1.43	0.95	9.20	8.96	15.1	17.1	23.1	22.7	29.6
Barium (Ba^{2+})	mg/l	0.045	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.015	0.016	0.019
Strontium (Sr^{2+})	mg/l	0.029	0.051	0.036	0.086	0.072	0.076	0.081	0.068	0.064	0.045
Aluminum (Al^{3+})	mg/l	< 0.02	0.091	0.139	0.066	0.097	0.041	0.044	0.026	0.026	0.034
Iron tot. (Fe_{tot})	mg/l	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Iron-II (Fe^{2+})	mg/l	< 0.01	0.027	0.013	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Iron-III (Fe^{3+})	mg/l	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Sodium (Na^{+})	mg/l	0.28	44.9	43.8	26.4	27.2	17.3	14.0	6.60	7.39	1.66
Potassium (K^{+})	mg/l	< 0.1	1.89	1.67	1.93	1.79	1.94	1.51	1.11	1.18	2.80
Calcium (Ca^{2+})	mg/l	10.1	6.58	7.12	10.6	9.60	11.0	10.3	10.2	10.2	11.0
Magnesium (Mg^{2+})	mg/l	0.482	0.062	0.040	0.131	0.098	0.256	0.270	0.375	0.348	0.404
Ammonium (NH_4^{+})	mg/l	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Hydrogen-carbonate (HCO_3^{-})	mg/l	31.1	53.7	41.5	40.3	34.8	40.9	31.2	32.3	31.1	29.3
Chloride (Cl^{-})	mg/l	0.3	3.76	3.20	2.76	2.86	2.63	2.31	1.72	1.73	3.09
Sulfate (SO_4^{2-})	mg/l	< 0.5	6.54	4.39	2.86	1.46	3.15	0.93	0.30	1.47	< 0.5
Nitrate (NO_3^{-})	mg/l	61.6	73.2	73.1	74.1	74.3	77.7	77.4	76.7	73.5	76.0
Fluoride (F^{-})	mg/l	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1

CEC experiment 0.15-0.3 mm IG_BH05_AR43

Appendix Table A-12: Element concentrations of the final CEC experiment solutions with the middle grain size fraction (0.15-0.3 mm) after 74 h. Sample name IG_BH05_AR43 0.15-0.3 mm.

Hydro Lab.-No.											
Sample		Ni-en solution	1:1 No. 1	1:1 No. 2	1:2 No. 1	1:2 No. 2	1:4 No. 1	1:4 No. 2	1:10 No. 1	1:10 No. 2	Blank
Rock/ test solution Mass ratio		-	1:1	1:1	1:2	1:2	1:4	1:4	1:10	1:10	-
Rock mass	g	-	39.961	40.009	19.988	19.978	10.009	9.998	5.001	5.000	0
Solution mass	g	-	39.660	39.741	39.401	40.017	39.819	42.460	49.575	49.668	50.344
pH value start		-	9.10	9.03	9.01	9.04	9.02	9.02	8.95	8.58	8.18
pH value end		-	9.32	9.38	9.40	9.36	9.36	9.36	9.20	9.16	7.98
Redox potential start	mV	-	55.3	62.5	68.1	65.6	66.7	62.9	93.3	82.0	111.1
Redox potential end	mV	-	-125.3	-148.5	-73.7	-74.7	-55.1	-53.0	-14.4	-30.6	136.6
Nickel (Ni^{2+})	mg/l	26.9	< 0.0001	0.084	0.240	0.010	0.330	0.380	5.26	5.20	28.0
Barium (Ba^{2+})	mg/l	< 0.1	< 0.1	< 0.1	0.01	0.03	< 0.1	0.01	0.02	< 0.1	< 0.1
Strontium (Sr^{2+})	mg/l	< 0.1	0.09	0.09	0.08	0.07	0.07	0.08	0.04	0.03	< 0.1
Aluminum (Al^{3+})	mg/l	2.59	12.8	25.3	3.53	2.08	2.78	3.68	2.84	8.77	2.40
Iron tot. (Fe_{tot})	mg/l	< 0.01	< 0.01	2.63	0.424	< 0.01	< 0.01	< 0.01	0.62	< 0.01	< 0.01
Iron-II (Fe^{2+})	mg/l	< 0.01	< 0.01	< 0.01	0.003	< 0.01	< 0.01	< 0.01	0.01	< 0.01	< 0.01
Iron-III (Fe^{3+})	mg/l	< 0.01	< 0.01	2.63	0.421	< 0.01	< 0.01	< 0.01	0.61	< 0.01	< 0.01
Sodium (Na^{+})	mg/l	0.23	22.0	20.0	15.9	12.5	8.3	13.2	4.0	5.5	2.3
Potassium (K^{+})	mg/l	0.13	7.1	8.1	4.5	4.7	4.4	5.8	4.3	6.0	4.5
Calcium (Ca^{2+})	mg/l	37.9	60.6	78.9	37.7	56.2	40.2	51.6	40.0	46.9	35.0
Magnesium (Mg^{2+})	mg/l	0.01	7.1	7.0	5.8	5.9	4.9	4.9	2.7	2.5	0.04
Ammonium (NH_4^{+})	mg/l	0.02	< 0.1	0.03	0.05	0.03	0.08	0.05	0.11	0.04	0.07
Hydrogen-carbonate (HCO_3^{-})	mg/l	100.7	73.2	49.91	43.9	40.9	35.8	33.1	75.1	87.9	106.8
Chloride (Cl^{-})	mg/l	0.31	24.5	26.7	13.4	14.3	9.7	9.5	6.7	7.4	5.4
Sulfate (SO_4^{2-})	mg/l	0.19	21.2	15.4	14.1	8.4	4.7	8.1	1.6	4.1	0.39
Nitrate (NO_3^{-})	mg/l	72.6	68.5	70.5	71.2	71.8	71.3	16.8	72.3	71.3	71.7
Fluoride (F^{-})	mg/l	0.05	0.39	0.36	0.18	0.23	0.13	0.17	0.23	0.10	0.15

CEC experiment 1-2 mm IG_BH05_AR43

Appendix Table A-13: Element concentrations of the final CEC experiment solutions with the middle grain size fraction (1-2 mm) after 72 h. Sample name IG_BH05_AR43 1-2 mm.

Hydro Lab.-No.											
Sample		Ni-en solution	1:1 No. 1	1:1 No. 2	1:2 No. 1	1:2 No. 2	1:4 No. 1	1:4 No. 2	1:10 No. 1	1:10 No. 2	Blank
Rock/ test solution Mass ratio		-	1:1	1:1	1:2	1:2	1:4	1:4	1:10	1:10	-
Rock mass	g	-	40.006	40.000	20.002	20.005	10.003	10.001	10.003	9.999	0
Solution mass	g	-	39.791	39.278	39.886	40.255	39.854	39.984	98.897	99.101	74.469
pH value start		-	8.92	8.86	8.79	9.04	8.55	8.38	8.23	8.23	8.06
pH value end		-	9.73	9.73	9.71	9.67	9.66	9.66	9.42	9.34	8.02
Redox potential start	mV	-	50.2	59.8	61.8	56.9	75.0	63.7	90.4	82.5	113.0
Redox potential end	mV	-	-137.3	-151.3	-76.2	-112.8	-63.9	-65.4	-36.9	-42.2	34.0
Nickel (Ni^{2+})	mg/l	27.9	0.049	0.053	0.120	0.120	0.440	0.430	4.33	4.95	31.8
Barium (Ba^{2+})	mg/l	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.001	0.003	< 0.1
Strontium (Sr^{2+})	mg/l	< 0.1	0.11	0.06	0.06	0.08	0.07	0.07	0.03	0.02	< 0.1
Aluminum (Al^{3+})	mg/l	1.24	1.15	1.28	1.13	1.44	< 0.01	2.16	4.02	1.65	< 0.01
Iron tot. (Fe_{tot})	mg/l	0.290	0.470	0.620	0.530	0.610	0.570	0.250	0.910	1.30	0.600
Iron-II (Fe^{2+})	mg/l	0.034	0.011	0.09	0.40	0.10	0.054	0.019	< 0.01	0.10	0.015
Iron-III (Fe^{3+})	mg/l	0.26	0.46	0.53	0.13	0.51	0.52	0.23	0.91	1.2	0.59
Sodium (Na^{+})	mg/l	0.19	27.5	20.5	11.2	11.1	6.7	7.4	2.2	2.0	0.33
Potassium (K^{+})	mg/l	0.14	5.6	5.4	3.6	4.2	3.4	3.8	1.3	1.6	1.6
Calcium (Ca^{2+})	mg/l	9.6	20.8	24.4	35.1	28.9	34.3	23.9	113.0	41.3	8.0
Magnesium (Mg^{2+})	mg/l	0.02	3.5	3.0	3.5	3.7	4.0	3.7	3.7	3.5	0.02
Ammonium (NH_4^{+})	mg/l	0.083	0.28	0.28	0.27	0.27	0.23	0.25	0.15	0.13	0.046
Hydrogen-carbonate (HCO_3^{-})	mg/l	36.6	45.8	58.9	48.8	50.0	50.0	27.2	54.9	61.6	47.6
Chloride (Cl^{-})	mg/l	0.16	25.6	15.7	8.3	8.5	5.5	6.0	2.3	2.7	1.7
Sulfate (SO_4^{2-})	mg/l	0.08	12.4	6.1	3.5	2.5	1.6	1.5	0.7	0.9	0.17
Nitrate (NO_3^{-})	mg/l	69.2	74.7	72.6	71.6	72.9	73.7	72.9	73.4	72.1	74.2
Fluoride (F^{-})	mg/l	< 0.1	< 0.1	1.9	0.69	0.02	0.16	0.06	0.01	0.03	0.01

CEC experiment 2-4 mm IG_BH05_AR43

Appendix Table A-14: Element concentrations of the final CEC experiment solutions with the middle grain size fraction (2-4 mm) after 74 h. Sample name IG_BH05_AR43 2-4 mm.

