

**Studying the influence of pore
water electrical conductivity on
the formation factor, as estimated
based on electrical methods**

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This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the authors. SKB may draw modified conclusions, based on additional literature sources and/or expert opinions.

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Abstract

In this report the geometric formation factor, as obtained in tracer tests, is compared with the apparent formation factor, as obtained by electrical methods. This should provide information on the data uncertainty associated with the electrical methods utilised in situ within the SKB site investigation programme. Generally, if directly estimating the formation factor from the apparent formation factor, there is a risk of substantial overestimations. This is especially the case at shallow depth at the Forsmark and Oskarshamn sites, where the groundwater is of low salinity.

This study is performed on nine drill core samples from the Forsmark and Oskarshamn sites. The formation factor and apparent formation factor of these samples have previously been determined by the through diffusion method, using HTO as the tracer, and by the electrical resistivity method, as part of the site investigation programme.

The study is divided in two parts where part 2 was performed successfully, while part 1 suffered from problems. In part 2, eight rock samples were saturated by either a 0.05 or 0.1 M NaCl electrolyte. These electrolytes should represent the groundwater at repository depth. The formation factor of these samples was obtained by the through-electromigration (TEM) method, using iodide as the tracer. In addition, the apparent formation factors were obtained by electrical resistivity methods using direct current and alternating current at 10, 100, and 2,000 Hz. The measurements were performed in duplicates or triplicates, and generally a good reproducibility was achieved. As expected, the apparent formation factors were a few times larger than the TEM formation factor for the same sample. The ratio of the apparent formation factors and TEM formation factors range between about 2 and 12, where larger ratios were found for rock samples of low formation factors. The results were compared with modelled apparent formation factors, where input data were a range of formation factors and generic surface conductivities, and fairly good agreement was obtained.

Part 1 suffered from methodology problems, which ultimately lead to poor reproducibility and accuracy. Here a single sample was in sequence saturated with the 0.001, 0.03, 0.5, 0.1 and 1.0 M NaCl electrolytes. The aim was to see if the apparent formation factor increasingly overestimates the formation factor with decreasing electrical conductivity of the pore water. Notwithstanding the experimental problems and errors, it was shown that this is clearly the case. For the electrolyte 0.001 M NaCl, and for this particular sample, the apparent formation factor overestimates the formation factor by at least one order of magnitude. The measured apparent formation factors were compared with modelled apparent formation factors, where input data were the sample's measured formation factor and surface conductivity, and fairly good agreement was obtained.

The formation factors obtained by the TEM method were comparable with those obtained in the previous through diffusion experiments on the same samples. Especially for the Forsmark samples of part 2, the TEM results agreed with the through diffusion results, indicating that anion exclusion is not a major issue. From comparison of the TEM formation factors, obtained with anionic tracer iodide, and estimated formation factors based on the resistivity methods, it is indicated that anion exclusion should not reduce the effective diffusivity by more than a few factors.

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1 Introduction

Within the SKB site investigation programme, the formation factor of the rock matrix has been estimated based on in situ electrical methods /e.g. Löfgren and Neretnieks 2005/. It has been verified in the laboratory that the apparent formation factor, as measured by electrical methods, can be used as an estimate of the geometric formation factor. This verification has been done by the use of both alternating current /e.g. Skagius and Neretnieks 1986a, Ohlsson 2000/ and direct current /Löfgren and Neretnieks 2006/. However, these verifications have been performed on rock samples that are saturated with electrolytes of high ionic strength, typically 1 M NaCl. The groundwater, and supposedly also the pore water, at repository depth at the investigated sites have a significantly lower ionic strength than that of 1 M NaCl /cf. Gascoyne and Laaksoharju 2008/. Furthermore, it is recognised that if the rock is saturated by an electrolyte of low ionic strength, surface conduction may give rise to considerable errors, if directly using the apparent formation factor as an estimate of the formation factor /e.g. Ohlsson 2000/.

To avoid that surface conduction induces too much errors in the estimated in situ formation factors, a criterion is used that states that the apparent formation factor should only be obtained if the electrical conductivity of the pore water is equal to, or above, 0.5 S/m /Löfgren and Neretnieks 2005/. This criterion is based on surface conductivities measured on rock samples saturated by electrolytes of very low ionic strength /Ohlsson 2000, Löfgren 2004/. It is hypothesised that the apparent formation factor should overestimate the formation factor by not more than two times, as long as this criterion is met. However, prior to this present study, the actual effect of surface conduction has never been studied on rock samples saturated by electrolytes resembling the groundwater at repository depth, including that of the electrical conductivity 0.5 S/m.

In this study, the apparent formation factor of a number of rock samples is measured by electrical methods using both alternating current (AC) and direct current (DC). Furthermore, the formation factor is measured by tracer tests, with iodide as the tracer, by using the through-electromigration (TEM) method /cf. Löfgren and Neretnieks 2006/. A number of different electrolytes are used, ranging from 0.001 M NaCl to 1.0 M NaCl, including the 0.05 M NaCl electrolyte having an approximate electrical conductivity of 0.5 S/m. The results from this study can be used for estimating data uncertainty of the previously estimated in situ formation factors. Furthermore, the results should provide information on the effect of anion exclusion on the effective diffusivity.

All measurements have been conducted by Petr Vecernik at the Nuclear Research Institute Řež pl. (NRI) in the Czech Republic, with the aid from Martin Löfgren, Kemakta Konsult AB. The TEM method, and the methodology utilised in this study, have been developed by Martin Löfgren. The experimental apparatus was constructed on the basis of Martin Löfgren's set up, including some modifications (stirring, drop wise flow stages, etc). The apparatus main part design is based on NRI Řež through-diffusion cell design, including sample sealing.

2 Objective and scope

The overall objective of this study is to deliver results that can be used for estimating the data uncertainty of in situ formation factors previously estimated from electrical methods within the SKB site investigation programme. A specific aim is at determining the error induced by surface conduction for rock samples saturated by either of the two electrolytes 0.05 M NaCl and 0.1 M NaCl, having the electrical conductivities of about 0.5 S/m and 1.0 S/m. The interest of the former electrolyte comes from a criterion used by SKB when estimating in situ formation factors based on electrical methods. The interest of the latter electrolyte comes from the fact that at the Forsmark and Oskarshamn sites, the groundwater at repository depth typically has the electrical conductivity of about 1.0 S/m.

To achieve the objectives, formation factors and apparent formation factors are measured on nine rock samples from both the Forsmark and Oskarshamn sites, which are saturated by different electrolytes ranging from 0.001 to 1.0 M NaCl. The formation factor is measured by the TEM method using iodide as the tracer, and apparent formation factors are measured by electrical resistivity methods using both AC and DC.

The study is divided into two different parts where in part 1, a single sample is saturated in sequence by the five different electrolytes 0.001, 0.03, 0.05, 0.1, and 1.0 M NaCl. For the 0.001 M NaCl electrolyte, only the apparent formation factors are obtained but for the other electrolytes, also the TEM formation factor is obtained, with the purpose of facilitating comparisons.

In part 2, four samples are saturated by 0.05 M NaCl and four samples are saturated by 0.1 M NaCl. Formation factors and apparent formation factors are obtained by all three above mentioned methods.

It is not an objective of this report to develop a process based framework with the purpose of in detail explaining the results, even if some processes are suggested as partly responsible for the expected outcome. Furthermore, it is not an objective to postulate a final strategy on how to quantitatively incorporate results from this study, by way of correcting previously estimated in situ formation factors. However, we do give some guidance on how such a correction could be performed.

This work has not had as an objective to quantify the electro-osmotic flow, or to correct the TEM measurements for electro-osmotic effects. In hindsight, this decision can be questioned.

As opposed to measurements performed within the SKB site investigation programme, no method description as part of the SKB quality assurance programme guides the performance of these measurements. Therefore, extra care has been taken to describe how the measurements are performed. In case of repeating the measurements, even for other samples, this report can be used as a method description. The preparation of the experiments is described in Sections 4.2 to 4.4. The execution of the experiments is described in Chapter 5. To ensure traceability, raw data spread sheets from the experiments are given in Appendices A and B. Some guidance in how to read the raw data spread sheets is given in Appendix C.

3 Theory

3.1 Diffusion and electromigration in porous media

In this report, as in most of the scientific literature, the geometric formation factor is defined by the geometry of the porous system, and dependent on the transport porosity ε_t (-), the tortuosity τ^2 (-), and the constrictivity δ (-).

$$F_f = \varepsilon_t \frac{\delta}{\tau^2} \quad \text{Equation 3-1}$$

In most cases in this report we use the shorter term “formation factor”, as is common in the scientific literature. It should be noted that based on this definition, the formation factor should be independent of the nature of the migrating solute, and of interactions between mineral surfaces and solutes.

In case of diffusion through an inert porous medium, the effective diffusivity D_e (m²/s) can be calculated from the product of the formation factor and the diffusivity in unconfined pore water D_w (m²/s).

$$D_e = F_f \cdot D_w \quad \text{Equation 3-2}$$

In the experimental study, iodide is used as the tracer, with a D_w of $2 \cdot 10^{-9}$ m²/s /CRC 2008/. According to Maxwell-Stefan diffusion theory /Krishna and Wesselingh 1997/, the ion pair of the experiment would be I-Cl⁻, where chloride has about the same D_w as iodide.

The theory being the foundation of the through-electromigration method is described in /Löfgren and Neretnieks 2006/. It is based on the Einstein relation, describing the relation between the diffusivity and ionic mobility of ionic solutes /e.g. Atkins 1999/:

$$D = \frac{\mu RT}{z F} \quad \text{Equation 3-3}$$

where D (m²/s) is the diffusivity, μ (m²/V·s) is the ionic mobility, z (-) is the charge number of the migrating ionic solute, and R (J/mol·K), T (K), and F (C/mol) are the gas constant, temperature, and Faraday constant, respectively. In an inert porous medium, the diffusivity and ionic mobility in Equation 3-3 can be substituted by the effective diffusivity and effective ionic mobility μ_e (m²/V·s), respectively:

$$D_e = \frac{\mu_e RT}{z F} \quad \text{Equation 3-4}$$

When applying an electric field over a saturated rock sample holding an ionic tracer, the electromigratory tracer flux N_μ (mol/m²·s) through the sample is:

$$N_\mu = -\mu_e C_p \frac{dU}{dx} \quad \text{Equation 3-5}$$

where C_p (mol/m³) is the tracer concentration in the pore water and dU/dx (V/m) is the electrical potential gradient over the sample. If assuming a homogenous sample, a constant electrical potential gradient can be calculated from the quotient of the potential drop over the sample and the sample length. If combining Equations 3-4 and 3-5, and substituting the D_e for the product of F_f and D_w (cf. Equation 3.2) the electromigratory tracer flux through an inert porous medium is described by:

$$N_\mu = -F_f \cdot \frac{F z D_w}{RT} C_p \frac{dU}{dx} \quad \text{Equation 3-6}$$

In order to assess the total flux through the porous medium, other processes such as diffusion and electro-osmosis should be formally accounted for. However, diffusion can for practical purposes be ignored, as it is a much slower transport mechanism than electromigration. In /Löfgren and

Neretnieks 2006/ it was found that although electroosmosis has a notable effect on the results, this effect is minor. If having an anionic tracer, and if accounting for electro-osmosis, the total flux N_{tot} (mol/m²·s) through the porous medium is:

$$N_{tot} = -(\mu_e - \mu_{eo,e})C_p \frac{dU}{dx} \quad \text{Equation 3-7}$$

where $\mu_{e,eo}$ is the effective electro-osmotic mobility /Löfgren and Neretnieks 2006/. In a TEM experiment, the total flux through the rock sample is measured and if not accounting for electro-osmosis, the obtained formation factor is underestimated (if using anionic tracers). In /Löfgren and Neretnieks 2006/, where the effective electro-osmotic mobility was measured by use of the non-charged tracer quinoxaline, it was estimated that if not accounting for electro-osmosis, the induced error is on the order of 10%. In that study, drill core samples from the Laxemar site was used.

3.2 The through-electromigration method

With the TEM method, the electromigratory tracer flux N_μ can be obtained directly, if ignoring electro-osmotic effects and using N_{tot} as an estimate of N_μ (cf. Equation 3-7). This is achieved by applying an electrical potential gradient over a saturated rock sample and by allowing an ionic tracer to migrate through the sample. By recording and analysing a breakthrough curve, as in a traditional through-diffusion experiment, N_μ can be obtained. The equipment used for the TEM experiments is discussed below. It will be shown that all parameters of Equation 3-6 can be measured or are already known, enabling calculations of the formation factor.

The TEM method can be seen as a further development of the traditional through-diffusion method. The rock sample is placed between two compartments, one holding an electrolyte with high tracer concentration and one holding an electrolyte initially free of the tracer. As electromigration is the main process of solute transport, the studied tracer should be ionic and in this present study the non-radioactive anion I⁻ is used. The potential gradient over the sample could be achieved by placing an electrode in each electrolyte and connecting the electrodes to a direct current power supply. However, if this is done, a pH gradient will evolve over the studied rock sample, as electrolysis will occur at the anode and cathode.

To avoid this, the anode and cathode are placed in compartments that are separated from the high and low concentration tracer compartments. Furthermore, the high and low pH electrolytes formed in the anode and cathode compartments are used to neutralise each other, by intermixing them. Hence, the TEM cell consists of four compartments, as illustrated in Figure 3-1.

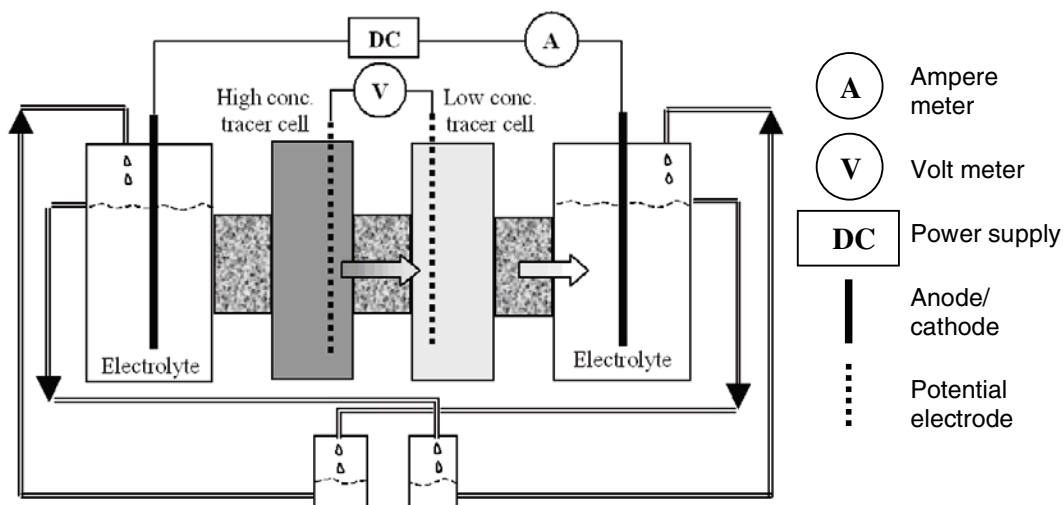


Figure 3-1. Schematics of the through-electromigration cell.

To avoid current from being propagated in the hoses used for intermixing the anode and cathode electrolytes, stages of drop wise flow of the electrolytes are needed. As shown in Figure 3-1, the anode and the cathode are connected to a direct current power supply through an ampere meter. As the potential gradient over the studied sample dU/dx is needed in Equation 3-6, separate potential electrodes in form of nets are placed in the high and low concentration tracer compartments, and are connected to a volt meter.

When running the experiment, the tracer will migrate into the porous system of the rock with the electrical potential gradient as the main driving force. After some time, all transport pores of the sample will achieve approximately the same tracer concentration as in the high concentration tracer compartment (as opposed to the situation in a through diffusion experiment, where there will be a concentration gradient over the sample within the porous system). As the tracer concentration in the pores can be approximated by that of the high concentration tracer compartment, this gives C_p in Equation 3-6. As only a small fraction of the tracer ($< 1\%$) is transported out of the high concentration tracer compartment, its concentration is assumed to be constant throughout the experiment.

As seen from the setup illustrated in Figure 3-1, the tracer migrating into the low concentration tracer compartment may just as well migrate further, into the anode compartment (in case of an anionic tracer). However, if the transport resistance in the filter separating the compartments is similar to the transport resistance of the studied rock sample, the fraction of tracer that is being lost in this fashion can be approximated by the ratio of tracer concentrations of the low and high concentration tracer compartments. In this present study, slices of granitic rock are being used as filters.

When running a TEM experiment, the obtained breakthrough curve is much easier to evaluate if the potential gradient over the studied rock sample is constant. Therefore it is recommended to have the same electrolytes in all compartments, as well as in the porous systems of the studied rock sample and filter rocks. In this way only minor corrections of the output of the direct current power supply are needed. Furthermore, by having the same background electrolyte in the entire system, varying electro-osmosis effects are avoided. The exception is that a small fraction of the background electrolyte of the high concentration tracer compartment is exchanged for the tracer (which then is allowed to migrate to other parts of the system).

3.3 The electrical resistivity methods

Within the SKB site investigations, the apparent formation factor has been obtained by an electrical method that do not utilise tracers, but instead the solutes in the background electrolyte /e.g. Löfgren and Neretnieks 2005, Thunehed 2007a/. In this method the porous system of the rock sample is saturated by a pore water (electrolyte) of known resistivity ρ_w (ohm.m). By measuring the resistivity of the rock sample ρ_r (ohm.m) and by taking the ratio of the pore water resistivity and rock resistivity, the apparent formation factor is obtained.

$$F_f^{app} = \frac{\rho_w}{\rho_r} \quad \text{Equation 3-8}$$

Within the site investigation programme, alternating current has been used in the measurements but it is shown in /Löfgren and Neretnieks 2006/ that direct current can be used equally well. It is also shown in /Löfgren and Neretnieks 2006/ that measurements using AC can be performed while the rock sample is placed in the TEM cell.

The rock resistivity is determined by:

1. The capacity of solutes in the bulk pore water to conduct current, described by the pore conductivity κ_p (S/m)
2. The capacity of solutes at the pore water/mineral grain interface to conduct current, described by the surface conductivity κ_s (S/m)
3. The capacity of the matrix (mineral grains) to conduct current. Compared to the current conducted by pore conduction and surface conduction, the current conducted in the matrix is negligible. The resistivity of the minerals commonly found in intrusive igneous rock is on the orders of 10^8 – 10^{14} ohm.m /Schön 1996/, which is many orders of magnitude larger than the resistivity of saturated rock, where solutes in the pores conduct current.

The concept of pore conduction and surface conduction is shortly explained below and for further reading /Stumm and Morgan 1996/ and /Revil and Glover 1997/ are recommended. In intrusive igneous rock, such as granite, the mineral grains constituting the pore walls are generally negatively charged. The charge is balanced by a surplus of cations that are either more or less strongly bound to the mineral surface, or dissolved in the pore water in a diffuse layer (also called the electrical double layer) close to the mineral surface. This is illustrated in Figure 3-2, where an idealised pore is shown.