Hydro Lab.-No.											
Sample		Ni-en solution	1:1 No. 1	1:1 No. 2	1:2 No. 1	1:2 No. 2	1:4 No. 1	1:4 No. 2	1:10 No. 1	1:10 No. 2	Blank
Rock/ test solution Mass ratio		-	1:1	1:1	1:2	1:2	1:4	1:4	1:10	1:10	-
Rock mass	g	-	40.011	39.997	19.994	20.005	10.000	9.998	10.004	10.005	0
Solution mass	g	-	39.834	39.816	38.797	38.937	39.08	39.751	99.056	99.632	38.839
pH value start		-	8.71	8.64	8.68	8.53	8.29	8.11	8.03	8.08	7.95
pH value end		-	10.15	10.10	9.98	9.99	9.82	9.80	9.50	9.45	8.10
Redox potential start	mV	-	100.0	109.1	108.3	102.2	63.8	77.7	85.4	94.7	98.2
Redox potential end	mV	-	-127.0	-126.3	-103.6	-99.6	-70.7	-66.8	-49.0	-43.1	107.7
Nickel (Ni^{2+})	mg/l	27.5	0.170	0.074	0.170	0.110	0.960	0.740	6.76	5.51	31.1
Barium (Ba^{2+})	mg/l	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Strontium (Sr^{2+})	mg/l	< 0.1	0.05	0.05	0.07	0.07	0.09	0.09	0.05	0.05	< 0.1
Aluminum (Al^{3+})	mg/l	2.14	1.22	< 0.01	1.79	1.33	1.78	1.42	2.05	< 0.01	6.10
Iron tot. (Fe_{tot})	mg/l	0.41	0.800	15.8	0.950	< 0.01	1.18	1.31	0.930	2.25	2.30
Iron-II (Fe^{2+})	mg/l	< 0.01	0.38	0.06	0.054	0.03	0.48	0.14	0.01	0.012	< 0.01
Iron-III (Fe^{3+})	mg/l	0.41	0.42	15.7	0.89	0.42	0.7	1.17	0.92	2.23	2.30
Sodium (Na^{+})	mg/l	0.70	37.0	38.7	27.0	31.7	14.3	13.3	7.3	5.9	42.6
Potassium (K^{+})	mg/l	0.46	5.2	6.7	6.3	8.5	3.8	3.7	2.9	2.0	7.0
Calcium (Ca^{2+})	mg/l	29.6	33.4	13.7	21.1	22.5	36.8	84.9	423.0	21.4	184.0
Magnesium (Mg^{2+})	mg/l	0.02	1.2	2.2	3.0	2.6	2.6	3.0	4.4	4.1	0.34
Ammonium (NH_4^{+})	mg/l	2.62	0.57	0.58	0.46	< 0.05	0.46	0.43	0.71	0.88	< 0.05
Hydrogen-carbonate (HCO_3^{-})	mg/l	90.9	131.8	103.7	92.7	98.2	92.7	100.7	105.6	106.2	124.5
Chloride (Cl^{-})	mg/l	0.13	13.9	22.8	11.9	12.6	5.7	6.2	2.7	3.0	91.9
Sulfate (SO_4^{2-})	mg/l	0.41	6.4	10.1	7.7	8.5	2.8	3.3	3.3	1.8	1.2
Nitrate (NO_3^{-})	mg/l	76.7	67.1	76.6	76.2	77.8	65.5	67.4	77.1	77.4	77.3
Fluoride (F^{-})	mg/l	0.01	1.8	1.8	1.0	1.1	0.23	0.28	0.07	0.07	< 0.1

CEC zero experiment 0.065-0.2 mm IG_BH05_SA001

Appendix Table A-15: Element concentrations of the final CEC zero experiment solutions with the smallest grain size fraction (0.065-0.2 mm) after 48 . Sample name IG_BH05_SA001 0.065-0.2 mm.

Hydro Lab.-No.		381673	381669	381670	381671
Sample		Zero Start Solution	Zero 1:1 No. 1	Zero 1:1 No. 2	Zero Blank
Rock/ test solution Mass ratio		-	1:1	1:1	-
Rock mass	g	-	40.008	40.003	0
Solution mass	g	-	39.688	39.096	74.339
pH value start		-	10.05	9.86	7.05
pH value end		-	9.73	9.73	7.92
Redox potential start	mV	-	-5.7	-6.4	32.6
Redox potential end	mV	-	-35.7	-46.2	-5.5
Nickel (Ni^{2+})	mg/l	< 0.0001	0.005	< 0.001	< 0.001
Barium (Ba^{2+})	mg/l	0.001	0.235	0.123	< 0.001
Strontium (Sr^{2+})	mg/l	< 0.002	0.062	0.068	< 0.002
Aluminum (Al^{3+})	mg/l	< 0.02	19.6	29.9	< 0.02
Iron tot. (Fe_{tot})	mg/l	< 0.01	80.4	65.8	< 0.01
Iron-II (Fe^{2+})	mg/l	< 0.01	53.6	58.9	< 0.01
Iron-III (Fe^{3+})	mg/l	< 0.01	26.7	6.90	< 0.01
Sodium (Na^{+})	mg/l	< 0.2	67.2	69.7	1.50
Potassium (K^{+})	mg/l	< 0.1	2.47	2.72	3.93
Calcium (Ca^{2+})	mg/l	0.079	6.62	6.53	0.102
Magnesium (Mg^{2+})	mg/l	< 0.01	9.71	9.38	< 0.01
Ammonium (NH_4^{+})	mg/l	< 0.1	< 0.1	0.23	< 0.1
Hydrogencarbonate (HCO_3^{-})	mg/l	2.44	114	102	4.27
Chloride (Cl^{-})	mg/l	< 0.2	26.9	33.0	7.21
Sulfate (SO_4^{2-})	mg/l	< 0.5	20.3	21.5	1.03
Nitrate (NO_3^{-})	mg/l	< 0.2	1.59	0.65	< 0.2
Fluoride (F^{-})	mg/l	< 0.1	1.08	0.93	< 0.01

CEC zero experiment 2-4 mm IG_BH05_SA001

Appendix Table A-16: Element concentrations of the final CEC zero experiment solutions with the middle grain size fraction (2-4 mm) after 96 h. Sample name IG_BH05_SA001 2-4 mm.

Hydro Lab.-No.		380686	380698	380699	380700
Sample		Zero Start Solution	Zero 1:1 No. 1	Zero 1:1 No. 2	Zero Blank
Rock/ test solution Mass ratio		-	1:1	1:1	-
Rock mass	g	-	40.034	40.031	0
Solution mass	g	-	39.372	39.538	74.324
pH value start		-	9.64	9.19	6.81
pH value end		-	9.98	9.78	7.77
Redox potential start	mV	-	115.2	92.5	85.6
Redox potential end	mV	-	-75.9	-195.1	10.7
Nickel (Ni^{2+})	mg/l	< 0.001	0.023	0.0075	< 0.001
Barium (Ba^{2+})	mg/l	< 0.001	0.182	0.083	< 0.001
Strontium (Sr^{2+})	mg/l	< 0.002	0.065	0.022	< 0.002
Aluminum (Al^{3+})	mg/l	< 0.02	24.2	7.79	< 0.02
Iron tot. (Fe_{tot})	mg/l	< 0.01	87.8	41.5	< 0.01
Iron-II (Fe^{2+})	mg/l	< 0.01	101	27.8	0.01264
Iron-III (Fe^{3+})	mg/l	< 0.01	< 0.01	13.7	< 0.01
Sodium (Na^{+})	mg/l	0.41	43.4	54.4	0.34
Potassium (K^{+})	mg/l	< 0.1	1.97	3.80	4.82
Calcium (Ca^{2+})	mg/l	0.082	7.08	3.44	0.043
Magnesium (Mg^{2+})	mg/l	< 0.01	8.47	4.38	< 0.01
Ammonium (NH_4^{+})	mg/l	< 0.1	< 0.1	< 0.1	< 0.1
Hydrogencarbonate (HCO_3^{-})	mg/l	2.99	80.5	79.3	3.356
Chloride (Cl^{-})	mg/l	0.72	5.27	6.11	4.04
Sulfate (SO_4^{2-})	mg/l	< 0.5	8.33	4.92	< 0.5
Nitrate (NO_3^{-})	mg/l	< 0.2	< 0.2	68.4	< 0.2
Fluoride (F^{-})	mg/l	< 0.1	0.95	0.92	< 0.01

CEC zero experiment 10-20 mm IG_BH05_SA001

Appendix Table A-17: Element concentrations of the final zero CEC experiment solutions with the largest grain size fraction (10-20 mm) after 184 days. Sample name IG_BH05_SA001 10-20 mm.

Hydro Lab.-No.		380688	388023	388024	388025
Sample		Zero Start Solution	Zero 1:1 No. 1	Zero 1:1 No. 2	Zero Blank
Rock/ test solution Mass ratio		-	1:1	1:1	-
Rock mass	g	-	59.959	59.935	0
Solution mass	g	-	59.602	59.522	74.085
pH value start		-	8.04	7.70	5.91
pH value end		-	9.30	9.31	8.23
Redox potential start	mV	-	45.9	93.5	168.7
Redox potential end	mV	-	88.4	78.8	160.7
Nickel (Ni^{2+})	mg/l	< 0.0001	0.0015	0.0019	0.0011
Barium (Ba^{2+})	mg/l	< 0.001	< 0.001	< 0.001	0.019
Strontium (Sr^{2+})	mg/l	< 0.002	0.009	0.010	< 0.002
Aluminum (Al^{3+})	mg/l	< 0.02	1.33	1.13	0.00656
Iron tot. (Fe_{tot})	mg/l	< 0.01	< 0.01	< 0.01	< 0.01
Iron-II (Fe^{2+})	mg/l	< 0.01	0.051	0.055	< 0.01
Iron-III (Fe^{3+})	mg/l	< 0.01	< 0.01	< 0.01	< 0.01
Sodium (Na^{+})	mg/l	< 0.2	34.6	37.2	1.49
Potassium (K^{+})	mg/l	< 0.1	1.81	4.53	2.06
Calcium (Ca^{2+})	mg/l	0.076	1.10	1.15	0.055
Magnesium (Mg^{2+})	mg/l	< 0.01	0.056	0.087	0.015
Ammonium (NH_4^{+})	mg/l	< 0.1	< 0.1	< 0.1	< 0.1
Hydrogencarbonate (HCO_3^{-})	mg/l	2.56	60.405	60.405	3.66
Chloride (Cl^{-})	mg/l	< 0.1	5.6	13.7	2.26
Sulfate (SO_4^{2-})	mg/l	< 0.5	9.1	7.12	< 0.5
Nitrate (NO_3^{-})	mg/l	< 0.2	< 0.2	< 0.2	< 0.2
Fluoride (F^{-})	mg/l	< 0.1	< 0.01	< 0.01	< 0.01

CEC zero experiment 0.15-0.3 mm IG_BH05_AR43

Appendix Table A-18: Element concentrations of the final zero CEC experiment solutions with the largest grain size fraction (0.15-0.3 mm) after 74 h. Sample name IG_BH05_AR43 0.15-0.3 mm.

Hydro Lab.-No.					
Sample		Zero Start Solution	Zero 1:1 No. 1	Zero 1:1 No. 2	Zero Blank
Rock/ test solution Mass ratio		-	1:1	1:1	-
Rock mass	g	-	16.511	16.518	0
Solution mass	g	-	16.378	16.741	49.602
pH value start		-	9.47	9.76	7.88
pH value end		-	9.59	9.40	7.37
Redox potential start	mV	-	142.8	87.9	122.9
Redox potential end	mV	-	21.8	-18.7	100.1
Nickel (Ni^{2+})	mg/l	< 0.0001	0.010	< 0.0001	< 0.0001
Barium (Ba^{2+})	mg/l	< 0.1	< 0.1	0.02	< 0.1
Strontium (Sr^{2+})	mg/l	< 0.1	0.04	0.07	< 0.1
Aluminum (Al^{3+})	mg/l	4.20	5.61	5.00	3.09
Iron tot. (Fe_{tot})	mg/l	2.30	2.04	< 0.01	2.16
Iron-II (Fe^{2+})	mg/l	< 0.01	0.017	< 0.01	0.016
Iron-III (Fe^{3+})	mg/l	2.30	2.02	< 0.01	2.15
Sodium (Na^{+})	mg/l	0.23	13.8	18.6	2.3
Potassium (K^{+})	mg/l	0.07	5.7	7.7	5.2
Calcium (Ca^{2+})	mg/l	24.0	72.4	81.6	58.7
Magnesium (Mg^{2+})	mg/l	0.02	2.4	3.7	0.38
Ammonium (NH_4^{+})	mg/l	< 0.1	0.01	0.01	< 0.1
Hydrogencarbonate (HCO_3^{-})	mg/l	34.8	57.8	51.6	35.4
Chloride (Cl^{-})	mg/l	0.23	16.2	27.3	5.5
Sulfate (SO_4^{2-})	mg/l	< 0.1	16.4	17.1	1.4
Nitrate (NO_3^{-})	mg/l	1.4	2.0	1.3	0.15
Fluoride (F^{-})	mg/l	0.11	0.46	0.41	0.05

CEC zero experiment 1-2 mm IG_BH05_AR43

Appendix Table A-19: Element concentrations of the final zero CEC experiment solutions with the largest grain size fraction (1-2 mm) after 72 h. Sample name IG_BH05_AR43 1-2 mm.

Hydro Lab.-No.					
Sample		Zero Start Solution	Zero 1:1 No. 1	Zero 1:1 No. 2	Zero Blank
Rock/ test solution Mass ratio		-	1:1	1:1	-
Rock mass	g	-	40.004	40.000	0
Solution mass	g	-	39.586	39.452	74.711
pH value start		-	9.67	9.65	7.62
pH value end		-	10.03	9.98	7.43
Redox potential start	mV	-	117.6	95.2	104.6
Redox potential end	mV	-	-81.9	-53.1	19.0
Nickel (Ni^{2+})	mg/l	0.094	0.110	0.051	0.130
Barium (Ba^{2+})	mg/l	< 0.1	< 0.1	< 0.1	< 0.1
Strontium (Sr^{2+})	mg/l	< 0.1	0.02	0.02	< 0.1
Aluminum (Al^{3+})	mg/l	2.28	2.19	11.7	1.24
Iron tot. (Fe_{tot})	mg/l	1.52	2.29	2.83	0.160
Iron-II (Fe^{2+})	mg/l	0.02	0.055	0.011	0.012
Iron-III (Fe^{3+})	mg/l	1.50	2.24	2.82	0.15
Sodium (Na^{+})	mg/l	0.37	21.4	19.6	0.24
Potassium (K^{+})	mg/l	0.10	5.0	5.5	2.1
Calcium (Ca^{2+})	mg/l	8.5	18.8	17.7	6.5
Magnesium (Mg^{2+})	mg/l	0.07	0.79	0.85	0.01
Ammonium (NH_4^{+})	mg/l	0.011	< 0.1	< 0.1	0.005
Hydrogencarbonate (HCO_3^{-})	mg/l	26.2	83.0	71.4	28.1
Chloride (Cl^{-})	mg/l	0.25	16.2	17.8	3.4
Sulfate (SO_4^{2-})	mg/l	0.11	8.4	9.4	< 0.1
Nitrate (NO_3^{-})	mg/l	0.16	0.78	0.13	< 0.1
Fluoride (F^{-})	mg/l	< 0.1	1.6	1.6	0.03

CEC zero experiment 2-4 mm IG_BH05_AR43

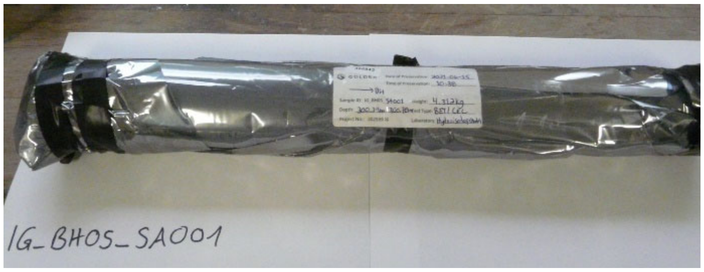
Appendix Table A-20: Element concentrations of the final zero CEC experiment solutions with the largest grain size fraction (2-4 mm) after 74 h. Sample name IG_BH05_AR43 2-4 mm.

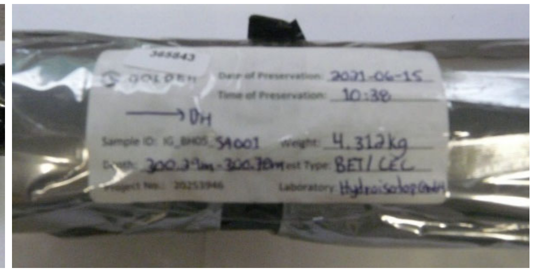
Hydro Lab.-No.					
Sample		Zero Start Solution	Zero 1:1 No. 1	Zero 1:1 No. 2	Zero Blank
Rock/ test solution Mass ratio		-	1:1	1:1	-
Rock mass	g	-	40.003	39.998	0
Solution mass	g	-	39.582	39.535	39.373
pH value start		-	9.65	9.35	7.73
pH value end		-	10.30	10.32	8.18
Redox potential start	mV	-	130.0	83.3	99.7
Redox potential end	mV	-	-55.0	-36.0	134.2
Nickel (Ni^{2+})	mg/l	0.11	0.210	0.240	0.10
Barium (Ba^{2+})	mg/l	< 0.1	< 0.1	< 0.1	< 0.1
Strontium (Sr^{2+})	mg/l	< 0.1	0.02	0.02	0.002
Aluminum (Al^{3+})	mg/l	< 0.01	1.780	3.160	< 0.01
Iron tot. (Fe_{tot})	mg/l	0.48	2.00	1.94	0.85
Iron-II (Fe^{2+})	mg/l	0.14	0.10	0.079	0.27
Iron-III (Fe^{3+})	mg/l	0.34	1.90	1.86	0.58
Sodium (Na^{+})	mg/l	0.24	41.6	40.4	2.6
Potassium (K^{+})	mg/l	0.14	6.3	6.7	5.3
Calcium (Ca^{2+})	mg/l	131	156	184	12.8
Magnesium (Mg^{2+})	mg/l	0.09	0.77	0.77	0.08
Ammonium (NH_4^{+})	mg/l	< 0.05	< 0.05	< 0.05	0.34
Hydrogencarbonate (HCO_3^{-})	mg/l	32.3	124.5	119.0	84.8
Chloride (Cl^{-})	mg/l	0.15	16.9	20.9	5.7
Sulfate (SO_4^{2-})	mg/l	0.10	10.8	9.9	1.2
Nitrate (NO_3^{-})	mg/l	0.52	0.83	0.24	0.06
Fluoride (F^{-})	mg/l	0.02	1.6	1.7	< 0.1

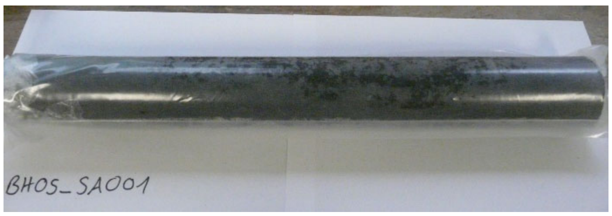
APPENDIX B

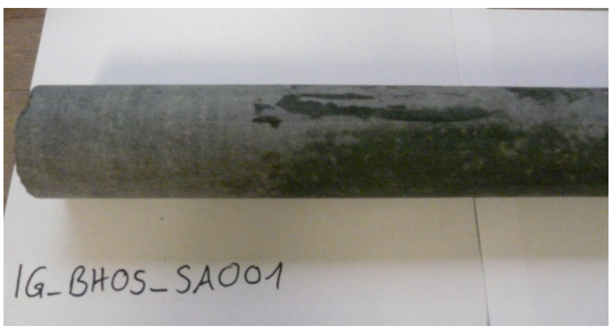
Photo Documentation

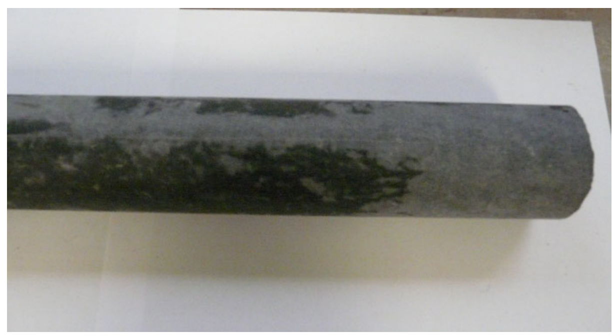
Photos of the intact core and a core slice IG_BH05_SA001

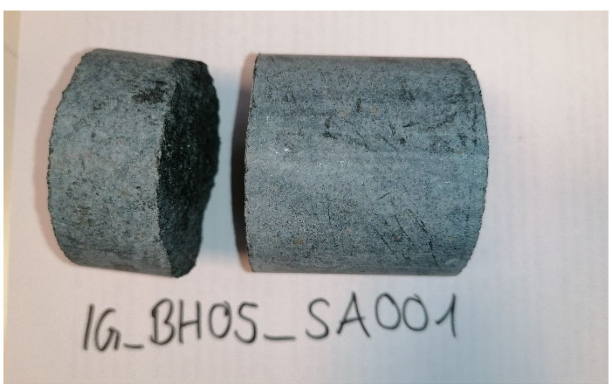










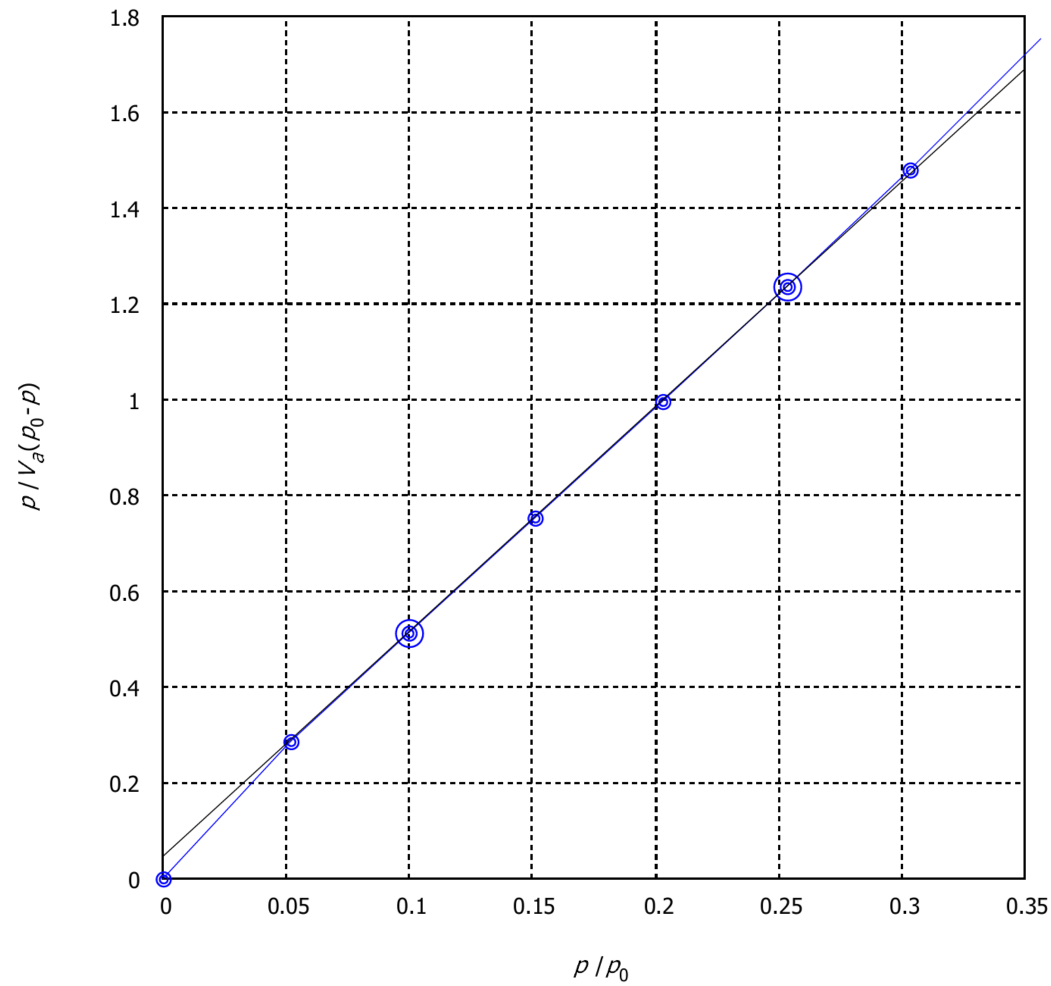


Photos of the intact core and a core slice IG_BH05_AR43

APPENDIX C

Lab Report Uni Bern

Core size 0.065-0.2 mm IG_BH05_SA001



BET-Plot

Adsorptive N2

Adsorption temperature 77.350 [K]