The cations in the diffuse layer are mobile and can conduct current, a process generally referred to as surface conduction. As their amount is determined by the negative charge of the mineral surface, they cannot be removed from the pore water by attempting to saturate the rock sample by, for example, deionised water. If placing a potential gradient over a rock sample, the current which runs through the rock will be propagated by both cations in the diffuse layer and by cations and anions of the chosen electrolyte in the bulk pore. Here the bulk pore should be seen as the part of the pore volume largely unaffected by the surface effects. It can be shown that the relation between the formation factor and apparent formation factor is /Crawford and Sidborn 2009/:

$$F_f = F_f^{app} - \frac{\kappa_s}{\kappa_w} \tag{Equation 3-9}$$

If saturating the rock sample with an electrolyte of high ionic strength, such as 1 M NaCl, the amount of anions and cations in the bulk pore will outweigh the amount of cations in the diffuse layer. In this case, if using the apparent formation factor as an estimate of the geometric formation factor, only very small errors are introduced. In the laboratory part of the SKB site investigations, 1 M NaCl has been used to saturate the rock samples before measuring the apparent formation factor by electrical methods /e.g. Thunehed 2007a/. At the intermediate ionic strengths of the pore water common in situ at the Forsmark and Oskarshamn sites, surface conduction may cause significant errors if directly using the apparent formation factor as an estimate of the formation factor. The electrical conductivity of the pore water likely to be encountered in situ at the Forsmark and Oskarshamn sites is low in shallow rock (> 0.5 S/m) and intermediate at depth (0.5 to 3.5 S/m).

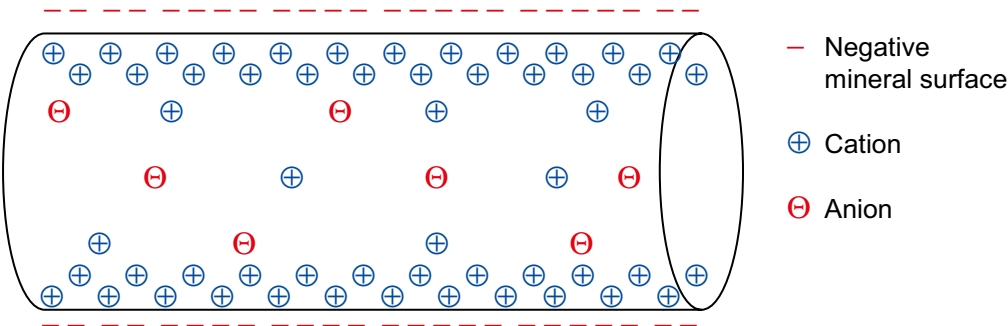


Figure 3-2. Illustration of an idealised pore with negative mineral surfaces, a positive diffuse layer and a bulk pore water of low ionic strength.

4 Samples and experimental method description

4.1 The rock samples

In the study, nine rock samples from the Forsmark and Oskarshamn site investigation areas are used. For all samples, the formation factor and apparent formation factor have been obtained in previous campaigns by use of the electrical method /Thunehed 2007a, b/ and the through diffusion method using HTO as the tracer /Selnert et al. 2008, 2009/. In /Selnert et al. 2008, 2009/ one can also find a geological description of the samples. The columns in Table 4-1 show 1) the sample number; 2) from which site investigation area the sample is taken; 3) from which borehole the sample is taken; 4) from which borehole length the sample is taken; 5) the rock type code of the sample; 6) the length of the sample; 7) the apparent formation factor previously obtained by electrical methods with 1.0 M NaCl as background electrolyte; and 8) the formation factor previously obtained by the HTO through diffusion method. All samples have the diameter 50 mm.

The length and diameter of the samples was measured by a Vernier calliper. In the remaining of this report, the samples will be denoted sample 1, sample 2, etc.

4.2 The drying and vacuum saturation of samples

Section 4.2 to 4.7 is a method description that can also be used for future measurements. As the samples arrive to the laboratory they may be partly saturated. In order to achieve complete saturation in the subsequent vacuum saturation step, it is preferable to start with completely dry samples. The drying of the samples is carried out for 24 hours at 105°C. Before the drying, the samples are stripped from any potential silicon based polymer applied in previous experimental campaigns. The oven used for the drying is equipped with a thermostat facilitating a constant drying temperature. After the drying, the samples are allowed to cool in a desiccator.

The samples are saturated by using the vacuum saturation method /Ohlsson 2000, Melnyk and Skeet 1986/. An electrolyte solution is prepared by dissolving an appropriate amount of NaCl in deionised water. Thereafter, the solution is boiled with the purpose of degassing it. The solution is placed in a desiccator while still being warm (about 50°C). The sample (or samples) is placed on a stand above the electrolyte, and the lid is placed on the desiccator. This is illustrated in Figure 4-1a. In Figure 4-1b the desiccator used is shown.

Table 4-1. Description of samples.

Sample	Site	Borehole	Borehole length (m)	Rock type code ¹	Sample length (mm) ²	F_i^{app} electrical methods	F_i HTO through-diffusion ³
1	Forsmark	KFM01A	312.66 – 312.67	101057	10.25	$2.06 \cdot 10^{-4}$	$1.41 \cdot 10^{-4}$
2	Forsmark	KFM01A	312.54 – 312.55	101057	10.18	$1.66 \cdot 10^{-4}$	$9.39 \cdot 10^{-5}$
3	Forsmark	KFM02A	554.60 – 554.61	101051	12.64	$1.85 \cdot 10^{-4}$	$1.78 \cdot 10^{-4}$
4	Forsmark	KFM02A	554.71 – 554.72	101051	11.66	$1.89 \cdot 10^{-4}$	$1.50 \cdot 10^{-4}$
5	Forsmark	KFM02A	554.84 – 554.85	101051	11.38	$1.85 \cdot 10^{-4}$	$1.41 \cdot 10^{-4}$
6	Oskarshamn	KLX04	489.49 – 489.50	501036	9.68	$8.05 \cdot 10^{-5}$	$6.13 \cdot 10^{-5}$
7	Oskarshamn	KLX04	489.61 – 489.62	501036	9.85	$3.50 \cdot 10^{-5}$	$2.63 \cdot 10^{-5}$
8	Oskarshamn	KSH02	474.47 – 474.48	501030	10.29	$2.21 \cdot 10^{-5}$	$2.39 \cdot 10^{-5}$
9	Oskarshamn	KSH02	474.66 – 474.67	501030	10.27	$4.45 \cdot 10^{-5}$	$4.46 \cdot 10^{-5}$

¹ Rock codes: 101051: Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained. 101057: Granite to granodiorite, metamorphic, medium-grained. 501030: Fine-grained dioritoid (metavolcanite, volcanite). 501036: Quartz monzonite to monzodiorite, equigranular to weakly porphyritic.

² Measured in this study by Vernier calliper.

³ Calculated from effective diffusivities in /Selnert et al. 2008, 2009/ using the $D_w = 2.13 \cdot 10^{-9}$ m²/s for HTO.

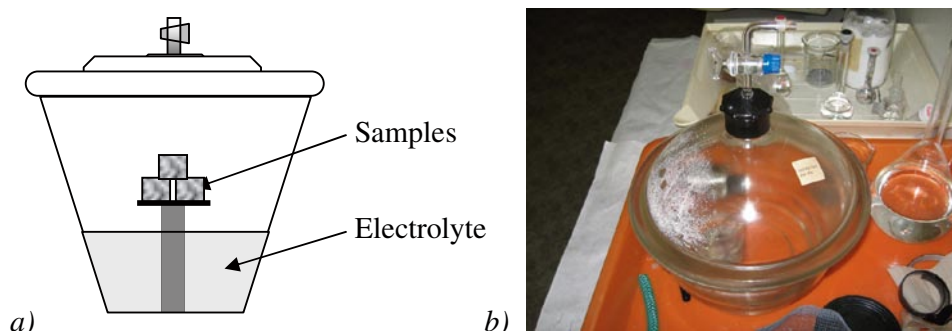


Figure 4-1. a) Illustration of the setup for the vacuum saturation method. b) The desiccator used in the study.

The air is evacuated and as a result, the electrolyte will start to boil. Thus all remaining air is replaced by water vapour at its vapour pressure. The desiccator is sealed and left for five to six hours. Thereafter the sample is shook off the stand so that it becomes totally immersed in the electrolyte. Then the pressure should be slowly increased until atmospheric pressure is achieved. In essence, the longer the time period of the pressure increase, the better the saturation becomes. The pressure increase should be performed during at least ten hours.

In the present study the pressure of the desiccator is increased passively, that is by minute leakage of air into the desiccator, over night (about 16 h). At the end of the pressure increase phase, it is checked that some under pressure still remains in the desiccator. Although increasing the pressure in this fashion presents no problem, it is likely that some air leaks into the desiccator during the time the sample remains on the stand, above the electrolyte surface. This may compromise the saturation to a minor degree and the effect can be counteracted by from time to time (no less than once per hour) applying vacuum to remove potential air. Furthermore, a few minutes prior to shaking the sample into the electrolyte, this should be done.

After the saturation, the sample is left in the saturation electrolyte until it is used in the measurements. During this time the electrolyte should be considered to be in contact with the atmosphere.

4.3 Preparing the TEM experiment

4.3.1 Assembling the through-electromigration cell

After having completed saturation, the sample is taken out of the saturation electrolyte and immediately placed in the TEM cell. In the process of fitting the sample in the TEM cell, it is important to avoid letting the rock surfaces dry. This is prevented by from time to time spraying (or otherwise applying) the saturation electrolyte to the surfaces.

As a first step, the sample is fitted in a flexible sealing ring made from silicon polymer paste (Lukopren N 5221). This is shown in Figure 4-2a and Figure 4-2b.

Thereafter the sample with its sealing ring is placed into the TEM cell in a manner making the sealing complete. In Figure 4-3, this is demonstrated by fitting a rock sample in a through-diffusion cell having the same sealing mechanism as the TEM cell.

First the sample with its sealing ring is placed upon one of the compartments made of Plexiglas (Figure 4-3a). Thereafter the Plexiglas middle piece of the cell is applied with the purpose of bounding the sample and squeezing the sealant towards the Plexiglas walls (Figure 4-3b, c). The geometry of the sealing ring and Plexiglas parts are made to provide an exact fit. Thereafter the other cell is assembled (Figure 4-3d).

By using an impervious Plexiglas sample instead of the rock sample, and then measure the resistance of the sample and sealing, it has been confirmed that virtually no current leaks between the sealing and the equipment (see Appendix D). Furthermore, by gluing a rock sample to the sealing and com-



Figure 4-2. a) Fitting the sealing ring on the sample. b) The sample fitted by the sealing ring.



Figure 4-3. Placing the rock sample in the cell.

paring results from electrical measurement with those obtained on the same unglued sample, it has been shown that for the unglued sample, only an insignificant amount of current leaks between the sealing and the rock sample.

In the through-electromigration setup, except for the high and low concentration tracer compartments there are anode and cathode compartments that need to be fitted to the cell, as illustrated in Figure 3-1. In the present study the filter rocks used are granite samples from the Melechov site, Czech Republic, which are fitted by using similar (but not the same) sealing rings as shown in Figure 4-2.

The TEM cell used in the study, which could be compared with the illustration in Figure 3-1, is shown in Figure 4-4.

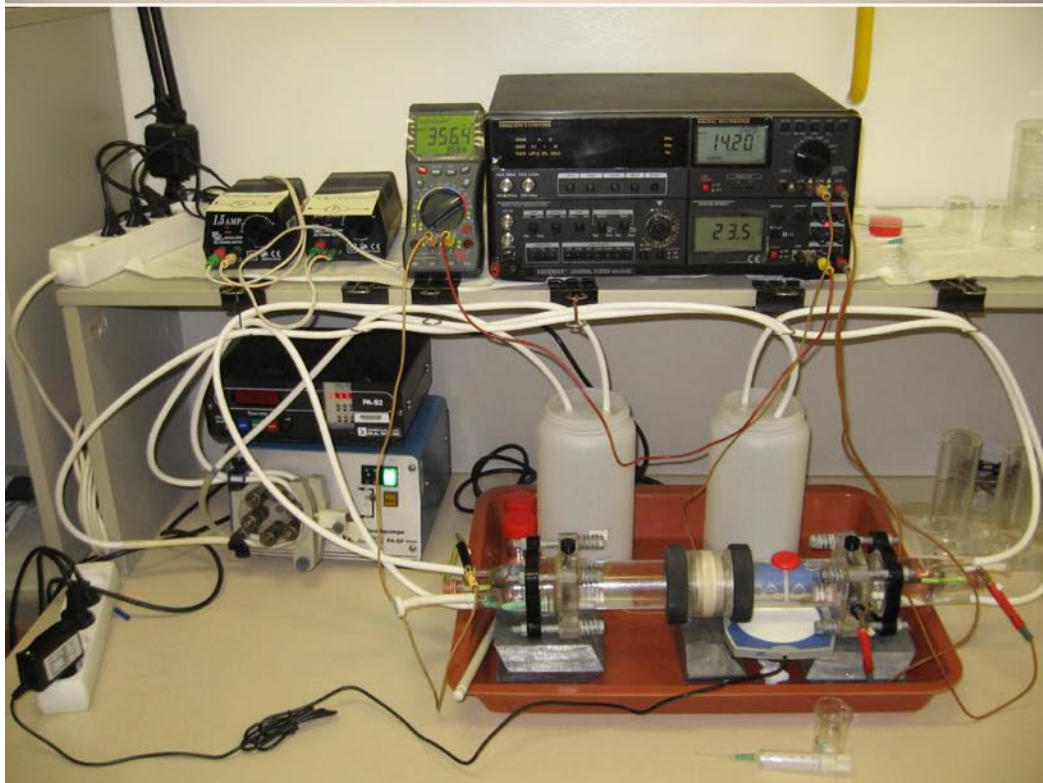
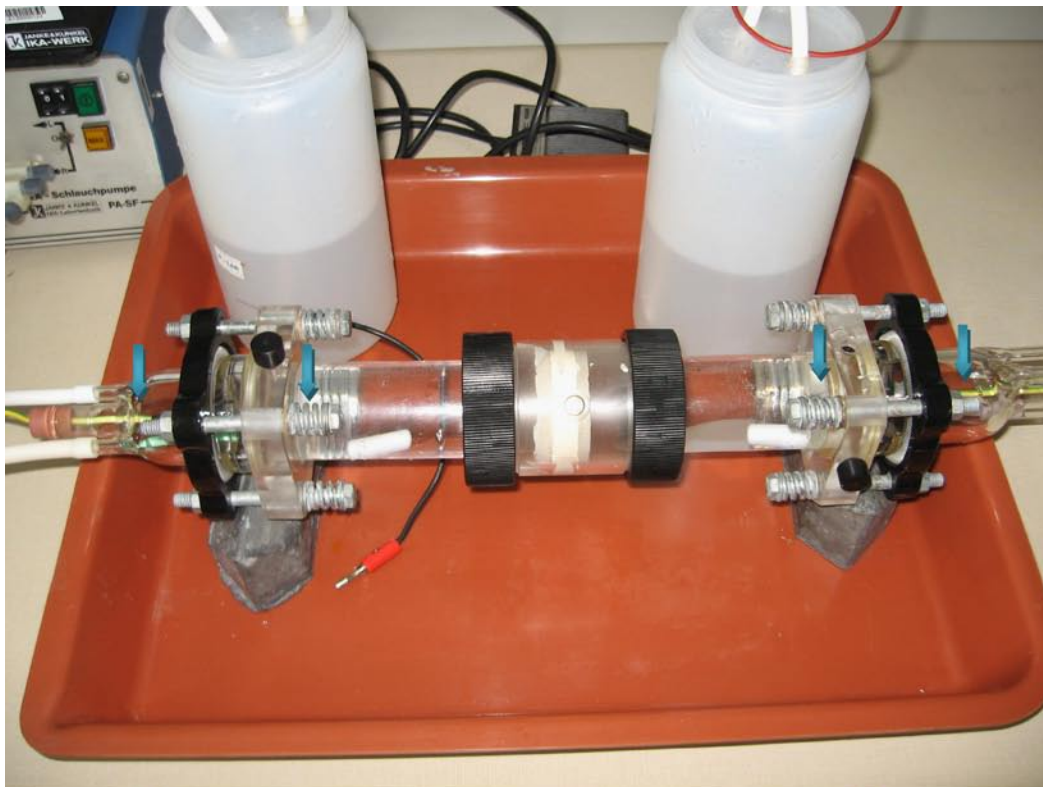


Figure 4-4. Upper image: The TEM cell, the blue arrows mark electrode positions. Lower image: The TEM cell connected to pumps, drop stages, power supply with internal ampere meter, and volt meter.

In the process of fitting the parts of the TEM cell, magnetic stirrers are placed in the high and low tracer concentration compartments. From the anode and cathode compartments, hoses are connected via a peristaltic pump to achieve intermixing of the electrolytes. Two large containers (the two white cylinders in Figure 4-4) are used to provide the drop wise flow stages, preventing current to be conducted in the hoses.

Finally the anode and cathode electrodes are connected to the power source and the potential electrodes are connected to a volt meter measuring the potential drop. In the study, titanium nets are used as potential electrodes. The connections between the nets and the copper wires outside the cell are made by gold wires. Platinum wires are used as current electrodes.

4.3.2 Stabilising a TEM experiment prior to tracer injection

Once the TEM cell is pieced together, all compartments are filled with the same appropriate background electrolyte. The conductivity and temperature of this background electrolyte are noted. The pump used for intermixing the anode and cathode electrolytes is switched on and thereafter the power is switched on. The current running through, as well as the potential drop over, the studied rock sample is monitored and noted for at least 30 minutes until a stable system is achieved (however, this may require considerably more time than 30 minutes). An example of results from the stabilising phase is shown in Figure 4-5 where it could be seen that the apparent rock resistivity first increases, then decreases, and then stabilises.

After having stabilised the system the tracer can be injected, as described in subsection 4.4.1.

4.4 Running the TEM experiment

4.4.1 Tracer injection

After having stabilised the system, the tracer can be injected. Prior to tracer injection, a sample is withdrawn from the low concentration tracer compartment to confirm low or non-detectable levels of iodide (see subsection 4.4.2 for sampling methodology). Thereafter, while still having the power supply switched on, tracer injection is performed by adding a small portion of iodide tracer to the high concentration tracer compartment.

In the present study the high and low concentration tracer compartments have the volume of 190 ml. Prior to the injection, 10 ml of NaCl background electrolyte of the high concentration tracer compartment is withdrawn by using a syringe. At time zero minutes, 1.9 ml of NaI solution of appropriate concentration is injected by use of a syringe, whereafter the compartment is stirred for one minute by a magnetic stirrer. Thereafter 8.1 ml of the NaCl electrolyte is re-injected, so that the total volume of the high concentration tracer electrolyte once more becomes 190 ml. For ten minutes after re-injecting the NaCl electrolyte, the high concentration tracer compartment should be stirred by the magnetic stirrer. Thereafter, the high concentration tracer compartment should at least be stirred from time to time.