◎ 65-200mu-Port1.DAT

, Vacuum degree before measurement:0.000E+0Pa

Information of Instrument	(S/N: 33,)		
Date of measurement	13/09/2021	Sample weight	6.1098 [g]
Time of measurement	2:59:43	Saturated vapor pressure	96.571 [kPa]

V_m	0.2109	[cm^3(STP) g^{-1}]	$a_{s,BET}$	9.1794E-01	[m^2 g^{-1}]
C	105.25		Total pore volume ($p/_0$=0.362)	4.9318E-04	[cm^3 g^{-1}]
			Mean pore diameter	2.1491	[nm]

BET-Plot

(1/1)

Filename	65-200mu-Port1.DAT
COMMENT	, Vacuum degree before measurement:0.000E+0Pa

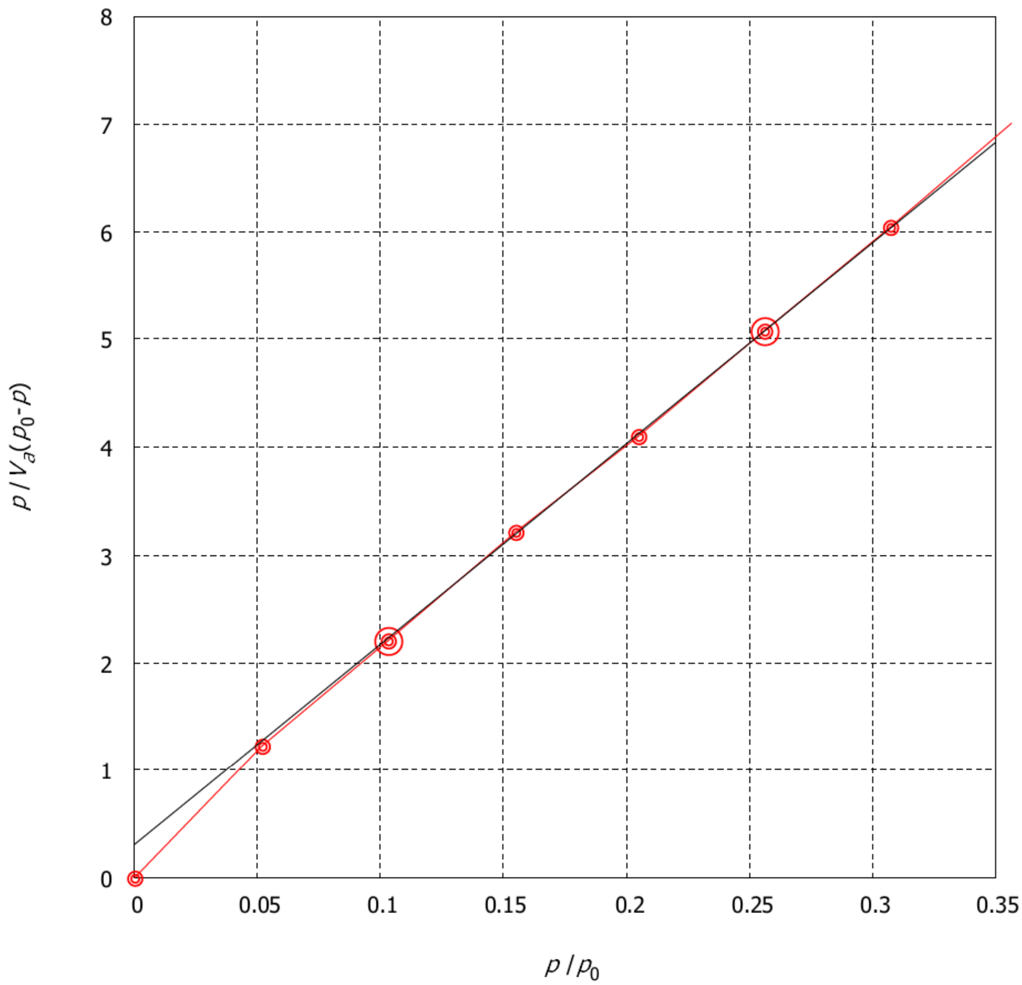
S/N	33	Vs_0	12.386
Date of measurement	13/09/2021	Time of measurement	2:59:43
Adsorptive	N2	Adsorption temperature	77.350 [K]
Sample weight	6.1098 [g]	Adsorbate molecules diameter	0.3540 [nm]
Saturated vapor pressure	96.571 [kPa]	Calculate mean pore diameter.	Do
Calculate mean particle size.	Do	Relative pressure for pore volume calculation	0.9900
Adsorptive molecular weight	28.013	Density	0.8080 [g cm^{-3}]
Adsorptive surface area	0.1620 [nm^2]	Analytic method	Use pressure range setting.
Pressure range	0.1000-0.2500		

S.P.	2	
E.P.	5	
Slope(Linear)	4.6973	
Intercept(Linear)	4.5057E-02	
Correlation coefficient	1.0000	
V_m	0.2109	[cm^3(STP) g^{-1}]
$a_{s,BET}$	9.1794E-01	[m^2 g^{-1}]
C	105.25	
Total pore volume (p/p_0=0.362)	4.9318E-04	[cm^3 g^{-1}]
Mean pore diameter	2.1491	[nm]

[Adsorption branch] Number of data point : 8

No	p/p_0	$p/V_a(p_0-p)$
0	0.0000	0.0000
1	5.1882E-02	0.2852
2	9.9721E-02	0.5142
3	0.1512	0.7548
4	0.2026	0.9956
5	0.2534	1.2360
6	0.3036	1.4811
7	0.3623	1.7819

Core size 0.15-0.3 mm IG_BH05_SA001



BET-Plot

Adsorptive N2

Adsorption temperature 77.350 [K]

◎ IG BH-05 0.15-0.3-Port2.DAT

, Vacuum degree before measurement:0.000E+0Pa

Information of Instrument	(S/N: 33,)		
Date of measurement	2/1/2023	Sample weight	7.5453 [g]
Time of measurement	1:40:44	Saturated vapor pressure	97.210 [kPa]

V_m	5.2796E-02	[cm^3(STP) g^{-1}]	$a_{s,BET}$	2.2979E-01	[m^2 g^{-1}]
C	62.139		Total pore volume (p/p_0 =0.368)	1.2450E-04	[cm^3 g^{-1}]
			Mean pore diameter	2.1672	[nm]

1 / 2

BET-Plot

(1/1)

Filename	IG BH-05 0.15-0.3-Port2.DAT
COMMENT	, Vacuum degree before measurement:0.000E+0Pa

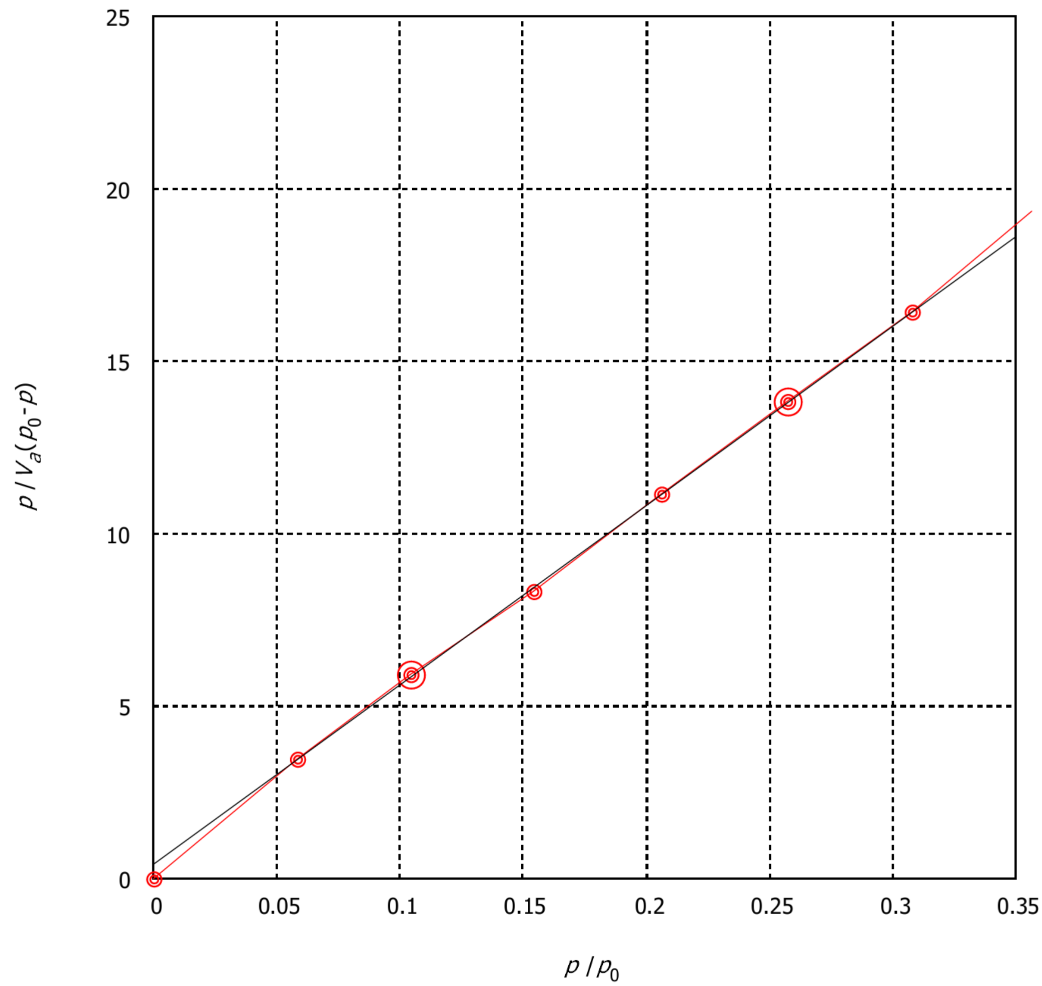
S/N	33	Vs_0	12.386
Date of measurement	2/1/2023	Time of measurement	1:40:44
Adsorptive	N2	Adsorption temperature	77.350 [K]
Sample weight	7.5453 [g]	Adsorbate molecules diameter	0.3540 [nm]
Saturated vapor pressure	97.210 [kPa]	Calculate mean pore diameter.	Do
Calculate mean particle size.	Do	Relative pressure for pore volume calculation	0.9900
Adsorptive molecular weight	28.013	Density	0.8080 [g cm $^{-3}$]
Adsorptive surface area	0.1620 [nm ^{2}]	Analytic method	Use pressure range setting.
Pressure range	0.1000-0.2500		

S.P.	2	
E.P.	5	
Slope(Linear)	18.636	
Intercept(Linear)	0.3048	
Correlation coefficient	0.9999	
V_m	5.2796E-02	[cm ^{3} (STP) g $^{-1}$]
$a_{s,BET}$	2.2979E-01	[m ^{2} g $^{-1}$]
C	62.139	
Total pore volume (p/p_0 =0.368)	1.2450E-04	[cm ^{3} g $^{-1}$]
Mean pore diameter	2.1672	[nm]

[Adsorption branch] Number of data point : 8

No	p / p_0	$p / V_a(p_0-p)$
0	0.0000	0.0000
1	5.1642E-02	1.2330
2	0.1029	2.2093
3	0.1548	3.2167
4	0.2049	4.1092
5	0.2560	5.0769
6	0.3074	6.0417
7	0.3684	7.2469

Core size 1-2 mm IG_BH05_SA001



BET-Plot

Adsorptive N2

Adsorption temperature 77.350 [K]

◎ IG BH-05 1-2-Port2.DAT

, Vacuum degree before measurement:0.000E+0Pa

Information of Instrument	(S/N: 33,)		
Date of measurement	2/3/2023	Sample weight	8.0043 [g]
Time of measurement	1:47:35	Saturated vapor pressure	98.732 [kPa]

V_m	1.9080E-02	[cm^3(STP) g^{-1}]	$a_{s,BET}$	8.3045E-02	[m^2 g^{-1}]
C	122.99		Total pore volume ($p/_0$ =0.370)	4.5022E-05	[cm^3 g^{-1}]
			Mean pore diameter	2.1686	[nm]

BET-Plot

(1/1)

Filename	IG BH-05 1-2-Port2.DAT
COMMENT	, Vacuum degree before measurement:0.000E+0Pa

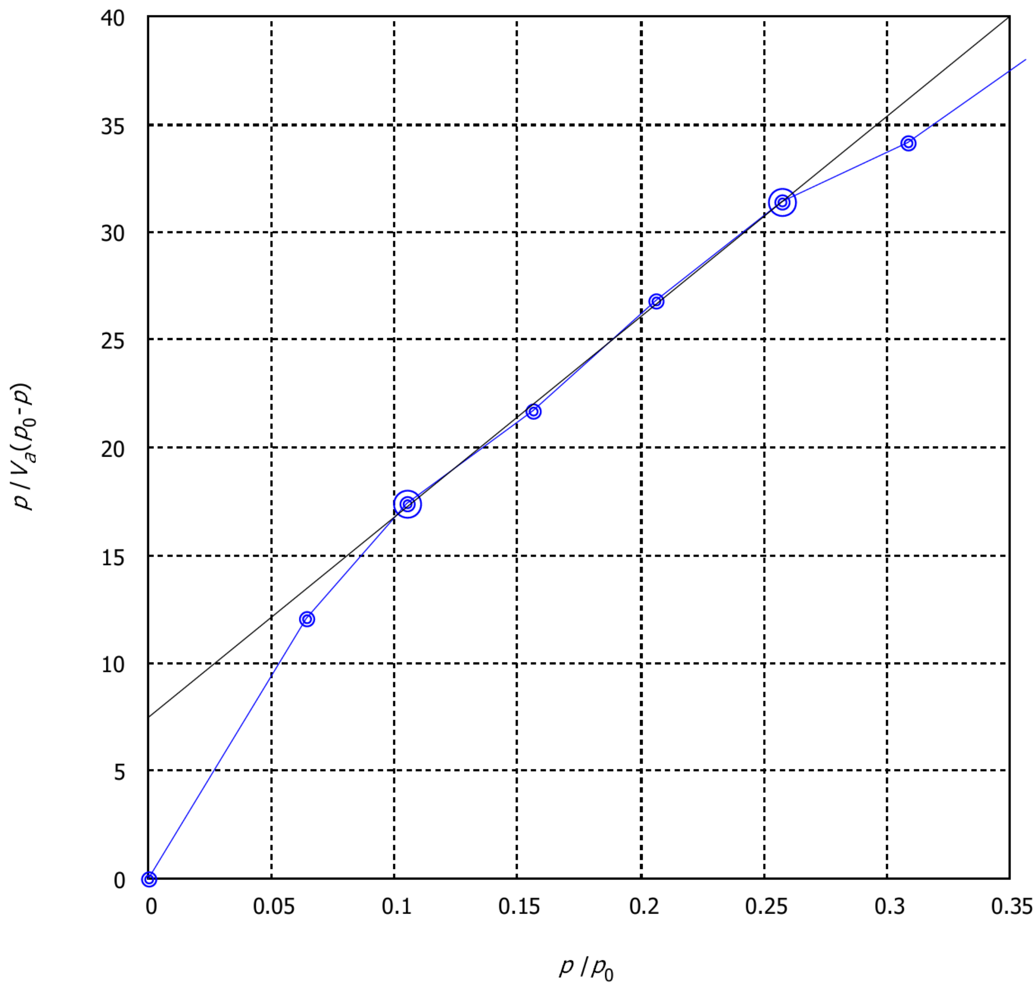
S/N	33	Vs_0	12.386
Date of measurement	2/3/2023	Time of measurement	1:47:35
Adsorptive	N2	Adsorption temperature	77.350 [K]
Sample weight	8.0043 [g]	Adsorbate molecules diameter	0.3540 [nm]
Saturated vapor pressure	98.732 [kPa]	Calculate mean pore diameter.	Do
Calculate mean particle size.	Do	Relative pressure for pore volume calculation	0.9900
Adsorptive molecular weight	28.013	Density	0.8080 [g cm $^{-3}$]
Adsorptive surface area	0.1620 [nm ^{2}]	Analytic method	Use pressure range setting.
Pressure range	0.1000-0.2500		

S.P.	2	
E.P.	5	
Slope(Linear)	51.986	
Intercept(Linear)	0.4262	
Correlation coefficient	0.9996	
V_m	1.9080E-02	[cm^3(STP) g^{-1}]
$a_{s,BET}$	8.3045E-02	[m^2 g^{-1}]
C	122.99	
Total pore volume (p/p_0=0.370)	4.5022E-05	[cm^3 g^{-1}]
Mean pore diameter	2.1686	[nm]

[Adsorption branch] Number of data point : 8

No	p/p_0	$p/V_a(p_0-p)$
0	0.0000	0.0000
1	5.8625E-02	3.4700
2	0.1041	5.9300
3	0.1546	8.3187
4	0.2064	11.162
5	0.2572	13.843
6	0.3077	16.455
7	0.3696	20.143

Core size 2-4 mm IG_BH05_SA001



BET-Plot

Adsorptive N2

Adsorption temperature 77.350 [K]

◎ IG BH-05 2-4mm-Port2.DAT

, Vacuum degree before measurement:0.000E+0Pa

Information of Instrument	(S/N: 33,)		
Date of measurement	5/17/2023	Sample weight	8.2150 [g]
Time of measurement	1:48:49	Saturated vapor pressure	96.266 [kPa]

V_m	9.9619E-03	[cm^3(STP) g^{-1}]	$a_{s,BET}$	4.3359E-02	[m^2 g^{-1}]
C	13.386		Total pore volume ($p/_0$=0.371)	2.3330E-05	[cm^3 g^{-1}]
			Mean pore diameter	2.1523	[nm]

1 / 2

BET-Plot

(1/1)

Filename	IG BH-05 2-4mm-Port2.DAT
COMMENT	, Vacuum degree before measurement:0.000E+0Pa

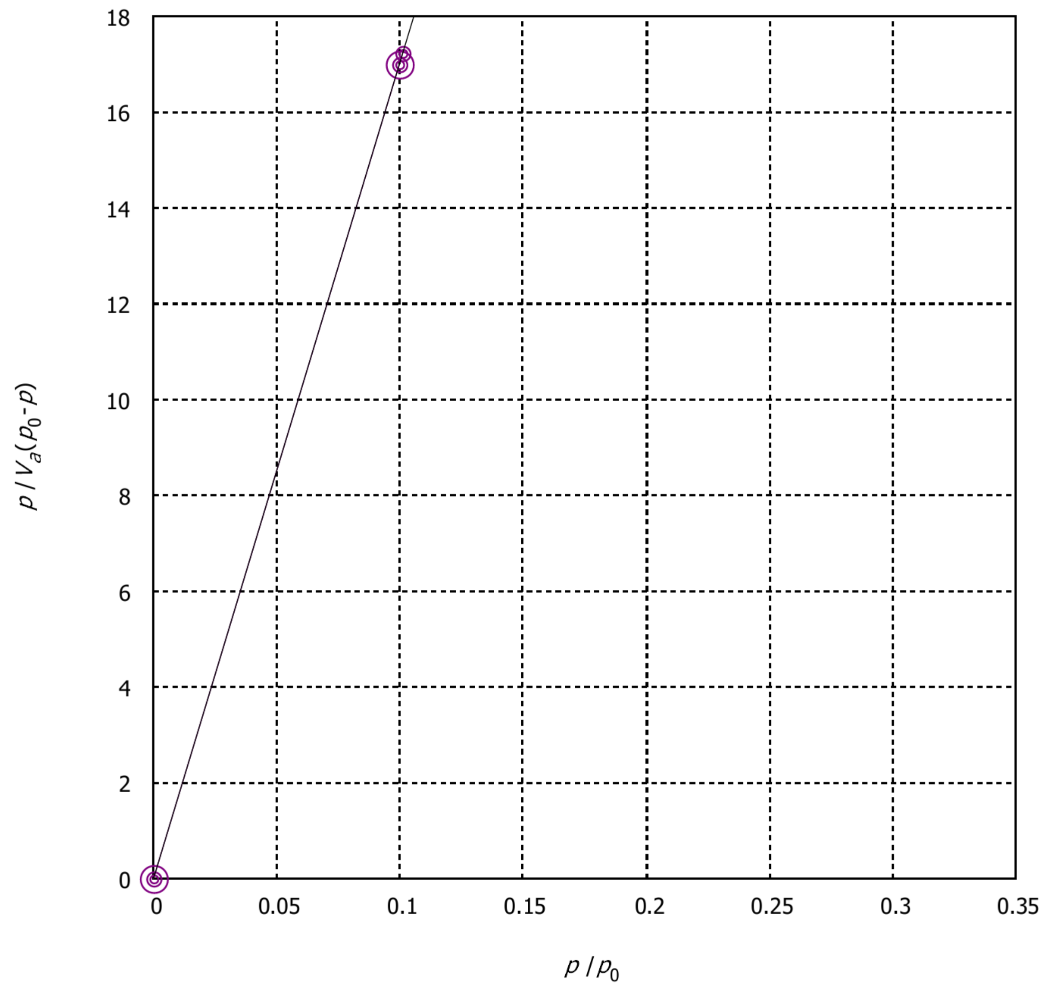
S/N	33	Vs_0	12.386
Date of measurement	5/17/2023	Time of measurement	1:48:49
Adsorptive	N2	Adsorption temperature	77.350 [K]
Sample weight	8.2150 [g]	Adsorbate molecules diameter	0.3540 [nm]
Saturated vapor pressure	96.266 [kPa]	Calculate mean pore diameter.	Do
Calculate mean particle size.	Do	Relative pressure for pore volume calculation	0.9900
Adsorptive molecular weight	28.013	Density	0.8080 [g cm $^{-3}$]
Adsorptive surface area	0.1620 [nm ^{2}]	Analytic method	Use pressure range setting.
Pressure range	0.1000-0.2500		