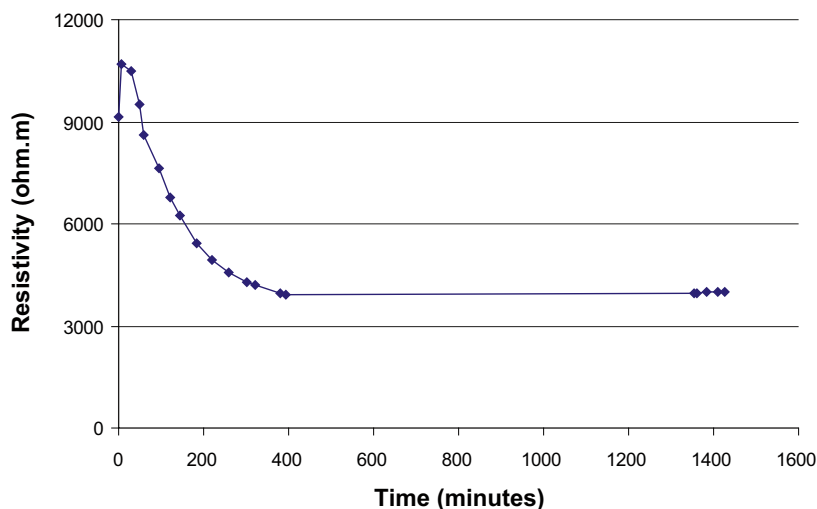


Figure 4-5. Stabilising sample 5 before tracer injection.

4.4.2 Tracer sampling and analysing

The low concentration tracer cell should be stirred during the entire experiment, except for short time periods when the magnetic stirrer is used for stirring the high concentration tracer electrolyte (in case only one magnetic stirrer is used). The sampling is performed with an interval estimated by the operator but with high enough temporal resolution to achieve reliable results. The sampling is performed by withdrawing 10 ml of the low concentration tracer electrolyte by use of a syringe (see Figure 4-6).

The sampled electrolyte is placed in a small beaker, which is stirred by a magnet during the time its iodide concentration is analysed. The analysis is performed by the use of an ion selective electrode, which calibration is described below. The electrode is allowed to stabilise for about one minute before the measurement is made. After analysing the electrolyte, it is re-injected into to the low concentration tracer compartment.

For analysing the iodide concentration an ion selective electrode of the brand Gryf Magic XBC System is used (see Figure 4-7).

The electrode is calibrated prior to and during the TEM experiment. Four calibration solutions are used with the iodide concentrations $1 \cdot 10^{-6}$ M, $1 \cdot 10^{-5}$ M, $1 \cdot 10^{-4}$ M, and $1 \cdot 10^{-3}$ M. All the calibration solutions have the same NaCl background as the background electrolyte of the TEM cell, for the specific TEM experiment being performed. The calibration curve is automatically calculated by the software associated with the Gryf Magic XBC System, which is also used to monitor the iodide measurements. During the experiment, recalibration is made about every hour. From time to time during the experiment, a check of the calibration is made by measuring one relevant calibration solution.

4.4.3 Measuring the rock resistivity by electrical methods

Throughout the TEM experiment, the rock resistivity should be measured by electrical methods. While the DC power supply is on, the potential drop over the rock sample is noted, as well as the current running though the cell. The mean value of the three last DC measurements of the rock resistivity is used as the basis for the DC apparent formation factor.

Upon completion of the tracer experiment, the DC power supply is disconnected and an AC power supply is connected to the potential electrodes of the TEM cell. By applying an appropriate and fixed potential drop, and by measuring the current, the rock resistivity is obtained. Measurements are generally performed at two different frequencies, 10 Hz and 100 Hz. In addition, for three samples, the frequency 2,000 Hz is also used. This is the frequency used in the in situ electrical resistivity method of the SKB site investigations.



Figure 4-6. Sampling of the low concentration tracer electrolyte.



Figure 4-7. The iodide selective electrode.

In case the background electrolyte is of low electrical conductivity, there may be a minor potential drop in the water columns between the potential electrodes and the rock sample. By knowing the dimensions of these water columns and also the electrical conductivity of the electrolytes, this can be corrected for. In the present study the length of the water columns were about 13 cm and only corrected rock conductivities were used in subsequent apparent formation factor calculations.

4.5 Finalising the TEM experiment

When all rock resistivity measurements have been made, a few control measurements are performed.

4.5.1 Measuring the pH, electrical conductivity, and temperature of electrolytes

After having completed the AC rock resistivity measurements, 10 ml of the high and low concentration tracer electrolytes are sampled, by use of a syringe. The electrical conductivity, temperature, and pH of both electrolytes are measured. In this present study a pH meter of the brand Hanna Instruments HI221/2Theta HC 113-G is used. After having performed the measurements the low concentration tracer electrolyte is re-injected in the TEM-cell.

The mean value of the two measured electrical conductivities is used as the pore water electrical conductivity in subsequent apparent formation factor calculations.

4.5.2 Estimating loss of electrolyte in sampling

The loss of low concentration tracer electrolyte due to sampling throughout the entire experiment is estimated at the very end of the experiment, by injecting sufficient electrolyte to achieve the original electrolyte level. In the present study this is done by filling up the entire 190 ml compartment by use of a syringe and noting the amount required to achieve this.

4.6 Preparing the next TEM run

4.6.1 Part 1

In part 1 of this study, different TEM experiments are carried out on the same rock sample, using different background electrolytes. When exchanging the pore water electrolyte, this is not done by drying and re-saturating the sample. Instead, as the saturated sample is still placed in the TEM cell the background electrolyte in all four compartments is exchanged for that to be used in the subsequent run. The DC power, pumps, etc are switched on and the pore water electrolyte is exchanged primarily by means of electro-osmosis.

By monitoring the rock resistivity one can determine when the pore water electrolyte is exchanged. As the pore water electrolyte is exchanged, the rock resistivity should become stable. Figure 4-8 shows this process for Sample 1, where the pore water is exchanged from 1 M NaCl to 0.03 M NaCl.

In the original method description it was believed that exchanging the pore water would take one or two days. After the study it has been realised that it may very well take up to a week.

After the system is stabilised, the background electrolyte of the high and low concentration tracer compartments is exchanged, to avoid iodide from the previous TEM run from interfering with the subsequent measurements. Thereafter, the steps described in subsection 4.3.2 up to section 4.6.1 are repeated.

4.6.2 Part 2

In part 2, only one background electrolyte per sample should be used, although duplicate measurements are required. Between the duplicate runs, the TEM cell should be dismantled and re-assembled (see Section 4.7). After the first run, the pore water electrolyte has the same iodide concentration as the high concentration tracer electrolyte of the subsequent run. Therefore, after re-assembling the cell and filling the compartments with new background electrolyte, tracer injection can be made before switching on the DC current. In this case, immediate tracer breakthrough is expected.

4.7 Dismantling and reassembling the TEM cell

Between duplicate runs of tracer tests, the TEM cell is dismantled and reassembled according to the steps in subsection 4.3.1. This is to make sure that the sealing ring of the studied rock sample does not leak. In case of leakages, the formation factors obtained in the duplicate runs should deviate significantly. Leakages are most easily spotted by monitoring the resistivity of the centre pieces, including the studied sample.

It should be noted that minor deviations in the measured formation factors of the two duplicate runs do not necessarily indicate that the sealing ring leaks. There are a number of other sources of error that may cause deviations.

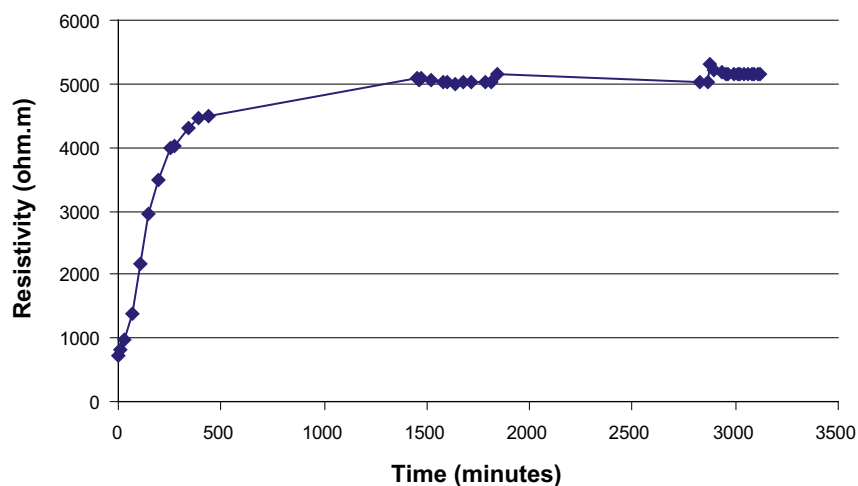


Figure 4-8. Rock resistivity while exchanging the pore water electrolyte in Sample 1 from 1 M NaCl to 0.03 M NaCl.

5 Execution

5.1 The experimental outline

The experimental outline is divided into two parts. In the first part, sample 1 was saturated by an electrolyte of low ionic strength and the NaCl concentration 0.001 M. After having measured the surface conductivity with this background electrolyte, TEM experiments were carried out using other background electrolytes (see Figure 5-1).

The second part concerns eight samples which were saturated with the same background electrolyte as later used in the TEM experiments (see Table 5-1). For four of the samples (two from each site) the 0.05 M NaCl electrolyte was used, and for the other four samples the 0.1 M NaCl electrolyte was used.

Table 5-1. Electrolytes used for saturating samples.

Sample	1	2	3	4	5	6	7	8	9
Electrolyte	0.001 M NaCl	0.1 M NaCl	0.05 M NaCl	0.1 M NaCl	0.05 M NaCl	0.1 M NaCl	0.05 M NaCl	0.1 M NaCl	0.05 M NaCl

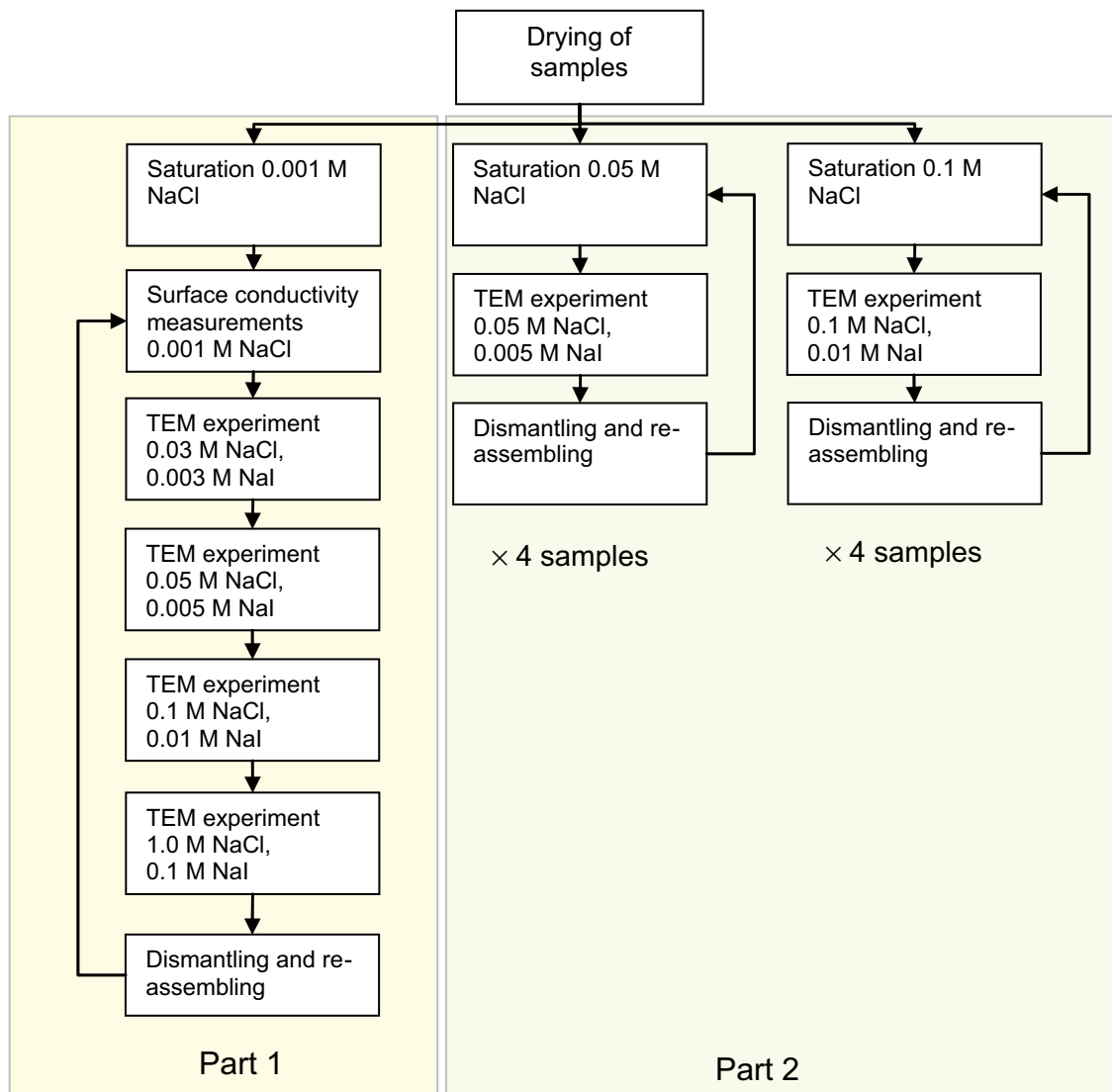


Figure 5-1. Chart illustrating the intended experimental outline.

All solutions in this study were prepared with great accuracy, with the estimated error on the order of 1%. However, as can be seen from Table 5-1, we have refrained from writing for example 0.0500 M NaCl and instead simply write 0.05 M NaCl.

Figure 5-1 shows a chart outlining the intended experimental scheme. Details in the different steps are discussed in Chapter 4.

As can be seen from Figure 5-1, all TEM runs were intended to be carried out in duplicates. However, as it turned out some runs were carried out in triplicates. During the study there were some issues interrupting the intended outline. For example, the iodide electrode broke down and had to be replaced. In another case there was some leakage. Due to such reasons some experiments had to be remade. Only the remade experiments are presented in this report.

Table 5-2 and Table 5-3 show the actual activities of the study, and the start and end dates of the activities. The numbers in the parentheses show whether the activity concerns the first, second, or third run of the duplicate or triplicate measurement.

All activities were performed by Petr Vecernik, except for the first surface conductivity measurement run on Sample 1, which was performed by Petr Vecernik and Martin Löfgren.

As seen in Chapter 4, each TEM run includes a number of activities. For example, the TEM cell was stabilized before every tracer injection. Furthermore, AC rock resistivity measurements were performed at the end of each activity, as well as the other measurements described in Section 4.5. The TEM cell was also dismantled according to the experimental outline in Figure 5-1.

Table 5-2. Activities of part 1 of the study.

Sample	Activity	Date
1	Drying	2008-08-04 2008-08-05
1	Saturation with in 0.001 M NaCl electrolyte	2008-08-05 2008-08-06
1	Surface conductivity measurement at 0.001 M NaCl (1/2)	2008-08-18
	<i>Various problems with TEM equipment, methodology, and iodide ion selective electrode. Adjustments lead to the methodology accounted for in Chapter 4. Testing period ending with sample saturated by 1 M NaCl.</i>	
1	TEM experiment with background 0.03 M NaCl (1/3)	2008-11-14
1	TEM experiment with background 0.05 M NaCl (1/2)	2008-11-19
1	TEM experiment with background 0.1 M NaCl (1/2)	2008-11-20
1	TEM experiment with background 1 M NaCl (1/2)	2008-11-25
1	Surface conductivity measurement at 0.001 M NaCl (2/2)	2008-11-25 2008-12-01
	<i>Breakdown and replacement of iodid ion selective electrode</i>	
1	TEM experiment with background 0.03 M NaCl (2/3)	2009-01-20
1	TEM experiment with background 0.05 M NaCl (2/2)	2009-01-22
1	TEM experiment with background 0.1 M NaCl (2/2)	2009-01-23
1	TEM experiment with background 1 M NaCl (2/2)	2009-01-27
1	TEM experiment with background 0.03 M NaCl (3/3)	2009-01-30

Table 5-3. Activities of part 2 of the study.

Sample	Activity	Date
2, 4, 6, 8	Drying of samples	2008-11-06 2008-11-07
3, 5, 7, 9	Drying of samples	2008-11-11 2008-11-12
2, 4, 6, 8	Saturation of samples in 0.05 M	2008-11-07 2008-11-11
3, 5, 7, 9	Saturation of Samples in 0.1 M	2008-11-12 2008-11-17
6	TEM experiment with background 0.1 M NaCl (1/3)	2009-02-02
6	TEM experiment with background 0.1 M NaCl (2/3)	2009-02-03
2	TEM experiment with background 0.1 M NaCl (1/2)	2009-02-04
2	TEM experiment with background 0.1 M NaCl (2/2)	2009-02-04
8	TEM experiment with background 0.1 M NaCl (1/3)	2009-02-05
8	TEM experiment with background 0.1 M NaCl (2/3)	2009-02-06
8	TEM experiment with background 0.1 M NaCl (3/3)	2009-02-09 2009-02-10
6	TEM experiment with background 0.1 M NaCl (3/3)	2009-02-11
4	TEM experiment with background 0.1 M NaCl (1/2)	2009-02-12
4	TEM experiment with background 0.1 M NaCl (2/2)	2009-02-12 2009-02-13
5	TEM experiment with background 0.05 M NaCl (1/2)	2009-02-17 2009-02-18
5	TEM experiment with background 0.05 M NaCl (2/2)	2009-02-18 2009-02-19
3	TEM experiment with background 0.05 M NaCl (1/2)	2009-02-25 2009-02-26
3	TEM experiment with background 0.05 M NaCl (2/2)	2009-02-26 2009-02-27
9	TEM experiment with background 0.05 M NaCl (1/3)	2009-03-03 2009-03-04
9	TEM experiment with background 0.05 M NaCl (2/3)	2009-03-04 2009-03-05
9	TEM experiment with background 0.05 M NaCl (3/3)	2009-03-06
7	TEM experiment with background 0.05 M NaCl (1/2)	2009-03-10 2009-03-11
7	TEM experiment with background 0.05 M NaCl (2/2)	2009-03-11 2009-03-12

5.2 Surface conductivity measurements

The surface conductivity of Sample 1 was measured in duplicates. Prior to the first duplicate run, the sample was dried and saturated by a NaCl electrolyte of the concentration of 0.001 M. At pore waters of such low ionic strength, conduction in the diffuse layer is thought to outweigh conduction in the bulk pore water. The surface conductivity was measured with DC in the TEM-cell, after stabilisation as described in subsection 4.3.2. The surface conductivity was approximated as the reciprocal of the rock resistivity. The rock resistivity was taken to be the mean value of the last three data points in the measurements. Thereafter the rock resistivity was also measured by AC at 10 and 100 Hz. In the first run, golden wires were used as potential electrodes. It was later found that the reproducibility of the potential measurements is poor when using wires, as the exact location of the wires in respect to the different parts of the (heterogeneous) rock sample significantly affects the results.

The second duplicate run was performed subsequent to a TEM experiment using the 1 M NaCl background electrolyte. This is quite a contrast to the 0.001 M NaCl background electrolyte used in the surface conductivity measurements. Therefore, it took about five days to stabilise the system. The measurements were made as in the first run, with the exception that titanium nets were used as potential electrodes.