S.P.	2	
E.P.	5	
Slope(Linear)	92.884	
Intercept(Linear)	7.4989	
Correlation coefficient	0.9994	
V_m	9.9619E-03	[cm ^{3}(STP) g $^{-1}$]
$a_{s,BET}$	4.3359E-02	[m ^{2} g $^{-1}$]
C	13.386	
Total pore volume (p/p_0=0.371)	2.3330E-05	[cm ^{3} g $^{-1}$]
Mean pore diameter	2.1523	[nm]

[Adsorption branch] Number of data point : 8

No	p/p_0	$p/V_a(p_0-p)$
0	0.0000	0.0000
1	6.4006E-02	12.107
2	0.1048	17.384
3	0.1559	21.681
4	0.2063	26.807
5	0.2573	31.403
6	0.3085	34.173
7	0.3713	39.153

Core size 10-20 mm IG_BH05_SA001



BET-Plot(Single Point Method)

Adsorptive N2

Adsorption temperature 77.350 [K]

◎ IG BH-05 10-20mm-Port2.DAT

, Vacuum degree before measurement:0.000E+0Pa

Information of Instrument	(S/N: 33,)		
Date of measurement	5/19/2023	Sample weight	5.5935 [g]
Time of measurement	1:46:36	Saturated vapor pressure	97.264 [kPa]

V_m	5.8823E-03	[cm^3(STP) g^{-1}]	$a_{s,BET}$	2.5603E-02	[m^2 g^{-1}]
Total pore volume ($p/_0$=0.101)	1.0125E-05	[cm^3 g^{-1}]	Mean pore diameter	1.5818	[nm]
Analytical pressure [p/p_0]	0.1				

1 / 2

BET-Plot(Single Point Method)

(1/1)

Filename	IG BH-05 10-20mm-Port2.DAT
COMMENT	, Vacuum degree before measurement:0.000E+0Pa

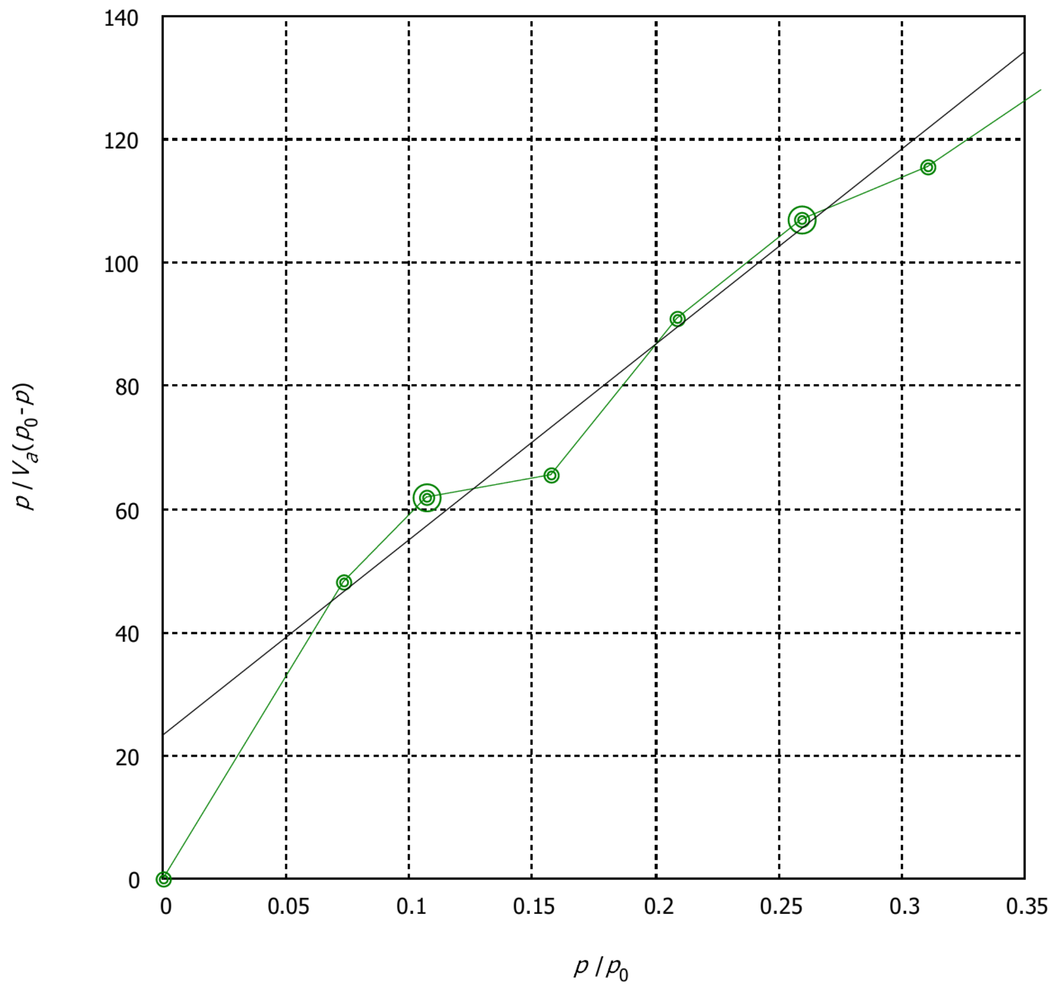
S/N	33	Vs_0	12.386
Date of measurement	5/19/2023	Time of measurement	1:46:36
Adsorptive	N2	Adsorption temperature	77.350 [K]
Sample weight	5.5935 [g]	Adsorbate molecules diameter	0.3540 [nm]
Saturated vapor pressure	97.264 [kPa]	Calculate mean pore diameter.	Do
Calculate mean particle size.	Do	Relative pressure for pore volume calculation	0.9900
Adsorptive molecular weight	28.013	Density	0.8080 [g cm $^{-3}$]
Adsorptive surface area	0.1620 [nm ^{2}]	Analytic method	Single Point Method.
Relative pressure	0.1000 [kPa]		

Analytical pressure	0.1	[p/p_0]
S.P.	0	
E.P.	1	
V_m	5.8823E-03	[cm^3(STP) g^{-1}]
$a_{s,BET}$	2.5603E-02	[m^2 g^{-1}]
Total pore volume (p/p_0 =0.101)	1.0125E-05	[cm^3 g^{-1}]
Mean pore diameter	1.5818	[nm]

[Adsorption branch] Number of data point : 3

No	p/p_0	$p/V_a(p_0-p)$
0	0.0000	0.0000
1	0.1000	17.000
2	0.1013	17.229

Core slice IG_BH05_SA001



BET-Plot

Adsorptive N2

Adsorption temperature 77.350 [K]

◎ Bohrkern-Port3.DAT

, Vacuum degree before measurement:0.000E+0Pa

Information of Instrument	(S/N: 33,)		
Date of measurement	15/09/2021	Sample weight	15.928 [g]
Time of measurement	1:37:32	Saturated vapor pressure	97.179 [kPa]

V_m	2.9407E-03	[cm^3(STP) g^{-1}]	$a_{s,BET}$	1.2799E-02	[m^2 g^{-1}]
C	14.557		Total pore volume ($p/_0$=0.380)	7.0538E-06	[cm^3 g^{-1}]
			Mean pore diameter	2.2044	[nm]

BET-Plot

(1/1)

Filename	Bohrkern-Port3.DAT
COMMENT	, Vacuum degree before measurement:0.000E+0Pa

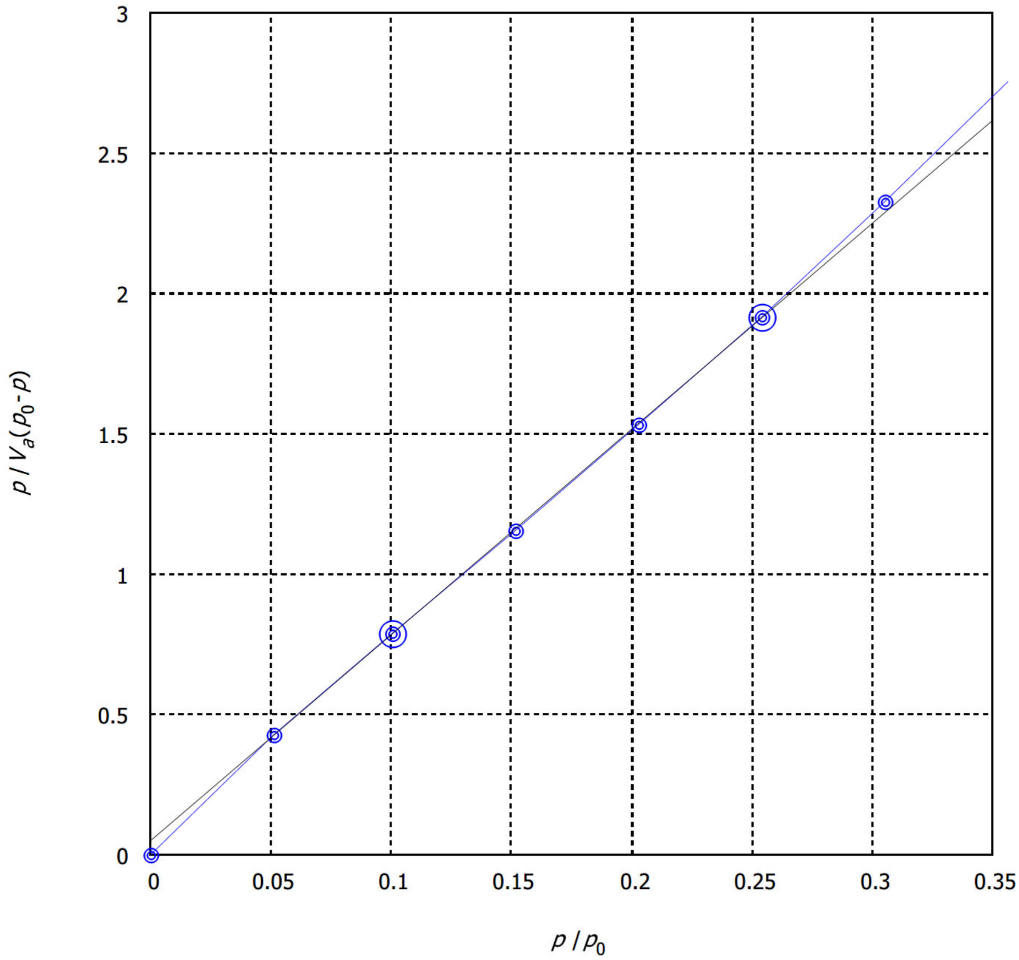
S/N	33	Vs_0	12.386
Date of measurement	15/09/2021	Time of measurement	1:37:32
Adsorptive	N2	Adsorption temperature	77.350 [K]
Sample weight	15.928 [g]	Adsorbate molecules diameter	0.3540 [nm]
Saturated vapor pressure	97.179 [kPa]	Calculate mean pore diameter.	Do
Calculate mean particle size.	Do	Relative pressure for pore volume calculation	0.9900
Adsorptive molecular weight	28.013	Density	0.8080 [g cm $^{-3}$]
Adsorptive surface area	0.1620 [nm ^{2}]	Analytic method	Use pressure range setting.
Pressure range	0.1000-0.2500		