5.3 Through electromigration experiments

The through electromigration experiments were performed according to the description in Chapter 4. Table 5-4 shows the concentrations in the high concentration tracer electrolyte, corresponding to different background electrolytes shown in Table 5-2 and Table 5-3.

At the start of the study, the time period over which the tracer tests were performed was only a few hours. This gave rise to poor reproducibility. At the end of the study this problem was addressed by running the tracer tests over night, which resulted in improved reproducibility. All TEM experiments in part 2, using the background electrolyte 0.05 M NaCl, were run over night (as seen in Table 5-3).

Throughout a TEM experiment the potential drop over the potential electrodes was kept constant. This was done by manually adjusting the potential output from the power supply from time to time. Typical potential outputs from the power supply were around 25 V, while the potential drops over the potential electrodes were between 5 and 15 V, depending on the sample.

Analysing the iodide concentration was made as described in subsection 4.4.2. Two times the iodide electrode broke down, which caused delays in the study. Measurements affected by these breakdowns, or other problems such as leakage and varying potential drop over the potential electrodes, were remade. Therefore, the problems should not affect the results.

In the TEM experiments there was some problems with the magnetic stirrers. Due to the cylindrical shape of the equipment, proper automatic stirring was not feasible. Instead the solutions were stirred manually from time to time (part 1), or as in part 2 the automatically stirred magnets “shook” instead of “swirled”. This resulted in stirred solutions but perhaps the stirring was inadequate.

5.4 AC rock resistivity measurements and other measurements

Concerning the AC rock resistivity measurements; these were performed as described in subsection 4.4.3. The frequencies 10 and 100 Hz were used for all samples. In addition, the frequency 2,000 Hz was used for Samples 3, 7, and 9.

From the pH measurements in the high and low concentration tracer compartments, it can be concluded that no significant pH gradient builds up over the central rock sample during the experiment. Therefore, the pH measurements are not further discussed in this report. In part 2, the pH typically was in the range of 6 to 7, while in part 1, the pH reached somewhat lower values. The pH raw data are displayed in Appendices A and B.

Table 5-4. Electrolytes at the initiation of the tracer tests.

Background electrolyte	High concentration tracer electrolyte
0.03 M NaCl	0.027 M NaCl 0.003 M NaI
0.05 M NaCl	0.045 M NaCl 0.005 M NaI
0.1 M NaCl	0.09 M NaCl 0.01 M NaI
1.0 M NaCl	0.9 M NaCl 0.1 M NaI

From the measurements of loss of electrolyte in the low concentration tracer compartments, due to sampling, it can be concluded that there was no significant loss of electrolyte. The losses were about 2% (3 to 4 ml) and therefore no correction was applied to the data. The losses are not further discussed in this report.

From the temperature measurements, it was shown that the temperature of the electrolytes did not significantly vary during the experiment. This indicates that the very low effect put into the cell from the DC power supply ($\approx 10\text{--}25$ mW) was not large enough to produce a significant temperature increase. The temperature raw data are displayed in Appendices A and B.

5.5 Nonconformities

From the time Sample 1 was dried and saturated and the first results from a TEM measurement were obtained, there was a period of about three months where the methodology was developed and the equipment fine-tuned. No nonconformities from this time period are accounted for, as no result from this time period is presented. The only exception is the first surface conductivity measurement on Sample 1 from which results are presented. Here gold wire potential electrodes were used instead of titanium nets.

5.5.1 Part 1

- In the first surface conductivity measurement on Sample 1, gold wires were used for potential electrodes, instead of titanium nets as in the rest of the study. This is thought to significantly have affected the result, especially in the AC measurements where the gold wires were used for introducing the current. It is recommended to put somewhat less weight on data from the first run.
- In a number of runs, the stabilisation period prior to tracer injection seems to have been too short. Furthermore, some tracer tests were run during a too short time period. The consequences of this are discussed in Chapter 6.
- About half of the TEM measurement in part 1 used an iodide selective electrode that in the middle of the study broke down (see Table 5-2). It is conceivable that the quality of the electrode deteriorated prior to the complete breakdown.
- The stirring of the high and low concentration tracer compartments may have been inadequate, giving rise to scattering in the tracer test breakthrough curves.

5.5.2 Part 2

- There are indications that the saturation was inadequate. However, it seems that the saturation was completed during the stabilisation period. It is conceivable that electro-osmosis aided the saturation.
- In a few of runs, the stabilisation period prior to tracer injection seems to have been too short. Furthermore, some tracer tests were run during a too short time period (especially for sample 8). The consequences of this are discussed in Chapter 7.
- The stirring of the high and low concentration tracer compartments may have been inadequate (but to a lesser degree than in part 1), giving rise to scattering in the tracer test breakthrough curves.
- In case the tracer test was ran over night, the first few measurements of the iodide concentration may have suffered from poor calibration of the iodide selective electrode. Apparently it took some time for the electrode to become stabilised.

6 Results – part 1

Part 1 was performed on sample 1, which was taken from the borehole depth 312.66 m in borehole KFM01A at the Forsmark site (see Table 4-1).

6.1 Limitations in methodology giving rise to data uncertainty.

The methodology being the basis for the experiments in part 1 had never been tested prior to this study, even though similar experiments had been successfully performed /Löfgren and Neretnieks 2006/. For this reason, there was a lot of fine-tuning of the equipment and the methodology before starting the experiments, as accounted for in this chapter. Even so, there is substantial data uncertainty in part 1 that we cannot account for. One issue that showed to be problematic was the exchanging of the pore water electrolyte between the runs. In the planning of the study it was thought that pore water exchange could be achieved over night, by means of electromigration. However, it was later shown that it rather takes a week to make this exchange. This is exemplified in Figure 6-1, showing the rock resistivity increase when exchanging the pore water electrolyte from 1.0 M NaCl to 0.001 M NaCl.

We have after the completion of the campaign become aware of that it is electro-osmosis that that is primarily responsible for exchanging the pore water. In /Löfgren and Neretnieks 2006/ the effective electro-osmotic mobility was found to be on the order of 10% of the effective ionic mobility. This would indicate that the exchanging of the pore water would take about 10 times as long as tracer breakthrough, and up to ten times longer than we initially planned for. Figure 4-8 show the rock resistivity increase while exchanging the pore water electrolyte in Sample 1 from 1 M NaCl to 0.03 M NaCl. The phase preceding the tracer tests is called the stabilising phase, which has the intention of achieving steady state conditions in the sample prior to tracer injection. This takes on the order of 1,000 minutes in Figure 4-8. In the following tracer test (see Appendix A11), tracer breakthrough is achieved after about 100 minutes.

Unfortunately, the problem with the time consuming stabilising phase was not fully recognised until after the study and therefore, many tracer injections were initiated too early. Generally this resulted in reduced accuracy and reproducibility of the duplicate and triplicate runs. Concerning the tracer tests, one can only speculate in the issues and processes occurring if not running it at steady state, which may disturb the measurements. If comparing the formation factors obtained in the different tracer test runs for each pore water electrolyte, on average the higher formation factor is almost a factor of three higher than the lower. It also seems to be systematic that the formation factors obtained in the first run are the highest.

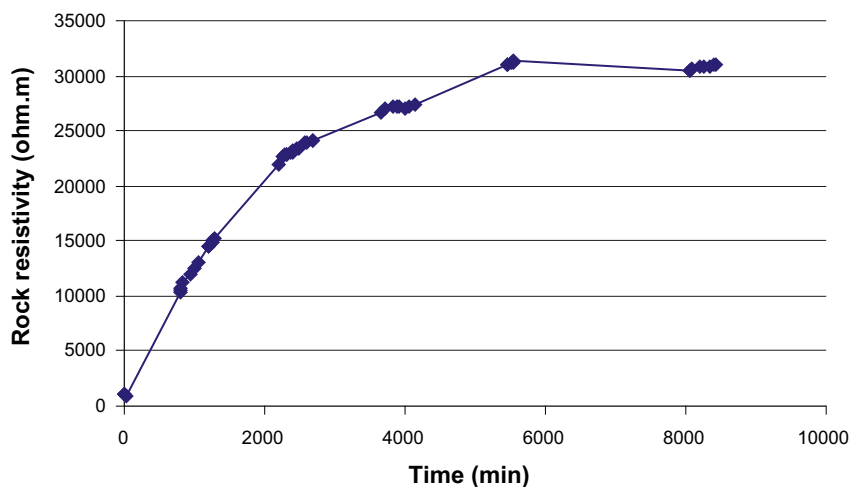


Figure 6-1. The stabilising phase when exchanging the pore water from 1.0 M to 0.001 M NaCl.

What seems also to be systematic is that the rock resistivity is lower in the first run, for each of the pore water electrolytes. This causes the apparent formation factor obtained by electrical methods to be the generally higher in the first run. It should be noted that if the system is not stabilised when measuring the apparent formation factor by electrical methods, there is no way of knowing the electrical conductivity of the pore water. If assuming that it is the same as in the surrounding electrolytes (which is done in this study) one will induce data uncertainty. If comparing the apparent formation factors obtained with the different electrical methods for each pore water electrolyte, on average the higher one is almost a factor of two higher than the lower one.

It was the general aim of part 1 to provide a basis for comparing formation factors obtained by different methods and for different pore water electrolytes. However, given the substantial data uncertainty, we suggest that one should avoid far-reaching conclusion and only draw very general conclusion. To achieve some of the aims of part 1, one would simply have to redo the measurements, but with an improved methodology.

It should also be noted that in part 2, the reproducibility of the duplicate and triplicate runs is good, indicating good accuracy. In part 2, only one background electrolyte was used per sample, wherefore no prolonged stabilising phase was required.

6.2 Surface conductivity

The surface conductivity was measured in duplicate runs on sample 1, when saturated by a 0.001 M NaCl electrolyte. The measurements were made by DC and AC. The first measurement was made subsequent to the saturation of the sample with the 0.001 M NaCl solution. Therefore, the short stabilising time of 180 minutes was used. It should be noted that in the first run, gold wires were used as potential electrodes, as opposed to the titanium nets used in all other measurements. This can be seen as a minor non-conformity.

The second run was made after the sample had been saturated with a 1.0 M NaCl solution. Therefore, the sample was allowed to stabilise for over 8,400 minutes before measurements were made. The raw data are found in Appendices A1 and A6. In Figure 6-2 the rock resistivity data of the two runs are translated to rock conductivity.

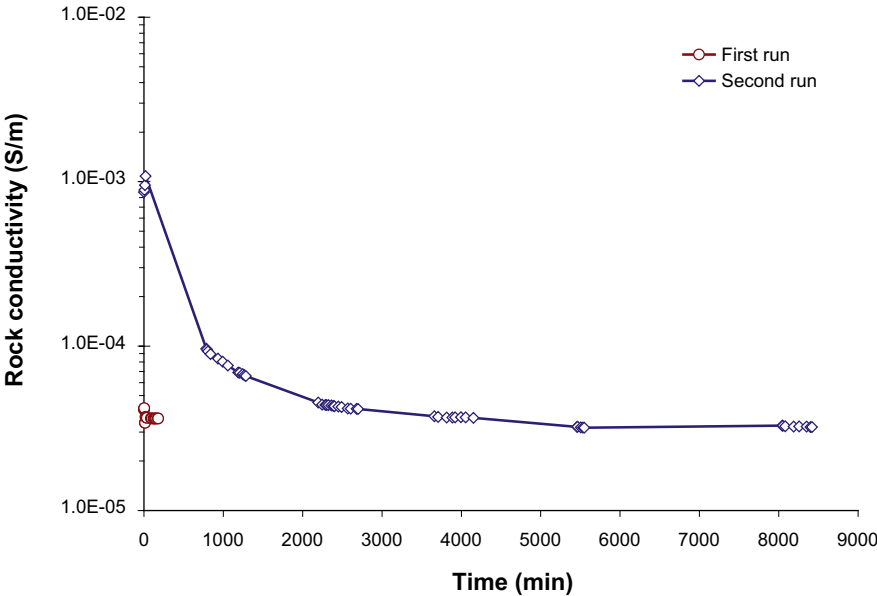


Figure 6-2. Rock conductivity of sample 1 at 0.001 M NaCl.

If having the electrical conductivity of the rock sample κ_r (S/m) and of the pore water electrolyte κ_w (S/m), the surface conductivity κ_s (S/m) can be obtained from Equation 6.1 (cf. Equation 3-9):

$$\kappa_s = \kappa_r - F_f \cdot \kappa_w \quad \text{Equation 6-1}$$

Table 6-1 summarises the results from the two runs.

As can be seen, the results could be reproduced when using DC even though the sample had been saturated by highly saline pore water in between the runs. The deviation between DC surface conductivities in the first and second run is about 13%. Here the deviation is defined as the difference between the measurements divided by the average value.

As can be seen in Table 6-1, the reproducibility is poorer in the AC measurements. In these measurements the current is introduced from the potential electrodes. Perhaps the deviation can be explained by the change of potential electrodes from golden wires in the first run to titanium nets in the second run.

Generally the surface conductivities obtained by the DC method are in the range expected from the work made by /Ohlsson 2000/ and /Löfgren 2004/, while those obtained by AC are relatively high.

Based on the rock resistivity and assumed pore water electrical conductivity, the apparent formation factors can be obtained, as shown in Table 6-2.

Even though there are deviations in the results from the different runs, one can see that the obtained apparent formation factors are at least one order of magnitude higher than the formation factor obtained in the through diffusion measurement using HTO (cf. $F_f=1.41 \cdot 10^{-4}$ in Table 4-1). Also one can see that the apparent formation factor is increasing with the frequency, which indicates capacitance effects. Such capacitance effects may stem from the studied rock sample but also from other parts of the TEM cell.

Table 6-1. Surface conductivity of sample 1.

Run/method	κ_r (S/m)	κ_w (S/m)	κ_s (S/m) ^{a)}
Run 1, DC	$3.63 \cdot 10^{-5}$	$1.14 \cdot 10^{-3}$	$3.60 \cdot 10^{-5}$
Run 1, AC 10 Hz	$7.48 \cdot 10^{-5}$	$1.14 \cdot 10^{-3}$	$7.45 \cdot 10^{-5}$
Run 1, AC 100 Hz	$8.60 \cdot 10^{-5}$	$1.14 \cdot 10^{-3}$	$8.57 \cdot 10^{-5}$
Run 2, DC	$3.23 \cdot 10^{-5}$	$2.24 \cdot 10^{-3}$ ^{b)}	$3.17 \cdot 10^{-5}$
Run 2, AC 10 Hz	$1.46 \cdot 10^{-4}$	$2.24 \cdot 10^{-3}$ ^{b)}	$1.45 \cdot 10^{-4}$
Run 2, AC 100 Hz	$1.49 \cdot 10^{-4}$	$2.24 \cdot 10^{-3}$ ^{b)}	$1.48 \cdot 10^{-4}$
DC, average			$3.38 \cdot 10^{-5}$
AC 10 Hz, average			$1.10 \cdot 10^{-4}$
AC 100 Hz, average			$1.17 \cdot 10^{-4}$

^{a)} Based on $F_f = 2.8 \cdot 10^{-4}$ (mean value of TEM formation factors in Table 6-6 at 1.0 M NaCl).

^{b)} Increased NaCl concentration due to solute transport out from sample in stabilising phase.

Table 6-2. Apparent formation factors of sample 1, at 0.001 M NaCl.

Method	Run 1	Run 2
DC, F_f^{app}	$3.18 \cdot 10^{-3}$	$1.44 \cdot 10^{-3}$
AC 10 Hz, F_f^{app}	$6.56 \cdot 10^{-3}$	$6.51 \cdot 10^{-3}$
AC 100 Hz, F_f^{app}	$7.55 \cdot 10^{-3}$	$6.64 \cdot 10^{-3}$

6.3 F_f and F_f^{app} at 0.03 M NaCl background

The formation factor and apparent formation factor were measured in triplicate runs on sample 1, when saturated by a 0.03 M NaCl electrolyte. The measurements were made by TEM, DC, and AC. The raw data are found in Appendices A2, A7, and A11.

The first run was made after the sample had been saturated with a 1.0 M NaCl solution. The sample was allowed to stabilise for almost 6,000 minutes before measurements were made. Even so, one can suspect that the rock resistivity was not entirely stable at the initiation of the tracer test. In addition, during the tracer test the potential drop was kept constant over the entire cell, and not over the central rock sample as in the other measurements. This resulted in a somewhat fluctuating potential drop over the studied sample, from 11.7 to 13.4 V. However, during the steady state part of the tracer test breakthrough curve, the potential drop only varied from 13.0 – 13.4 V. The rock resistivity during the stabilising and tracer test phases is shown in Figure 6-3.

The second run was made after the sample had been saturated with a 0.001 M NaCl solution. The sample was allowed to stabilise for only about 1,500 minutes before measurements were made. This showed to be too little time and the system should be considered as unstable during the run. Furthermore, after the stabilising phase and prior to the tracer test, the power was turned off for one week. This resulted in instability when turning on the power and conducting the tracer test (see Figure 6-3).

The third run was made after the sample had been saturated with a 1.0 M NaCl solution. The sample was allowed to stabilise for about 2,900 minutes before measurements were made. The rock resistivity measured while running the tracer test is close to that of the first tracer test run. It is reasonable to consider the sample to be well enough stabilised during the tracer test.

The breakthrough curves of the three runs are shown in Figure 3-1, together with the potential drop over the studied rock sample. Tracer injection occurred at time zero.

It was assumed that steady state is achieved when the iodide increase in the low concentration tracer cell corresponds to the iodide amount in one pore volume of the rock sample. The same assumption is made for the other tracer tests in the study. The porosity of sample 1 is 0.19% /Selnert et al. 2008/. By making a linear regression of the steady state data points, and adjusting for rock sample cross section area and low concentration tracer compartment volume, the total tracer flux can be calculated (cf. N_{tot} of Equation 3-7). By using the total tracer flux as an estimate of the electromigratory tracer flux N_{μ} in Equation 3-6, the formation factor can be obtained.

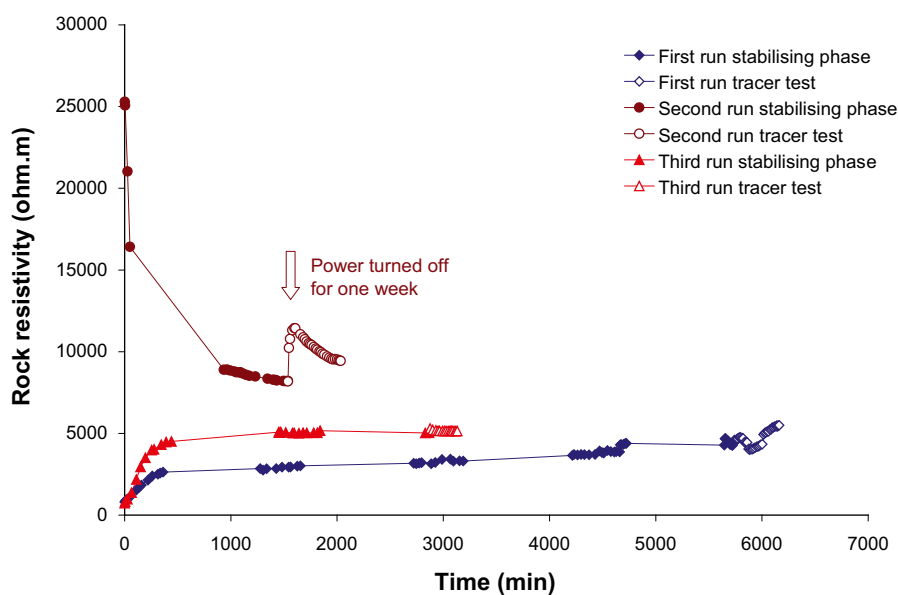


Figure 6-3. Rock resistivity during stabilising phase and tracer test phase. Sample 1, 0.03 M NaCl. The time is the effective time when the power was turned on.

Given the performance of the three runs, it is recommended to put most weight on the data from the third run and thereafter choose data from the first run. From the breakthrough curves in Figure 6-4 one can also see fairly good reproducibility between the two runs. Less weight should be put on data from the second run, as the formation factor measurements were made on an unstable system.

The formation factors from the tracer tests, and the apparent formation factors from electrical measurements, are shown in Table 6-3. Results from the second run are put into parentheses.

For the first and third run, the formation factors from the tracer tests agree fairly well (36% deviation). So do the apparent formation factors obtained from the DC measurements (3% deviation). However, there is a large discrepancy between the apparent formation factors obtained by the AC measurements that cannot be explained. It is the AC rock resistivities in the first run that are surprisingly low. Although we have speculated on different causes for this in terms of measurements errors (e.g. from leakage currents), we cannot substantiate any of them.

An explanation for the scattering in the iodide concentrations in Figure 6-4 may be poor stirring in the low concentration tracer container. Instead of using a magnetic stirrer constantly on, as requested in Section 4.4, stirring was only made manually from time to time. This non-conformity applies for all tracer tests described in this report.

For this pore water electrolyte, there is no clear trend in the third run that the apparent formation factor increases with frequency. However, such a trend is seen in the first two runs. Considering the data uncertainty in Table 6-3, perhaps one should refrain from drawing conclusions.

Table 6-3. Formation factor and apparent formation factor of sample 1, at 0.03 M NaCl.

Method	Run 1	Run 2	Run 3
TEM, F_f	$1.99 \cdot 10^{-4}$	$(6.30 \cdot 10^{-5})$	$1.38 \cdot 10^{-4}$
DC, $F^{\beta DP}$	$4.84 \cdot 10^{-4}$	$(2.80 \cdot 10^{-4})$	$4.98 \cdot 10^{-4}$
AC 10 Hz, $F^{\beta DP}$	$1.68 \cdot 10^{-3}$	$(3.75 \cdot 10^{-4})$	$4.14 \cdot 10^{-4}$
AC 100 Hz, $F^{\beta DP}$	$1.30 \cdot 10^{-3}$	$(3.84 \cdot 10^{-4})$	$4.27 \cdot 10^{-4}$

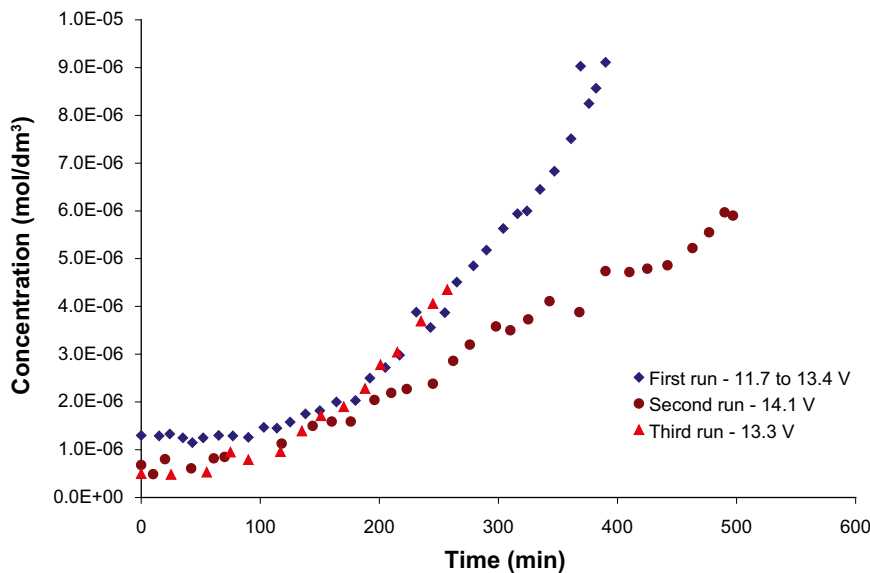


Figure 6-4. Breakthrough curves. Background concentration 0.03 M NaCl, tracer concentration 0.003 M iodide.

6.4 F_f and F_f^{app} at 0.05 M NaCl background

The formation factor and apparent formation factors were measured in duplicate runs on sample 1, when saturated by a 0.05 M NaCl electrolyte. The measurements were made by TEM, DC, and AC. The raw data are found in Appendices A3 and A8.

Both runs were made after the sample had been saturated with a 0.03 M NaCl solution. The sample was allowed to stabilise for about 1,100 and 1,700 minutes, respectively, before measurements were made in the first and second run. In the first run it seems that the sample is stabilised prior to and during the tracer test. However, this seems not to be the case in the second run, where the rock resistivity is decreasing. The rock resistivity during the stabilising and tracer test phases is shown in Figure 6-5.

The breakthrough curves of the two runs are shown in Figure 6-6, together with the potential drop over the rock sample. Tracer injection occurred at time zero.

Given the performance of the two runs, it is recommended to put more weight on the data from the first run. The formation factors from the tracer tests, and the apparent formation factors from electrical measurements are shown in Table 6-4, where the data from the second run is put in parentheses.

If comparing the tracer test formation factors in Table 6-4 with those obtained with the previous pore water electrolyte (Table 6-3), one can see that the results are similar.

In the second run it was assumed that the electrical conductivity of the pore water is the same as that of the surrounding 0.05 M NaCl electrolyte. If instead making the assumption that the pore water has the NaCl concentration 0.04 M NaCl (the mean of 0.03 and 0.05 M NaCl), this would increase the apparent formation factor by about 30%. However, as can be seen in Table 6-4 this modification would only explain part of the entire difference between the different runs.

In both runs, one can see that the apparent formation factor increases with increasing frequency, indicating minor capacitance effects.

Table 6-4. Formation factor and apparent formation factor of sample 1, at 0.05 M NaCl.

Method	Run 1	Run 2
TEM, F_f	$2.56 \cdot 10^{-4}$	$(8.81 \cdot 10^{-5})$
DC, F_f^{app}	$5.63 \cdot 10^{-4}$	$(2.92 \cdot 10^{-4})$
AC 10 Hz, F_f^{app}	$6.55 \cdot 10^{-4}$	$(3.59 \cdot 10^{-4})$
AC 100 Hz, F_f^{app}	$6.72 \cdot 10^{-4}$	$(3.73 \cdot 10^{-4})$

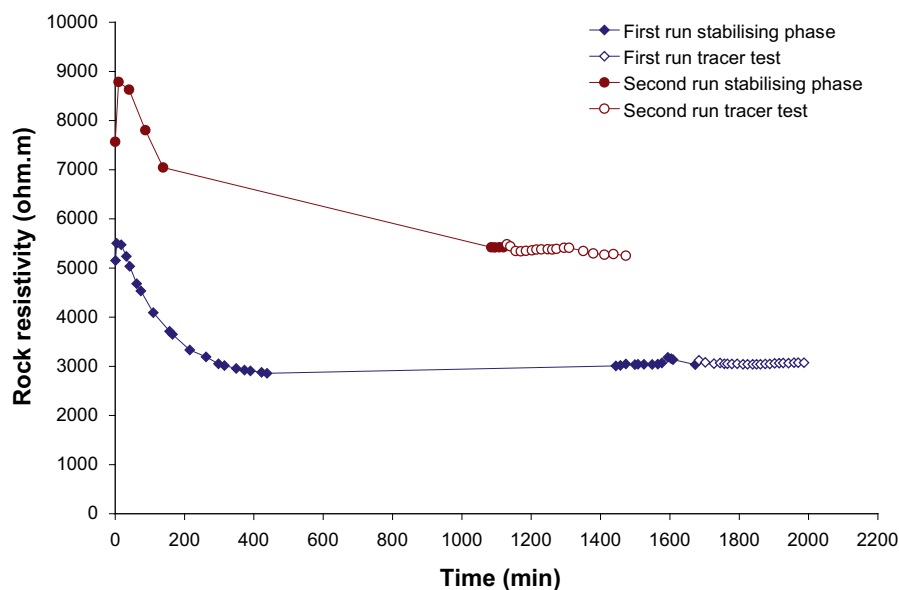


Figure 6-5. Rock resistivity during stabilising phase and tracer test. Sample 1, 0.05 M NaCl.

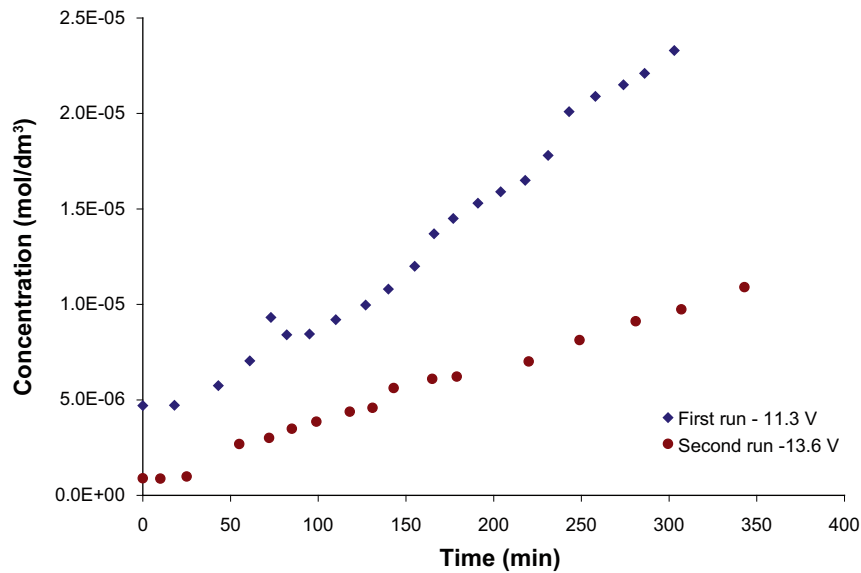


Figure 6-6. Breakthrough curves. Background concentration 0.05 M NaCl, tracer concentration 0.005 M iodide.

6.5 F_f and F_f^{app} at 0.1 M NaCl background

The formation factor and apparent formation factor were measured in duplicate runs on sample 1, when saturated by a 0.1 M NaCl electrolyte. The measurements were made by TEM, DC, and AC. The raw data are found in Appendices A4 and A9.

Both runs were made after the sample had been saturated with a 0.05 M NaCl solution. The sample was allowed to stabilise for about 1,100 and 1,300 minutes, respectively, before measurements were made in the first and second run. In both runs one can suspect that the rock resistivity somewhat decreases during the tracer test. Especially for the second run it appears that the rock sample is not fully stabilised prior to the tracer test. Even so, it is reasonable to say that the tracer tests are performed at a fairly well stabilised system. The rock resistivity during the stabilising and tracer test phases is shown in Figure 6-7.

The breakthrough curves of the two runs are shown in Figure 6-8, together with the potential drop over the rock sample. Tracer injection occurred at time zero.

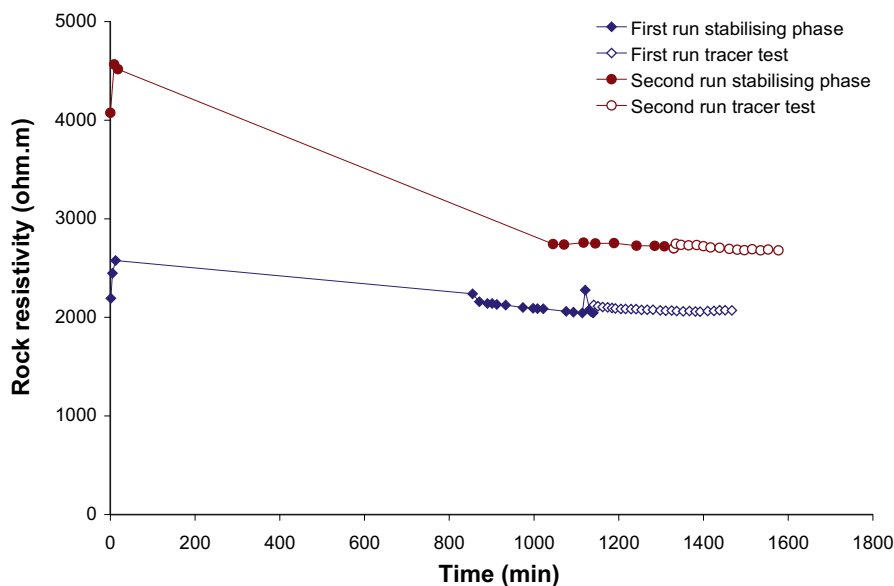


Figure 6-7. Rock resistivity during stabilising phase and tracer test. Sample 1, 0.1 M NaCl.

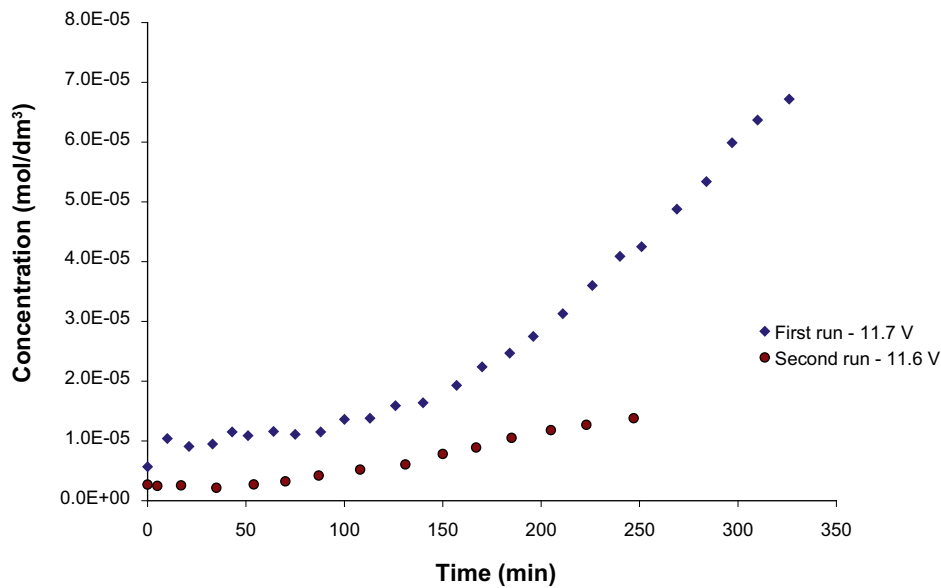


Figure 6-8. Breakthrough curves. Background concentration 0.1 M NaCl, tracer concentration 0.01 M iodide.

The formation factors from the tracer tests, and the apparent formation factors from electrical measurements are shown in Table 6-5.

The substantial difference between the TEM formation factors cannot be explained based on the performance of the experiments. It can be noted that the iodide selected electrode broke down between the first and second run, and was replaced. There is a general trend that the increase in trace concentration is larger when measured with the former electrode (first run) than with the latter (second run). However, potential bias in the electrode cannot be substantiated, as it is broke.

Generally one can see that the formation factor increases with increasing frequency, indicating minor capacitance effects. However, the error introduced due to an increased frequency, as compare to other uncertainties when estimating the formation factor, is small.

6.6 F_f and F_f^{app} at 1.0 M NaCl background

The formation factor and apparent formation factor were measured in duplicate runs on sample 1, when saturated by a 1.0 M NaCl electrolyte. The measurements were made by TEM, DC, and AC. The raw data are found in Appendix A5 and A10.

Both runs were made after the sample had been saturated with a 0.1 M NaCl solution. The sample was allowed to stabilise for about 2,100 and 1,500 minutes, respectively, before measurements were made in the first and second run. In both runs it seems that the samples were more or less stabilised, even though the final rock resistivity was somewhat lower in the first run compared to the second run. The rock resistivity during the stabilising and tracer test phases is shown in Figure 6-9.

The breakthrough curves of the two runs are shown in Figure 6-10, together with the potential drop over the rock sample. Tracer injection occurred at time zero.

Table 6-5. Formation factor and apparent formation factor of sample 1, at 0.1 M NaCl.

Method	Run 1	Run 2
TEM, F_f	$5.70 \cdot 10^{-4}$	$1.20 \cdot 10^{-4}$
DC, F_f^{app}	$4.41 \cdot 10^{-4}$	$2.89 \cdot 10^{-4}$
AC 10 Hz, F_f^{app}	$5.09 \cdot 10^{-4}$	$5.14 \cdot 10^{-4}$
AC 100 Hz, F_f^{app}	$5.29 \cdot 10^{-4}$	$5.13 \cdot 10^{-4}$

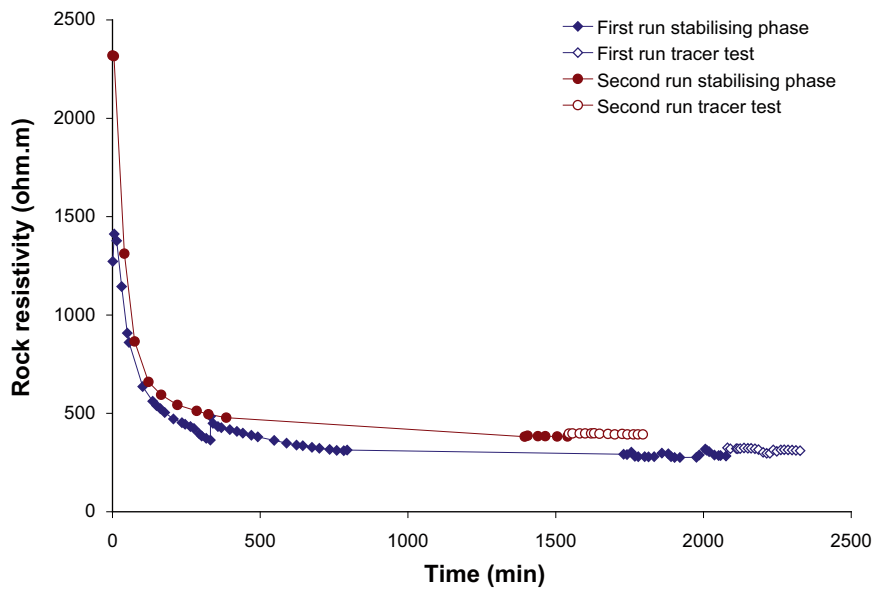


Figure 6-9. Rock resistivity during stabilising phase and tracer test. Sample 1, 1.0 M NaCl.