S.P.	2	
E.P.	5	
Slope(Linear)	316.70	
Intercept(Linear)	23.361	
Correlation coefficient	0.9690	
V_m	2.9407E-03	[cm ^{3}(STP) g $^{-1}$]
$a_{s,BET}$	1.2799E-02	[m ^{2} g $^{-1}$]
C	14.557	
Total pore volume (p/p_0 =0.380)	7.0538E-06	[cm ^{3} g $^{-1}$]
Mean pore diameter	2.2044	[nm]

[Adsorption branch] Number of data point : 8

No	p/p_0	$p/V_a(p_0-p)$
0	0.0000	0.0000
1	7.3509E-02	48.176
2	0.1070	61.838
3	0.1575	65.620
4	0.2089	90.988
5	0.2591	106.97
6	0.3106	115.69
7	0.3800	134.39

Core size 0.15-0.3 mm IG_BH05_AR43



BET-Plot

Adsorptive N2

Adsorption temperature 77.350 [K]

◎ 404997-Port3.DAT

, Vacuum degree before measurement:0.000E+0Pa

Information of Instrument	(S/N: 33,)		
Date of measurement	9/28/2023	Sample weight	6.6241 [g]
Time of measurement	1:42:38	Saturated vapor pressure	97.688 [kPa]

V_m	0.1354	[cm^3(STP) g^{-1}]	$a_{s,BET}$	5.8933E-01	[m^2 g^{-1}]
C	153.49		Total pore volume (p/p_0=0.365)	3.1435E-04	[cm^3 g^{-1}]
			Mean pore diameter	2.1336	[nm]

1 / 2

BET-Plot

(1/1)

Filename	404997-Port3.DAT
COMMENT	, Vacuum degree before measurement:0.000E+0Pa

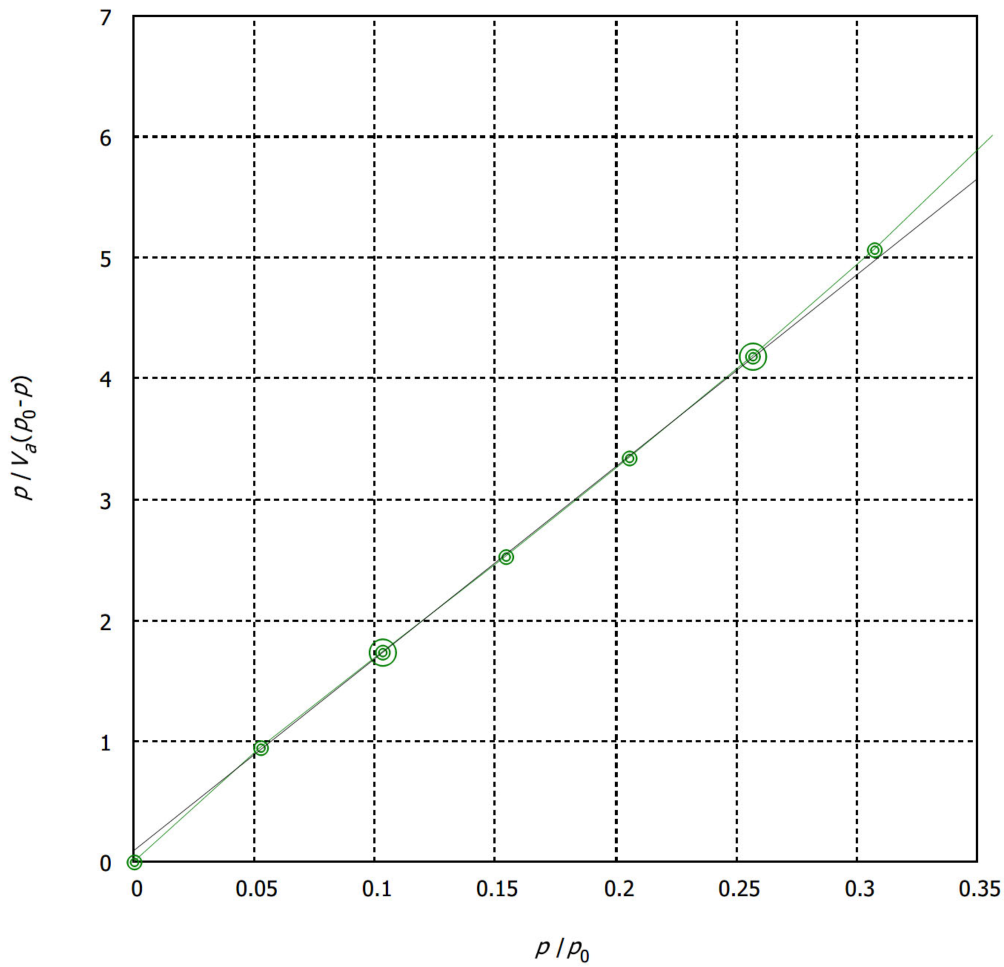
S/N	33	Vs_0	12.386
Date of measurement	9/28/2023	Time of measurement	1:42:38
Adsorptive	N2	Adsorption temperature	77.350 [K]
Sample weight	6.6241 [g]	Adsorbate molecules diameter	0.3540 [nm]
Saturated vapor pressure	97.688 [kPa]	Calculate mean pore diameter.	Do
Calculate mean particle size.	Do	Relative pressure for pore volume calculation	0.9900
Adsorptive molecular weight	28.013	Density	0.8080 [g cm $^{-3}$]
Adsorptive surface area	0.1620 [nm ^{2}]	Analytic method	Use pressure range setting.
Pressure range	0.1000-0.2500		

S.P.	2	
E.P.	5	
Slope(Linear)	7.3347	
Intercept(Linear)	4.8099E-02	
Correlation coefficient	0.9999	
V_m	0.1354	[cm ^{3}(STP) g $^{-1}$]
$a_{s,BET}$	5.8933E-01	[m ^{2} g $^{-1}$]
C	153.49	
Total pore volume (p/p_0=0.365)	3.1435E-04	[cm ^{3} g $^{-1}$]
Mean pore diameter	2.1336	[nm]

[Adsorption branch] Number of data point : 8

No	p/p_0	$p/V_a(p_0-p)$
0	0.0000	0.0000
1	5.0928E-02	0.4273
2	0.1003	0.7887
3	0.1516	1.1561
4	0.2031	1.5310
5	0.2541	1.9181
6	0.3054	2.3281
7	0.3653	2.8315

Core size 1-2 mm IG_BH05_AR43



BET-Plot

Adsorptive N2

Adsorption temperature 77.350 [K]

◎ 404996-Port2.DAT

, Vacuum degree before measurement:0.000E+0Pa

Information of Instrument	(S/N: 33,)		
Date of measurement	9/28/2023	Sample weight	7.3803 [g]
Time of measurement	1:38:57	Saturated vapor pressure	97.740 [kPa]

V_m	6.2491E-02	[cm^3(STP) g^{-1}]	$a_{s,BET}$	2.7199E-01	[m^2 g^{-1}]
C	186.72		Total pore volume (p/p_0=0.369)	1.4474E-04	[cm^3 g^{-1}]
			Mean pore diameter	2.1287	[nm]

1 / 2

BET-Plot

(1/1)

Filename	404996-Port2.DAT
COMMENT	, Vacuum degree before measurement:0.000E+0Pa

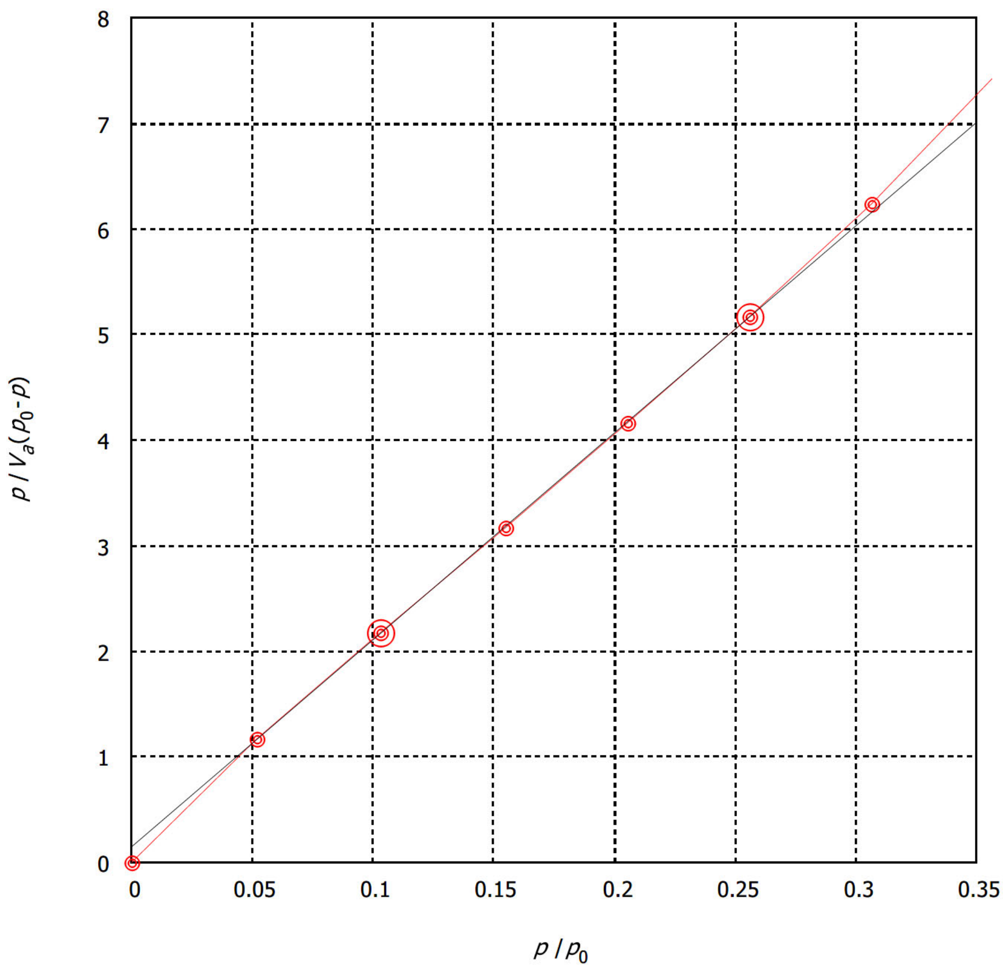
S/N	33	Vs_0	12.386
Date of measurement	9/28/2023	Time of measurement	1:38:57
Adsorptive	N2	Adsorption temperature	77.350 [K]
Sample weight	7.3803 [g]	Adsorbate molecules diameter	0.3540 [nm]
Saturated vapor pressure	97.740 [kPa]	Calculate mean pore diameter.	Do
Calculate mean particle size.	Do	Relative pressure for pore volume calculation	0.9900
Adsorptive molecular weight	28.013	Density	0.8080 [g cm $^{-3}$]
Adsorptive surface area	0.1620 [nm ^{2}]	Analytic method	Use pressure range setting.
Pressure range	0.1000-0.2500		