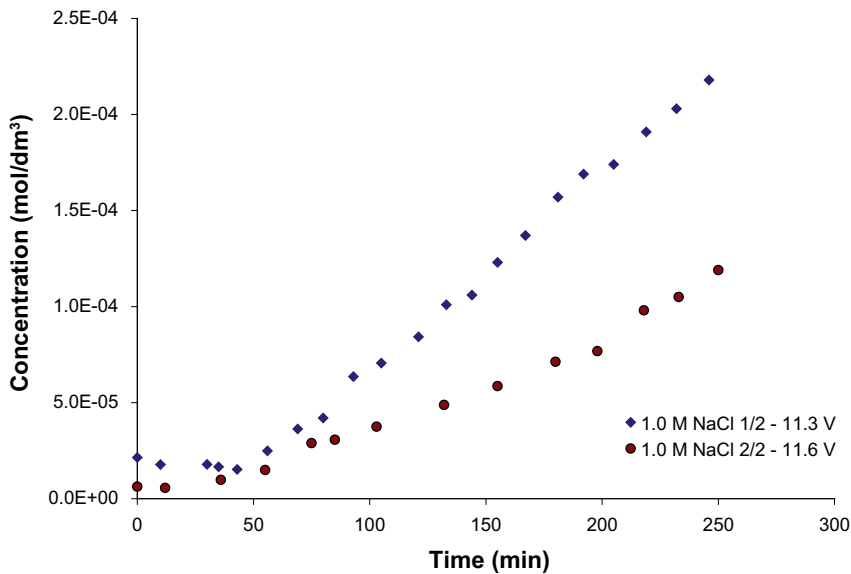


Figure 6-10. Breakthrough curves. Background concentration 1.0 M NaCl, tracer concentration 0.1 M iodide.

Given the performance of the two runs, it is recommended to put equal weight on their results. The formation factors from the tracer tests, and the apparent formation factors from electrical measurements are shown in Table 6-5.

No explanation can be found for the deviation in the formation factors, where the formation factors and apparent formation factors of the first run is almost half a factor higher than those of the second run.

It is worth comparing the AC apparent formation factors obtained for this electrolyte with that obtained by AC measurements at 1.0 M NaCl in /Thunehed 2007b/ for the same sample (see Table 4-1). /Thunehed 2007b/ obtained the apparent formation factor $2.06 \cdot 10^{-4}$. This is significantly lower than the apparent formation factors of Table 6-5, including those obtained by DC. This may indicate that the sample has been weathered or has been otherwise altered in-between the measurements. It may also indicate that the degree of saturation differed in the two studies, or that there are systematic errors between the methods.

6.7 Comparisons of formation factors in part 1

In Figure 6-11, all apparent formation factors and formation factors tabulated in this chapter are shown.

The TEM formation factors obtained in the duplicate or triplicate runs are shown by blue diamonds, while the DC apparent formation factors are shown by yellow triangles. Generally the differences in the apparent formation factors obtained by 10 and 100 Hz are small; so all AC apparent formation factors are shown by red dots. From Figure 6-11 it is evident that the reproducibility is poor. Figure 6-12 shows the same data as Figure 6-11, except for the data in parentheses in Table 6-3 and Table 6-4, which are disregarded.

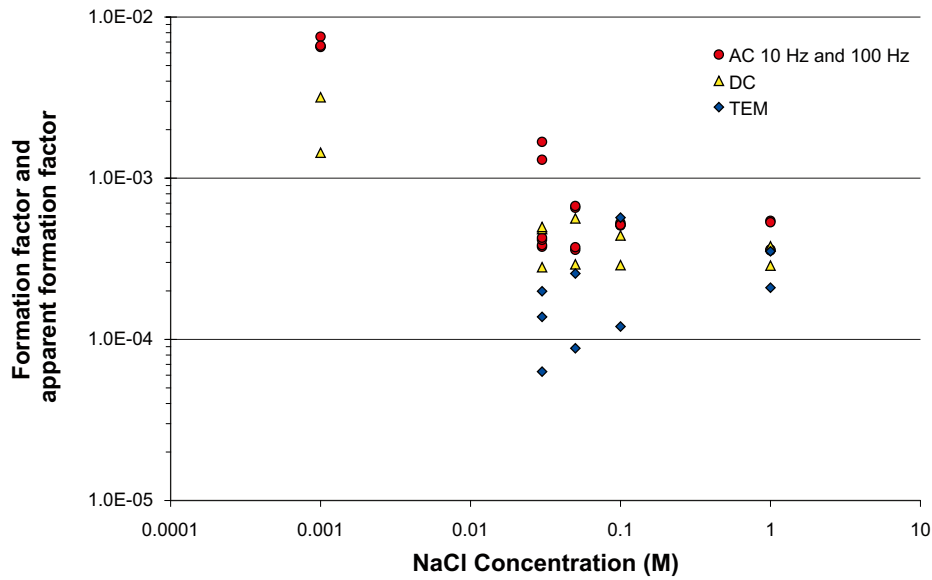


Figure 6-11. Formation factors and apparent formation factors obtained with different methods at different pore waters, all data.

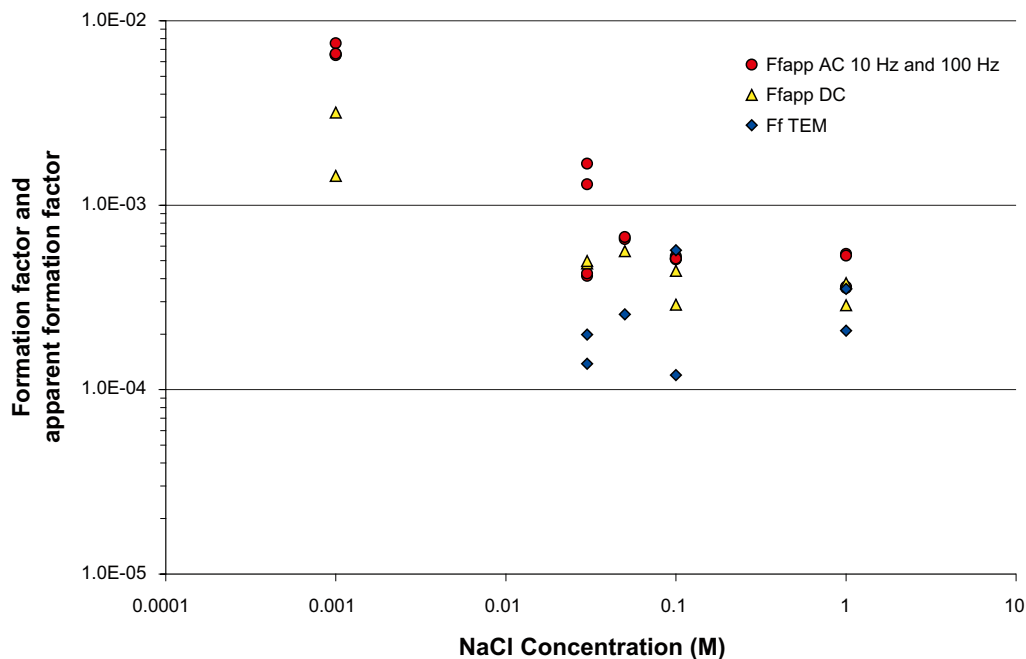


Figure 6-12. Formation factors and apparent formation factors obtained with different methods at different pore waters, data in parentheses in Table 6-3 and Table 6-4 are disregarded.

Even after sorting out data points that are the most affected by experimental errors, the reproducibility is fairly poor.

A clear trend from Figure 6-12 is that the apparent formation factor increases with decreasing pore water NaCl concentration. This is expected, as surface conduction will influence the apparent formation factor to a larger extent at pore waters of low electrical conductivity. The surface conductivity of the sample is on average $3.38 \cdot 10^{-5}$ S/m, as measured with DC (cf. Table 6-1). The apparent formation factor as measured at 1.0 M NaCl, using DC, is on average $3.33 \cdot 10^{-4}$ (cf. Table 6-6). At this high pore water ionic strength the formation factor should not significantly deviate from the apparent formation factor. By using Equation 3-9, as repeated below, the formation factor is calculated to $3.29 \cdot 10^{-4}$ (average $\kappa_w = 8.68$ S/m, cf. Appendices A5 and A10).

$$F_f = F_f^{app} - \frac{\kappa_s}{\kappa_w} \quad \text{Equation 3-9}$$

Based on this surface conductivity and formation factor, one could model the apparent formation factor at different pore water electrical conductivities, by use of Equation 3-9, and compare the modelled data with experimental data. This is done in Figure 6-13, where the modelled data are shown by the black curve. The same measured apparent formation factors are shown as in Figure 6-12.

If doing the same operations based on the AC measurements at 100 Hz, κ_s would on average be $1.17 \cdot 10^{-4}$ S/m and F_f would on average be $4.43 \cdot 10^{-4}$. The modelled apparent formation factors, based on these data, are shown by the red curve in Figure 6-13. Doing the same operation based on the AC measurements at 10 Hz, a very similar curve as the red one would be obtained, as data do not differ significantly.

Table 6-6. Formation factor and apparent formation factor of sample 1, at 1.0 M NaCl.

Method	Run 1	Run 2
TEM, F_f	$3.52 \cdot 10^{-4}$	$2.09 \cdot 10^{-4}$
DC, F_f^{app}	$3.78 \cdot 10^{-4}$	$2.87 \cdot 10^{-4}$
AC 10 Hz, F_f^{app}	$5.44 \cdot 10^{-4}$	$3.56 \cdot 10^{-4}$
AC 100 Hz, F_f^{app}	$5.33 \cdot 10^{-4}$	$3.61 \cdot 10^{-4}$

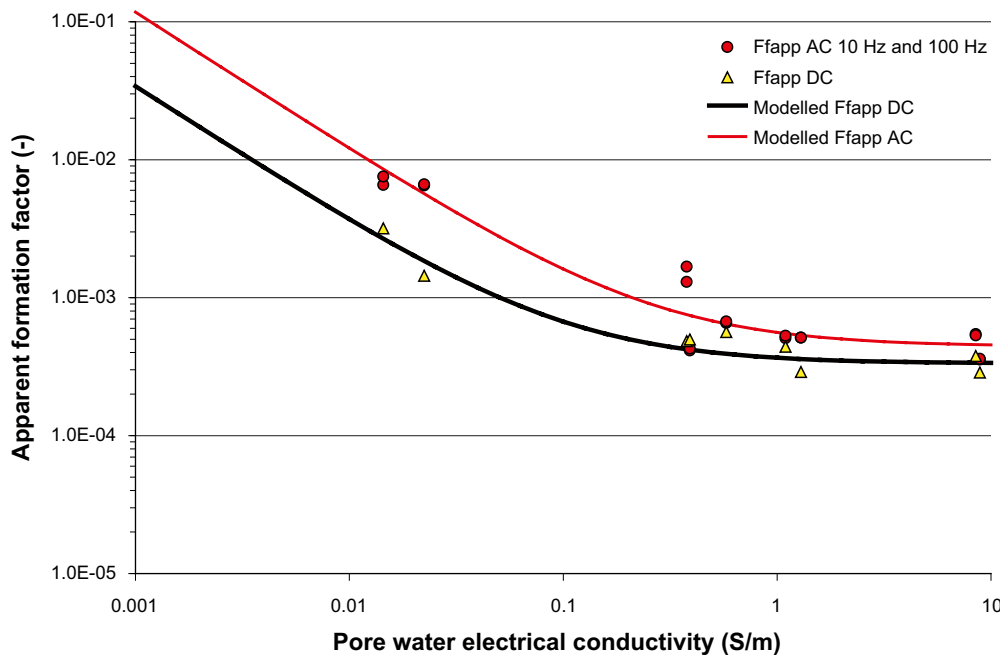


Figure 6-13. Comparison between modelled F_f^{app} and measured F_f^{app} .

As can be seen, the modelled curve based on AC measurements fairly well describes measured AC data, while the modelled curve based on DC measurements fairly well describes measured DC data. This strengthens Equation 3-9 and the process understanding behind it. However, the fact that different F_f and κ_s are needed to describe AC and DC data is a weakness. In fact, the formation factor is not the sensitive parameter, as almost as good fits can be obtained if using the DC formation factor for the AC apparent formation factor model, and vice versa. It is the difference in the surface conductivities, as measured by the two methods, that has the greater impact.

One could try to further refine the analysis (and we have tried), but ultimately one comes to the conclusion that the resolution in the data is too poor for such an attempt. An example of experimental deviations making more elaborate comparisons speculative is that in the first surface conductivity run, gold wires were used for introducing the AC current, while in the second run titanium nets were used. Except for this, if redoing the measurements, it is recommended to use the same 4-electrode setup when measuring both AC and DC, to avoid bias. In the present campaign a 2-electrode setup was used for the AC measurements, and therefore a conceivable potential drop associated with transferring current from the electrodes to the electrolytes cannot be separated from the potential drop over the studied rock sample.

Special attention should be given to the NaCl concentrations that best represent the in situ conditions at repository depth at the Forsmark and Oskarshamn site (0.05 and 0.1 M NaCl). In this range, the difference between apparent formation factors obtained by electrical methods and the TEM formation factor is not overwhelming. On average, for these measurements, the DC apparent formation factor is 1.8 times the TEM formation factor. The AC apparent formation factor is on average 2.6 times the TEM formation factor. This deviation does not only include the error induced by due to surface conduction (if not performing the correction according to Equation 3-9), but also the anion exclusion effect. Therefore, for this particular sample the anion exclusion effect is limited to a few factors.

7 Results – part 2

7.1 General remarks

Part 2 was performed on eight samples from the Forsmark and Oskarshamn sites. The samples were saturated by either a 0.05 or a 0.1 M NaCl electrolyte (see Table 5-1). The formation factor and apparent formation factor measurements were performed using the same electrolyte as the sample was saturated with, and no time consuming exchange of the pore water was required. As a result the reproducibility, and likely also the accuracy, was much improved compared to in part 1. What may also have improved the reproducibility is that the laboratory personnel had more experience in part 2, and that a new iodide selective electrode was used.

7.2 Sample 2

Sample 2 was taken from the borehole depth 312.54 m in borehole KFM01A at the Forsmark site (see Table 4-1). The sample was saturated with 0.1 M NaCl and the high concentration tracer cell initially held the electrolyte 0.01 M NaI and 0.09 M NaCl. Both runs were performed without problems or significant deviation from the method description in Chapter 4.

It was assumed that steady state is achieved when the iodide increase in the low concentration tracer cell corresponds to the iodide amount in one pore volume of the rock sample. The porosity of the sample is 0.20% /Selnert et al. 2008/. In Figure 7-1 steady state data points are marked with blue diamonds.

The raw data from the tracer tests and the electrical measurements are found in Appendices B1 and B2. The formation factors from the tracer tests, and the apparent formation factors from electrical measurements, are shown in Table 7-1.

As can be seen from Table 7-1, good reproducibility was achieved. At this pore water electrolyte, and for this sample, the ratio between the apparent formation factor and the TEM formation factor is about three. It is thought that this is mainly due to surface conduction in the electrical methods,

Table 7-1. Formation factor and apparent formation factors of sample 2, at 0.1 M NaCl.

Method	Run 1	Run 2
TEM, F_f	$5.27 \cdot 10^{-5}$	$5.11 \cdot 10^{-5}$
DC, F_f^{app}	$1.44 \cdot 10^{-4}$	$1.42 \cdot 10^{-4}$
AC 10 Hz, F_f^{app}	$1.66 \cdot 10^{-4}$	$1.68 \cdot 10^{-4}$
AC 100 Hz, F_f^{app}	$1.71 \cdot 10^{-4}$	$1.72 \cdot 10^{-4}$

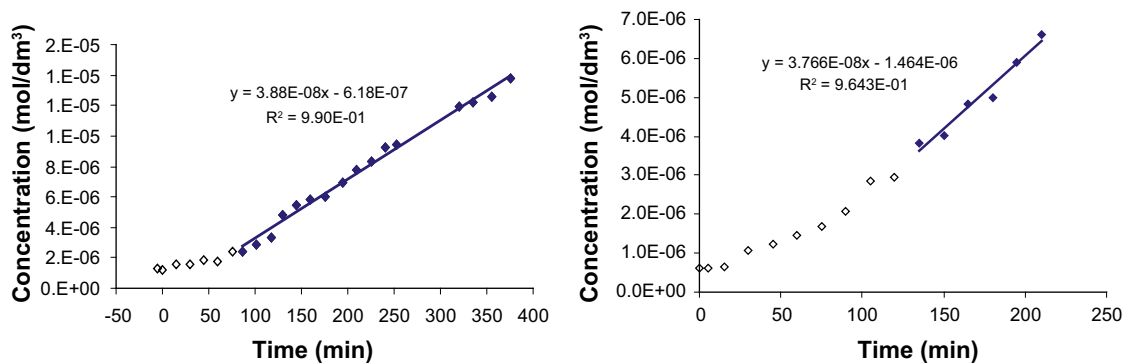


Figure 7-1. Breakthrough curves in first (left) and second (right) run. The background electrolyte is 0.1 M NaCl.

but anion exclusion in the tracer test can also contribute to some degree. If comparing the formation factor obtained previously using HTO in through diffusion measurements (HTO $F_f=9.39 \cdot 10^{-5}$, see Table 4-1) with the TEM formation factors, the former is almost a factor of two larger. This may indicate significant anion exclusion.

The apparent formation factor increases somewhat with frequency, indicating minor capacitance effects.

7.3 Sample 3

Sample 3 was taken from the borehole depth 554.60 m in borehole KFM02A at the Forsmark site (see Table 4-1). The sample was saturated with 0.05 M NaCl and the high concentration tracer cell initially held the electrolyte 0.005 M NaI and 0.045 M NaCl. Both runs were performed without problems or significant deviation from the method description in Chapter 4.

In Figure 7-2, data points marked with blue diamonds represent steady state conditions. The same assumption concerning the steady state was made as for sample 2. The porosity of sample 3 is 0.31% /Selnert et al. 2008/.

The raw data from the tracer tests and the electrical measurements are found in Appendices B3 and B4. The formation factors from the tracer tests, and the apparent formation factors from electrical measurements, are shown in Table 7-2.

As can be seen from Table 7-2, good reproducibility was achieved. At this pore water electrolyte, and for this sample, the ratio between the apparent formation factor and the TEM formation factor is about three. It is thought that this is mainly due to surface conduction in the electrical methods, but anion exclusion in the tracer test can also contribute to some degree. If comparing the formation factor obtained previously using HTO in through diffusion measurements (HTO $F_f=1.78 \cdot 10^{-4}$, see Table 4-1) with the TEM formation factors, they are about the same even though the latter are slightly smaller. This may indicate minor anion exclusion.

The apparent formation factor increases somewhat with frequency, indicating minor capacitance effects.

Table 7-2. Formation factor and apparent formation factors of sample 3, at 0.05 M NaCl.

Method	Run 1	Run 2
TEM, F_f	$1.49 \cdot 10^{-4}$	$1.43 \cdot 10^{-4}$
DC, F_f^{app}	$3.80 \cdot 10^{-4}$	$3.78 \cdot 10^{-4}$
AC 10 Hz, F_f^{app}	$4.50 \cdot 10^{-4}$	$4.45 \cdot 10^{-4}$
AC 100 Hz, F_f^{app}	$4.56 \cdot 10^{-4}$	$4.52 \cdot 10^{-4}$
AC 2,000 Hz, F_f^{app}	$4.75 \cdot 10^{-4}$	$4.72 \cdot 10^{-4}$

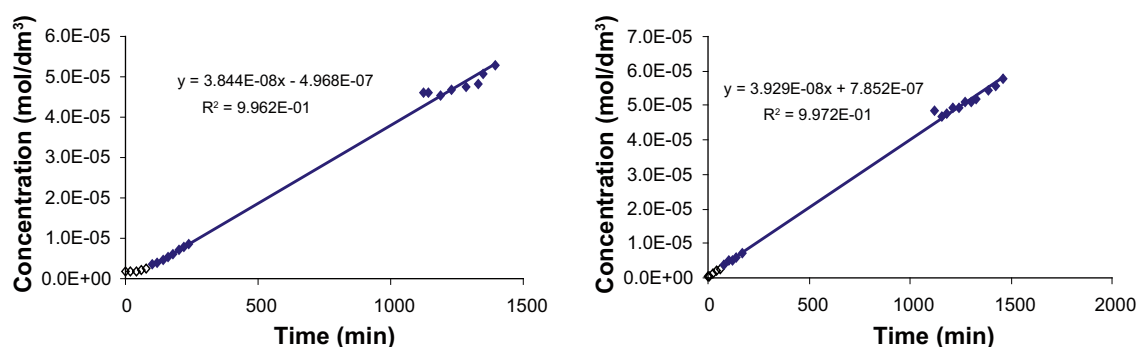


Figure 7-2. Breakthrough curves in first (left) and second (right) run. The background electrolyte is 0.05 M NaCl.

7.4 Sample 4

Sample 4 was taken from the borehole depth 554.71 m in borehole KFM01A at the Forsmark site (see Table 4-1). The sample was saturated with 0.1 M NaCl and the high concentration tracer cell initially held the electrolyte 0.01 M NaI and 0.09 M NaCl. Both runs were performed without problems or significant deviation from the method description in Chapter 4.

In Figure 7-3, data points marked with blue diamonds represent steady state conditions. The same assumption concerning the steady state was made as for sample 2. The porosity of the sample is 0.21% /Selnert et al. 2008/.

The raw data from the tracer tests and the electrical measurements are found in Appendices B5 and B6. The formation factors from the tracer tests, and the apparent formation factors from the electrical measurements, are shown in Table 7-3.

As can be seen from Table 7-3, good reproducibility was achieved. The deviation between the two TEM formation factors (~16%) can perhaps be explained by the relatively short time over which the first tracer test was performed. At this pore water electrolyte, and for this sample, the ratio between the apparent formation factor and the TEM formation factor is just over two. It is thought that this is mainly due to surface conduction. If comparing the formation factor obtained previously using HTO in through diffusion measurements (HTO $F_f=1.50 \cdot 10^{-4}$, see Table 4-1) with the TEM formation factor, they are about the same. This may indicate insignificant anion exclusion.

Generally, the apparent formation factor increases somewhat with frequency, indicating very small capacitance effects.

Table 7-3. Formation factor and apparent formation factors of sample 4, at 0.1 M NaCl.

Method	Run 1	Run 2
TEM, F_f	$1.80 \cdot 10^{-4}$	$1.57 \cdot 10^{-4}$
DC, F_f^{app}	$3.89 \cdot 10^{-4}$	$3.93 \cdot 10^{-4}$
AC 10 Hz, F_f^{app}	$4.09 \cdot 10^{-4}$	$4.11 \cdot 10^{-4}$
AC 100 Hz, F_f^{app}	$4.02 \cdot 10^{-4}$	$4.20 \cdot 10^{-4}$

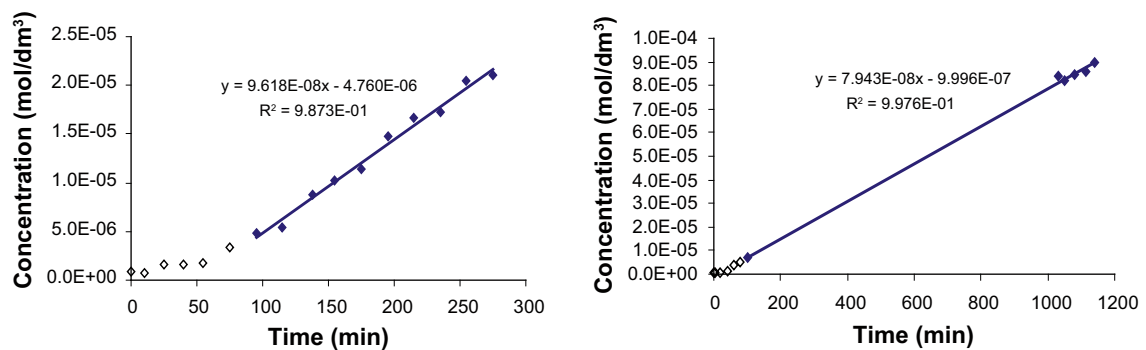


Figure 7-3. Breakthrough curves in first (left) and second (right) run. The background electrolyte is 0.1 M NaCl.

7.5 Sample 5

Sample 5 was taken from the borehole depth 554.84 m in borehole KFM02A at the Forsmark site (see Table 4-1). The sample was saturated with 0.05 M NaCl and the high concentration tracer cell initially held the electrolyte 0.005 M NaI and 0.045 M NaCl. Both runs were performed without problems or significant deviation from the method description in Chapter 4.

In Figure 7-4, data points marked with blue diamonds represent steady state conditions. The same assumption concerning the steady state was made as for sample 2. The porosity of the sample is 0.26% /Selnert et al. 2008/.

The raw data from the tracer tests and the electrical measurements are found in Appendices B7 and B8. The formation factors from the tracer tests, and the apparent formation factors from electrical measurements, are shown in Table 7-4.

As can be seen from Table 7-4, good reproducibility was achieved. At this pore water electrolyte, and for this sample, the ratio between the apparent formation factor and the TEM formation factor is just over two. It is thought that this is mainly due to surface conduction in the electrical methods. If comparing the formation factor obtained previously using HTO in through diffusion measurements (HTO $F_f=1.41 \cdot 10^{-4}$, see Table 4-1) with the TEM formation factors, the latter are somewhat higher. This may indicate insignificant anion exclusion.

The apparent formation factor increases somewhat with frequency, indicating minor capacitance effects.

7.6 Sample 6

Sample 6 was taken from the borehole depth 489.49 m in borehole KLX04 at the Oskarshamn site (see Table 4-1). The sample was saturated with 0.1 M NaCl and the high concentration tracer cell initially held the electrolyte 0.01 M NaI and 0.09 M NaCl. In this case triplicate runs were made, where all three tracer tests had relatively short duration. In the second tracer test, there also seem to be some deviation in the calibration of the iodide selective electrode, making the results somewhat more uncertain. Except for this, the runs were performed without problems or significant deviation from the method description in Chapter 4.

Table 7-4. Formation factor and apparent formation factors of sample 5, at 0.5 M NaCl.

Method	Run 1	Run 2
TEM, F_f	$1.94 \cdot 10^{-4}$	$1.87 \cdot 10^{-4}$
DC, F_f^{app}	$3.89 \cdot 10^{-4}$	$4.13 \cdot 10^{-4}$
AC 10 Hz, F_f^{app}	$4.69 \cdot 10^{-4}$	$4.49 \cdot 10^{-4}$
AC 100 Hz, F_f^{app}	$4.75 \cdot 10^{-4}$	$4.68 \cdot 10^{-4}$

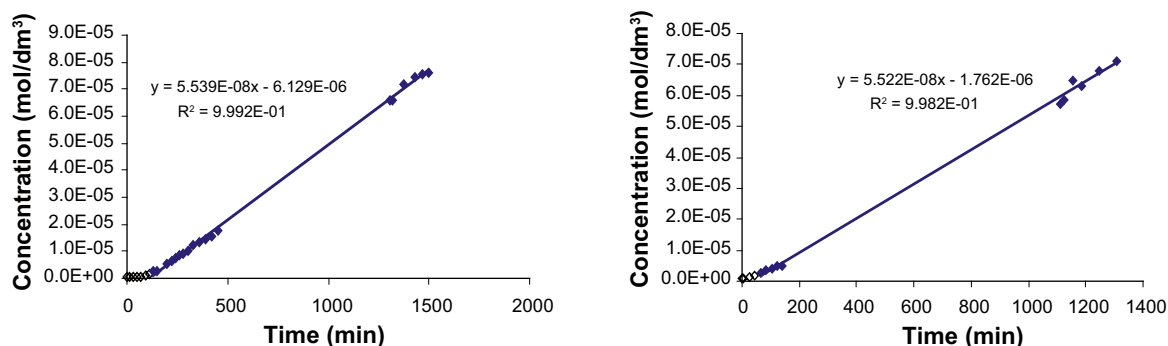


Figure 7-4. Sample 5: Breakthrough curves in first (left) and second (right) run. The background electrolyte is 0.05 M NaCl.

In Figure 7-5, data points marked with blue diamonds represent steady state conditions. The same assumption concerning the steady state was made as for sample 2. The porosity of the sample is 0.21% /Byegård et al. 2006/.

The raw data from the tracer tests and the electrical measurements are found in Appendices B9 to B11. The formation factors from the tracer tests, and the apparent formation factors from the electrical measurements, are shown in Figure 7-5. The TEM data from the second run is put in parentheses, due to the problem with calibrating the iodide selective electrode.

As can be seen from Table 7-5, good reproducibility was achieved in the tracer test (maximum deviation 16%). The reproducibility was for some reason poorer for the DC apparent formation factor, with the maximum deviation of about 47% (compare second and third run). Between the second and the third run, the equipment was used for other measurements (see Table 5-3) and the sample was stored in solution for about a week. The sample was stabilised for more than 1,300 minutes before tracer injection in the third run (see appendix B11). Even so it seems that the system was somewhat unstable during the tracer test with a slightly decreasing rock resistivity. It should also be noted that the potential drop over the studied rock sample was twice as large in the third run, compared to the previous two, even though the same potential drop was kept over the entire TEM cell.

At this pore water electrolyte, and for this sample, the ratio between the apparent formation factor and the TEM formation factor is on average about four. It is thought that this is mainly due to surface conduction in the electrical methods. If comparing the formation factor obtained previously using HTO in through diffusion measurements (HTO $F_f=6.13 \cdot 10^{-5}$, see Table 4-1) with the TEM formation factors, the latter are more than a factor of three larger.

Table 7-5. Formation factor and apparent formation factors of sample 6, at 0.1 M NaCl.

Method	Run 1	Run 2	Run 3
TEM, F_f	$1.93 \cdot 10^{-4}$	($2.28 \cdot 10^{-4}$)	$2.02 \cdot 10^{-4}$
DC, F_f^{app}	$7.23 \cdot 10^{-4}$	$8.34 \cdot 10^{-4}$	$5.17 \cdot 10^{-4}$
AC 10 Hz, F_f^{app}	$7.12 \cdot 10^{-4}$	$8.16 \cdot 10^{-4}$	$8.93 \cdot 10^{-4}$
AC 100 Hz, F_f^{app}	$7.30 \cdot 10^{-4}$	$8.27 \cdot 10^{-4}$	$8.70 \cdot 10^{-4}$

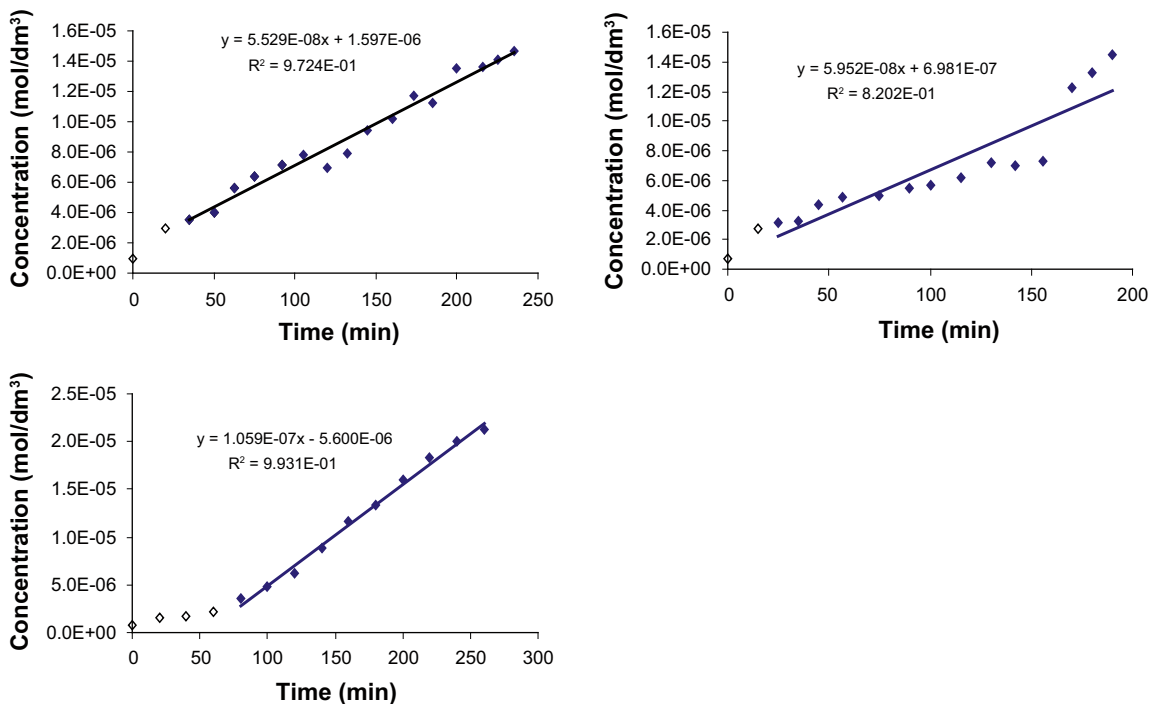


Figure 7-5. Breakthrough curves in first (upper left), second (upper right), and third run (lower). The background electrolyte is 0.1 M NaCl.

The fact that substantially larger formation factors are obtained using iodide compared to HTO may indicate that the sample has undergone weathering or other alteration, or that there is substantial data uncertainty in one (or both) of the compared tracer tests. This also applies to other samples (sample 7 and 9) where the TEM formation factor is substantially larger than the through diffusion formation factor.

For this sample there is no clear trend that the formation factor increases with frequency.

7.7 Sample 7

Sample 7 was taken from the borehole depth 489.49 m in borehole KLX04 at the Oskarshamn site (see Table 4-1). The sample was saturated with 0.05 M NaCl and the high concentration tracer cell initially held the electrolyte 0.005 M NaI and 0.045 M NaCl. Both runs were performed without problems or significant deviation from the method description in Chapter 4. Both runs were performed over night and, as also seen in other tracer tests, when returning in the morning and measuring the iodide concentration, there was a problem with the calibration of the iodide selective electrode. As a result, in the first run one data point is taken as an outlier (at 1,000 minutes).

In Figure 7-6, data points marked with blue diamonds represent steady state conditions. The same assumption concerning the steady state was made as for sample 2. The porosity of the sample is 0.16% /Byegård et al. 2006/.

The raw data from the tracer tests and the electrical measurements are found in Appendices B12 and B13. The formation factors from the tracer tests, and the apparent formation factors from the electrical measurements, are shown in Table 7-6.

As can be seen from Table 7-6, fairly good reproducibility was achieved in the tracer test (deviation ~30%) and good reproducibility was achieved in the electrical measurements. At this pore water electrolyte, and for this sample, the ratio between the apparent formation factor and the TEM formation factors is on average about four. It is thought that this is mainly due to surface conduction in the electrical methods. If comparing the formation factor obtained previously using HTO in through diffusion measurements (HTO $F_f=2.63 \cdot 10^{-5}$, see Table 4-1) with the TEM formation factor, the latter is about a factor of about six larger.

Table 7-6. Formation factor and apparent formation factors of sample 7, at 0.05 M NaCl.

Method	Run 1	Run 2
TEM, F_f	$1.32 \cdot 10^{-4}$	$1.78 \cdot 10^{-4}$
DC, F_f^{app}	$5.26 \cdot 10^{-4}$	$5.83 \cdot 10^{-4}$
AC 10 Hz, F_f^{app}	$6.16 \cdot 10^{-4}$	$6.27 \cdot 10^{-4}$
AC 100 Hz, F_f^{app}	$6.43 \cdot 10^{-4}$	$6.56 \cdot 10^{-4}$
AC 2,000 Hz, F_f^{app}	$6.56 \cdot 10^{-4}$	$6.66 \cdot 10^{-4}$

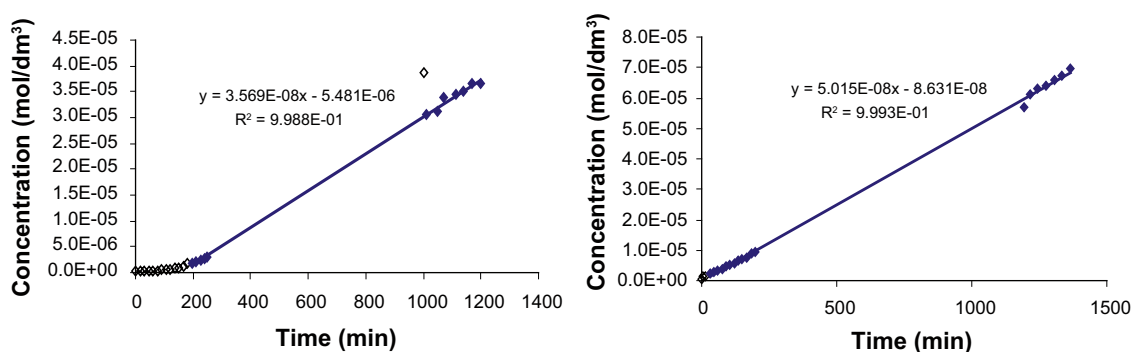


Figure 7-6. Breakthrough curves in first (left) and second (right) run. The background electrolyte is 0.05 M NaCl.

An interesting feature of the first run with this sample is shown in Appendix B12. The first few rock resistivity data points measured after saturation show much higher values than at stabilised conditions (by a factor of about six). This indicates that the sample was initially poorly saturated. This same is seen also for other samples. One can speculate that electro-osmosis is an important factor in saturating the samples during the stabilising phase. In any case, for some samples one can question the effectiveness of the standard saturation method. Furthermore one can speculate whether this is a source of disturbance responsible for part of the difference between formation factors obtained by the two tracer test methods.

The apparent formation factor increases somewhat with frequency, indicating minor capacitance effects.

7.8 Sample 8

Sample 8 was taken from the borehole depth 474.47 m in borehole KSH02 at the Oskarshamn site (see Table 4-1). The sample was saturated with 0.1 M NaCl and the high concentration tracer cell initially held the electrolyte 0.01 M NaI and 0.09 M NaCl.

Due to problems in the first run, three tracer tests were made. In the first run, the sample was somewhat unstable. More importantly, the tracer test was terminated before steady state conditions were obtained (that is before the iodide concentration increase in the low concentration tracer cell corresponded to the iodide amount in one pore volume of the rock sample). The porosity of the sample is 0.40% /Byegård et al. 2005/. Furthermore, no electrical measurements with AC were made.