S.P.	2	
E.P.	5	
Slope(Linear)	15.917	
Intercept(Linear)	8.5700E-02	
Correlation coefficient	0.9999	
V_m	6.2491E-02	[cm ^{3} (STP) g $^{-1}$]
$a_{s,BET}$	2.7199E-01	[m ^{2} g $^{-1}$]
C	186.72	
Total pore volume (p/p_0=0.369)	1.4474E-04	[cm ^{3} g $^{-1}$]
Mean pore diameter	2.1287	[nm]

[Adsorption branch] Number of data point : 8

No	p / p_0	$p / V_a(p_0-p)$
0	0.0000	0.0000
1	5.2542E-02	0.9438
2	0.1029	1.7385
3	0.1543	2.5270
4	0.2055	3.3407
5	0.2569	4.1907
6	0.3075	5.0634
7	0.3688	6.2433

Core size 2-4 mm IG_BH05_AR43



BET-Plot

Adsorptive N2

Adsorption temperature 77.350 [K]

◎ 404995-Port1.DAT

, Vacuum degree before measurement:0.000E+0Pa

Information of Instrument	(S/N: 33,)		
Date of measurement	9/28/2023	Sample weight	8.0056 [g]
Time of measurement	1:41:21	Saturated vapor pressure	97.700 [kPa]

V_m	5.0655E-02	[cm^3(STP) g^{-1}]	$a_{s,BET}$	2.2047E-01	[m^2 g^{-1}]
C	135.61		Total pore volume (p/p_0=0.370)	1.1726E-04	[cm^3 g^{-1}]
			Mean pore diameter	2.1273	[nm]

1 / 2

BET-Plot

(1/1)

Filename	404995-Port1.DAT
COMMENT	, Vacuum degree before measurement:0.000E+0Pa

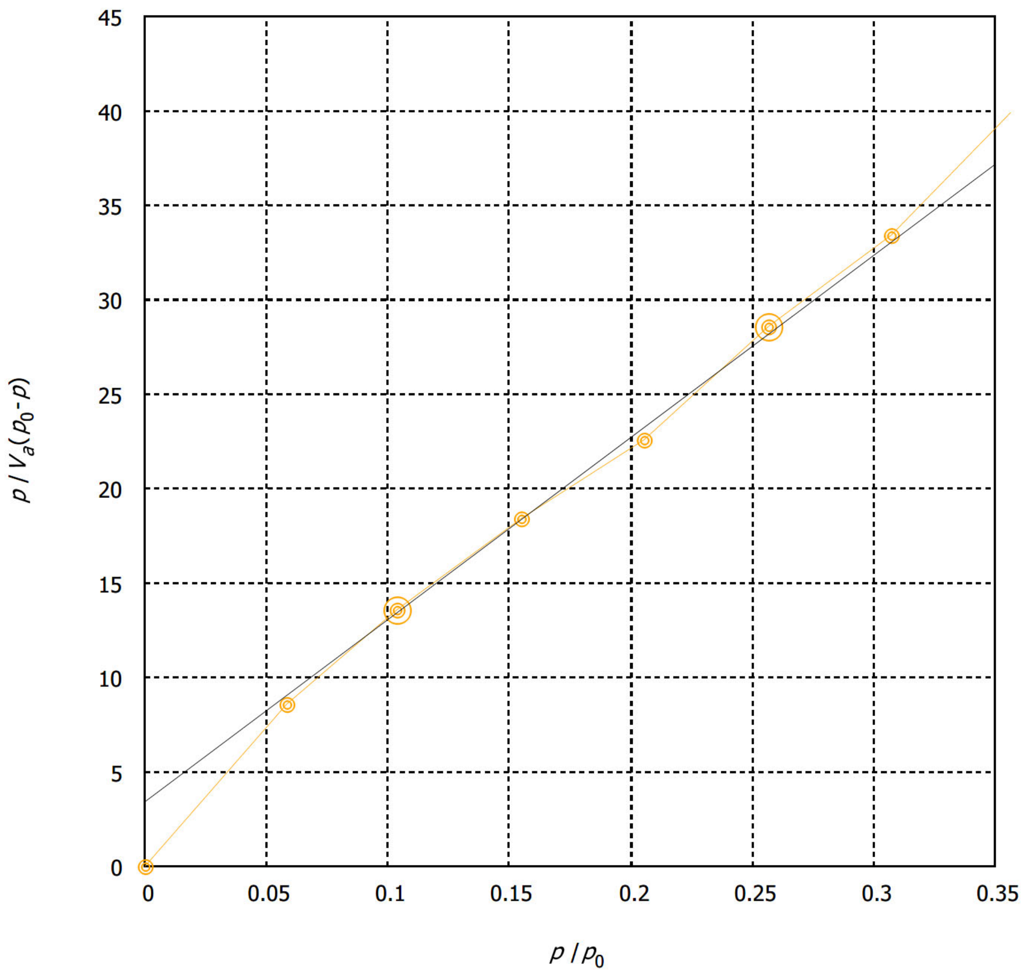
S/N	33	Vs_0	12.386
Date of measurement	9/28/2023	Time of measurement	1:41:21
Adsorptive	N2	Adsorption temperature	77.350 [K]
Sample weight	8.0056 [g]	Adsorbate molecules diameter	0.3540 [nm]
Saturated vapor pressure	97.700 [kPa]	Calculate mean pore diameter.	Do
Calculate mean particle size.	Do	Relative pressure for pore volume calculation	0.9900
Adsorptive molecular weight	28.013	Density	0.8080 [g cm $^{-3}$]
Adsorptive surface area	0.1620 [nm ^{2}]	Analytic method	Use pressure range setting.
Pressure range	0.1000-0.2500		

S.P.	2	
E.P.	5	
Slope(Linear)	19.596	
Intercept(Linear)	0.1456	
Correlation coefficient	1.0000	
V_m	5.0655E-02	[cm^3(STP) g^{-1}]
$a_{s,BET}$	2.2047E-01	[m^2 g^{-1}]
C	135.61	
Total pore volume (p/p_0=0.370)	1.1726E-04	[cm^3 g^{-1}]
Mean pore diameter	2.1273	[nm]

[Adsorption branch] Number of data point : 8

No	p/p_0	$p/V_a(p_0-p)$
0	0.0000	0.0000
1	5.2044E-02	1.1763
2	0.1032	2.1740
3	0.1546	3.1718
4	0.2058	4.1634
5	0.2562	5.1763
6	0.3069	6.2379
7	0.3701	7.7502

Core slice IG_BH05_AR43



BET-Plot

Adsorptive N2

Adsorption temperature 77.350 [K]

◎ 404994-Port1.DAT

, Vacuum degree before measurement:0.000E+0Pa

Information of Instrument	(S/N: 33,)		
Date of measurement	9/28/2023	Sample weight	6.2242 [g]
Time of measurement	1:30:26	Saturated vapor pressure	97.418 [kPa]

V_m	9.9974E-03	[cm^3(STP) g^{-1}]	$a_{s,BET}$	4.3513E-02	[m^2 g^{-1}]
C	29.572		Total pore volume (p/p_0=0.366)	2.1695E-05	[cm^3 g^{-1}]
			Mean pore diameter	1.9943	[nm]

1 / 2

BET-Plot

(1/1)

Filename	404994-Port1.DAT
COMMENT	, Vacuum degree before measurement:0.000E+0Pa

S/N	33	Vs_0	12.386
Date of measurement	9/28/2023	Time of measurement	1:30:26
Adsorptive	N_2	Adsorption temperature	77.350 [K]
Sample weight	6.2242 [g]	Adsorbate molecules diameter	0.3540 [nm]
Saturated vapor pressure	97.418 [kPa]	Calculate mean pore diameter.	Do
Calculate mean particle size.	Do	Relative pressure for pore volume calculation	0.9900
Adsorptive molecular weight	28.013	Density	0.8080 [g cm $^{-3}$]
Adsorptive surface area	0.1620 [nm ^{2}]	Analytic method	Use pressure range setting.
Pressure range	0.1000-0.2500		

S.P.	2	
E.P.	5	
Slope(Linear)	96.643	
Intercept(Linear)	3.3825	
Correlation coefficient	0.9975	
V_m	9.9974E-03	[cm ^{3}(STP) g $^{-1}$]
$a_{s,BET}$	4.3513E-02	[m ^{2} g $^{-1}$]
C	29.572	
Total pore volume (p/p_0=0.366)	2.1695E-05	[cm ^{3} g $^{-1}$]
Mean pore diameter	1.9943	[nm]

[Adsorption branch] Number of data point : 8

No	p/p_0	$p/V_a(p_0-p)$
0	0.0000	0.0000
1	5.8418E-02	8.6142
2	0.1038	13.560
3	0.1549	18.453
4	0.2055	22.603
5	0.2565	28.565
6	0.3073	33.446
7	0.3663	41.207

APPENDIX D

Lab Addendum Memo - Depth Correction

TECHNICAL MEMORANDUM

DATE August 4, 2024 **Reference No.** 20253946-5046-TM-001

TO File
WSP Canada Inc.

CC File

FROM George Schneider **EMAIL george.schneider@wsp.com**

ADDENDUM TO LABORATORY REPORT FROM HYDROISOTOP FOR WORK PACKAGE WP04F - BOREHOLE IG_BH05

This addendum corrects the depths (along borehole) of the samples for BET / CEC analysis included in this report. The depth adjustment is the result of a correction applied to the core logging depths after reconciliation with the drilling depth records. Refer to the WP03 report for details and to the acQuire database for corrected depths.

Refer to Table 1 for the list of samples containing the original logged depths and the corrected depths after reconciliation between the core logging and drilling depths. This addendum shall always accompany the laboratory report when distributed to other parties.

Table 1: List of samples requiring depth correction

Sample ID	Test / Sample Type	Original Logged Depth (mbgs downhole)		Corrected Depth (mbgs downhole)	
		From	To	From	To
IG_BH05_SA001	BET / CEC	300.29	300.78	300.09	300.58
IG_BH05_AR43	BET / CEC	788.10	788.29	787.79	787.98

WSP Canada Inc.

George Schneider, M.Sc., P.Geo.

GWS/

Distribution: File

Attachments: N/A

c:\gws-work\1 - active\nwmo bh456\lab samples\ig_bh05 wp04f depth memo 04aug2024.docx wsp.com

Hydroisotop