The same early termination was the case in the second tracer test. However, as the rock sample had already been saturated with the tracer in the first run, it was accepted that the increase in iodide concentration only had to correspond to the iodide amount in half a pore volume of the rock sample. The third tracer test was performed over night.

In the third tracer test, two data points were considered as outliers as it was confirmed that these data points suffered from problems with the calibration of the iodide selective electrode.

The raw data from the tracer tests and the electrical measurements are found in Appendices B14 to B16. The formation factors from the tracer tests, and the apparent formation factors from electrical measurements, are shown in Table 7-7.

As can be seen from Table 7-7, good reproducibility was achieved between the second and third run. At this pore water electrolyte, and for this sample, the ratio between the apparent formation factor and the TEM formation factor is about ten. It is thought that this is mainly due to surface conduction in the electrical methods. This large ratio should be noted and one explanation is that this sample has a relatively low formation factor, compared to the other samples. This sample is of interest as it is thought that such low formation factors are generally found in situ /e.g. SKB 2006/.

If comparing the formation factor obtained previously using HTO in through diffusion measurements (HTO $F_f=2.39 \cdot 10^{-5}$, see Table 4-1) with the TEM formation factor, they agree. This may indicate insignificant anion exclusion.

The apparent formation factor increases somewhat with frequency, indicating minor capacitance effects.

Table 7-7. Formation factor and apparent formation factors of sample 8, at 0.1 M NaCl.

Method	Run 1	Run 2	Run 3
TEM, F_f		$2.35 \cdot 10^{-5}$	$2.46 \cdot 10^{-5}$
DC, F_f^{app}	$1.97 \cdot 10^{-4}$	$2.05 \cdot 10^{-4}$	$2.59 \cdot 10^{-4}$
AC 10 Hz, F_f^{app}		$2.35 \cdot 10^{-4}$	$3.00 \cdot 10^{-4}$
AC 100 Hz, F_f^{app}		$2.43 \cdot 10^{-4}$	$3.02 \cdot 10^{-4}$

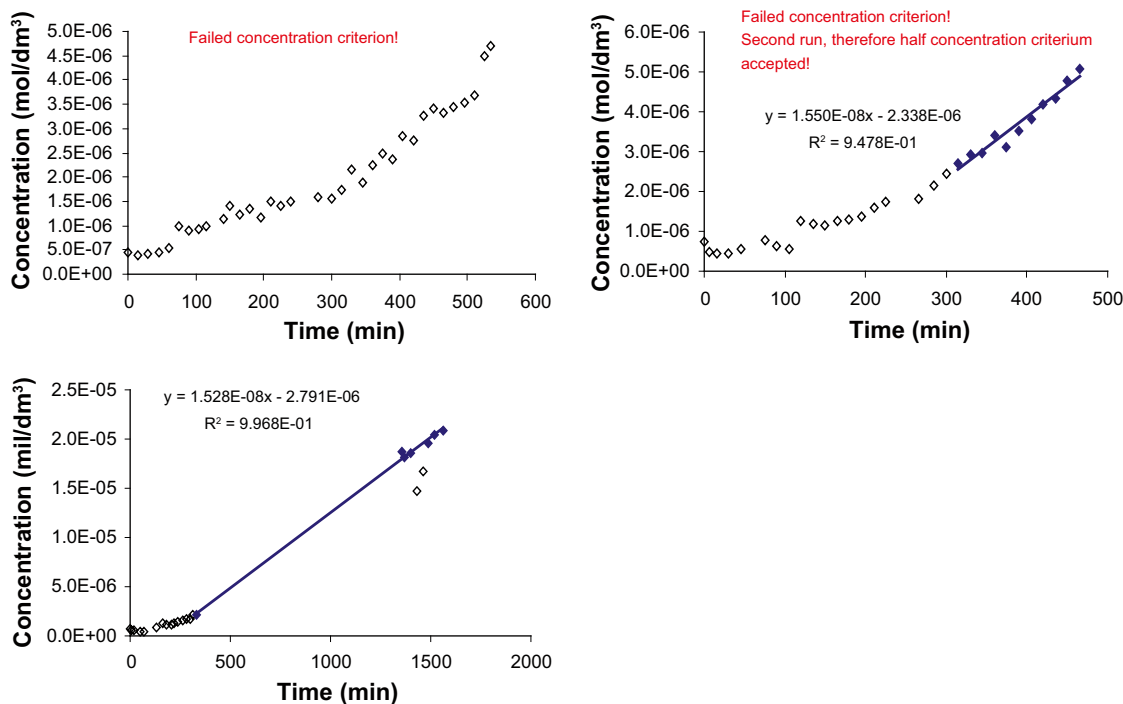


Figure 7-7. Breakthrough curves in first (upper left), second (upper right), and third run (lower). The background electrolyte is 0.1 M NaCl.

7.9 Sample 9

Sample 9 was taken from the borehole depth 474.66 m in borehole KSH02 at the Oskarshamn site (see Table 4-1). The sample was saturated with 0.05 M NaCl and the high concentration tracer cell initially held the electrolyte 0.005 M NaI and 0.045 M NaCl. Triplicate runs were performed without problems or significant deviation from the method description in Chapter 4, with the exception that the third run was performed on a somewhat unstable system (see Appendix B19)

In Figure 7-8, data points marked with blue diamonds represent steady state conditions. The same assumption concerning the steady state was made as for sample 2. The porosity of the sample is 0.20% /Byegård et al. 2005/.

The raw data from the tracer tests and the electrical measurements are found in Appendices B17 to B19. The formation factors from the tracer tests, and the apparent formation factors from electrical measurements, are shown in Table 7-8.

As can be seen from Table 7-8, fairly good reproducibility was achieved in the tracer test (maximum deviation ~45%). Furthermore, fairly good reproducibility was achieved in the electrical measurements (maximum deviation ~32%). At this pore water electrolyte, and for this sample, the ratio between the apparent formation factor and the TEM formation factor is on average about six. It is thought that this is mainly due to surface conduction in the electrical methods. If comparing the formation factor obtained previously using HTO in through diffusion measurements (HTO $F_f = 4.46 \cdot 10^{-5}$, see Table 4-1) with the TEM formation factors, the latter are on average about a factor of two larger.

The apparent formation factor increases somewhat with frequency, indicating minor capacitance effects.

Table 7-8. Formation factor and apparent formation factors of sample 9, at 0.05 M NaCl.

Method	Run 1	Run 2	Run 3
TEM, F_f	$7.05 \cdot 10^{-5}$	$1.12 \cdot 10^{-4}$	$9.36 \cdot 10^{-5}$
DC, F_f^{app}	$4.99 \cdot 10^{-4}$	$5.61 \cdot 10^{-4}$	$4.06 \cdot 10^{-4}$
AC 10 Hz, F_f^{app}	$5.93 \cdot 10^{-4}$	$6.39 \cdot 10^{-4}$	$4.91 \cdot 10^{-4}$
AC 100 Hz, F_f^{app}	$5.98 \cdot 10^{-4}$	$6.48 \cdot 10^{-4}$	$4.99 \cdot 10^{-4}$
AC 2,000 Hz, F_f^{app}	$5.68 \cdot 10^{-4}$	$6.22 \cdot 10^{-4}$	$5.28 \cdot 10^{-4}$

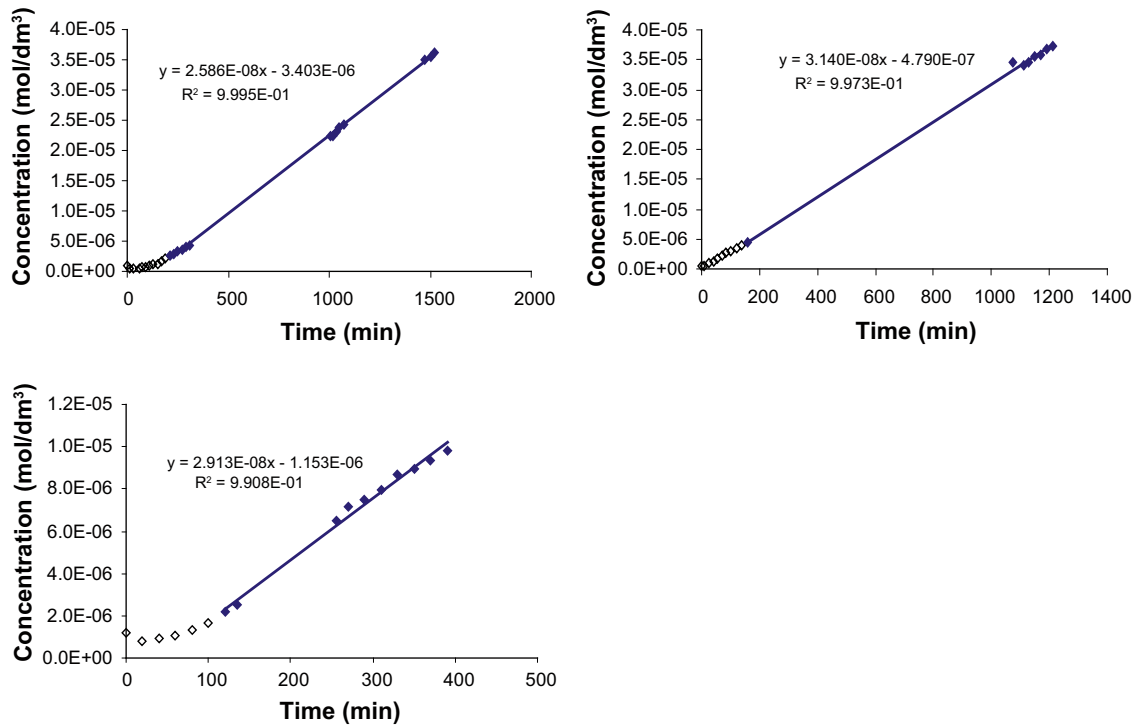


Figure 7-8. Breakthrough curves in first (upper left), second (upper right), and third run (lower). The background electrolyte is 0.05 M NaCl.

7.10 Comparisons of formation factors in part 2

7.10.1 Comparing the formation factor and apparent formation factor

In Figure 7-9 all formation factors and apparent formation factors obtained in part 2 are displayed. The different legends for the formation factors and apparent formation factors are explained in the figure.

As can be seen, the apparent formation factor is generally a few times larger than the formation factor. One can also see that in general, the apparent formation factor increases slightly with frequency.

It is worth remembering that samples 2, 4, 6, and 8 were saturated with 0.1 M NaCl while samples 3, 5, 7, and 9 were saturated by 0.05 M NaCl. Furthermore, samples 2 to 5 are from Forsmark and samples 6 to 9 are from Oskarshamn.

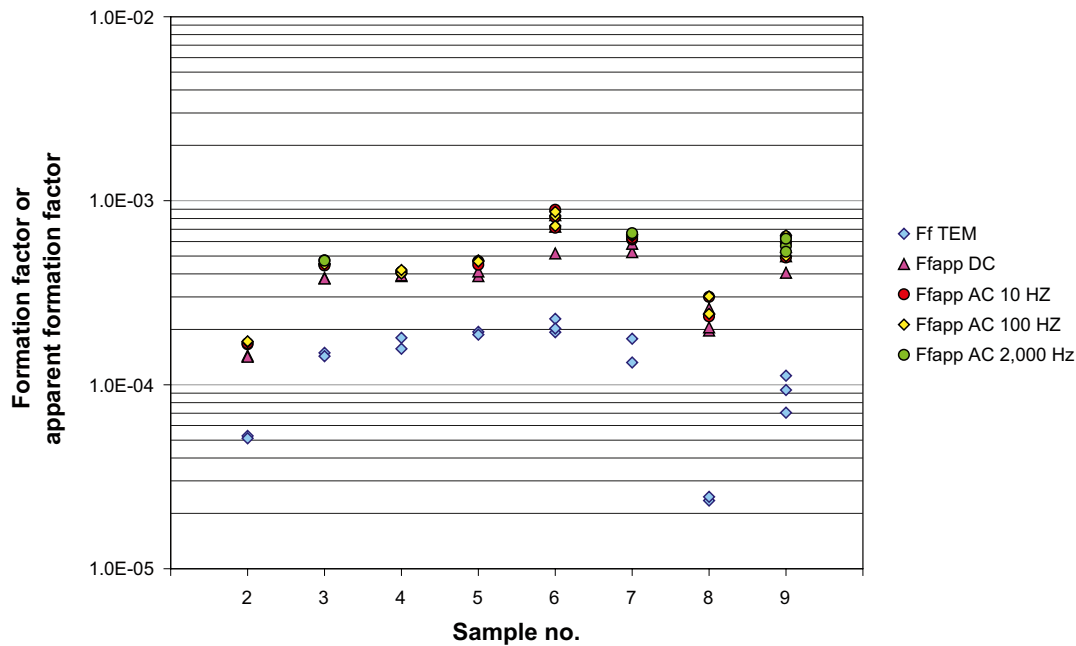


Figure 7-9. The formation factors and apparent formation factors of samples 2 to 9.

7.10.2 Bias and precision of the measurements

Discussing the bias of the methods is difficult, as we cannot calibrate them against known data. In Figure 7-10, the TEM formation factors obtained in part 2 are displayed together with the formation factors obtained by through diffusion (TD) measurements using HTO as the tracer (see Table 4-1).

The TEM formation factors (as averaged for each sample) are on average a factor of 2.0 ± 1.8 (mean \pm standard deviation) larger than the TD formation factors. This indicates that it is unlikely that the bias is larger than a factor of four, and likely that it is smaller. In case there is substantial anion exclusion, the data are expected to deviate, which is discussed in subsection 7.10.4.

Based on measurements of the effective electro-osmotic mobility in /Löfgren and Neretnieks 2006/ it is estimated that the TEM formation factors are underestimated by a factor of about 10%, if the sample was properly stabilized before the trace test (as in part 2). If the tracer test is run while the pore water electrical conductivity is changing (as sometimes the case in part 1), the effect from electro-osmosis is unknown.

The DC apparent formation factor overestimates on average the TEM formation factor 4.0 ± 2.4 times. However, this is partly due to surface conduction so the accuracy should be better than this.

The AC apparent formation factor obtained at 10 Hz overestimates the DC apparent formation factor 1.16 ± 0.16 times. The AC apparent formation factor obtained at 100 Hz overestimates the DC apparent formation factor 1.18 ± 0.15 times. The AC apparent formation factor obtained at 2,000 Hz overestimates the DC apparent formation factor 1.21 ± 0.07 times. It is interesting to note that if increasing the frequency from 10 Hz up to 2,000 Hz, which is the frequency used in situ, this does not induce significantly more data uncertainty.

The precision of the TEM method in part 2 can be assessed by taking the ratio of each TEM formation factor and the average TEM formation factor for the specific sample. This gives 18 ratios (18 TEM experiments were carried out) ranging from 0.77 to 1.22 with the standard deviation of 0.10. From this it can be said that data uncertainty due the precision is on the order of 10%, and is thus shadowed by data uncertainty due to accuracy issues.

Concerning, representativity it can be said that only eight samples from both sites are studied, wherefore the representativity may be limited. In addition, the samples measured upon are de-stressed.

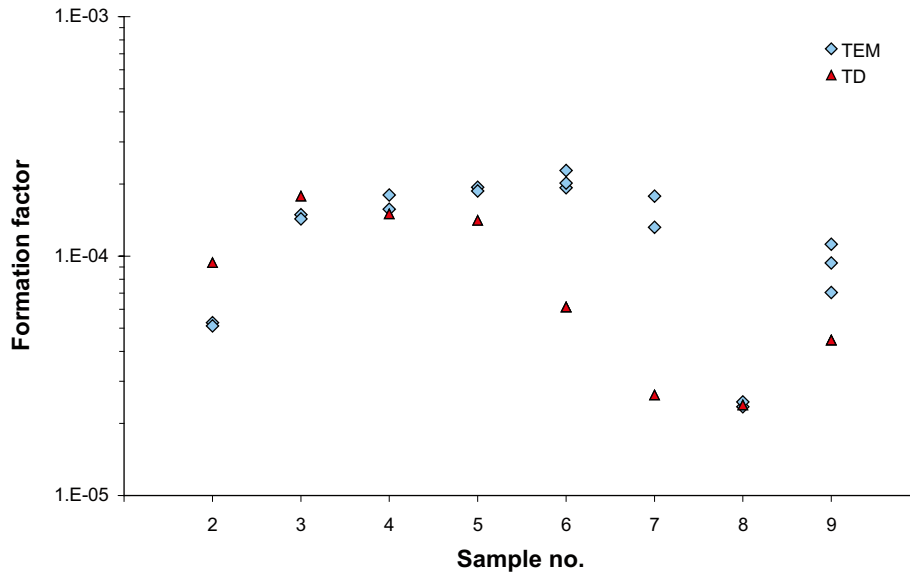


Figure 7-10. Comparing the TEM formation factors and HTO through diffusion (TD) formation factors.

7.10.3 Studying the F_f^{app}/F_f ratio

In Figure 7-11 the ratio of the apparent formation factor to the TEM formation factor in each separate run is shown, in relation to the TEM formation factor. The legends representing the different ratios are explained in the figure.

In Figure 7-11 one can see that the apparent formation factor is between 2 and 12 times larger than the formation factor. The difference is more pronounced for samples of low formation factor. By making some assumptions, it can be exemplified how much the apparent formation should overestimate the formation factor, assuming that Equation 3-9 is correct.

- The first assumption is that κ_s is constant for all rock, and that it is the same as that measured by DC for sample 1 ($\kappa_s = 3.38 \cdot 10^{-5}$ S/m). Surface conductivity measurements made on 82 samples by /Ohlsson 2000, Löfgren 2004/ resulted in a range between $7 \cdot 10^{-6}$ to $6 \cdot 10^{-5}$, indicating that although κ_s differs for different samples, it differs within one order of magnitude. Furthermore, our assumed κ_s values of $3.38 \cdot 10^{-5}$ S/m is in the centre of that range. Although an empirical correlation between κ_s and F_f is suggested in /Löfgren 2004/, for the sake of simplicity we choose a constant κ_s -value in this example.
- The second assumption is that κ_w equals 0.9 S/m, which is a about the average electrical conductivity of the electrolytes used in part 2 of this study. This is also a fair estimate of the groundwater electrical conductivity at the sites at repository depth (cf. Figure 4-11 of /Löfgren 2007/ for boreholes KFM01D and KFM08C).

The blue curve of Figure 7-12 shows the ratio of the modelled apparent formation factor and the formation factor used as input to the model.

Of course, if modifying the assumptions within reasonable ranges, the curve would be somewhat modified. This is done by assuming the highest and lowest value of κ_s measured in /Ohlsson 2000/ and /Löfgren 2004/, which is $6 \cdot 10^{-5}$ and $7 \cdot 10^{-6}$ S/m, respectively. These latter κ_s -values give rise to the red and green curves in Figure 7-12. What is important is that Figure 7-11 and Figure 7-12 share similar features, even though Figure 7-11 displays higher ratios. It should be kept in mind that the higher ratios of Figure 7-11 may be partly explained by anion exclusion.

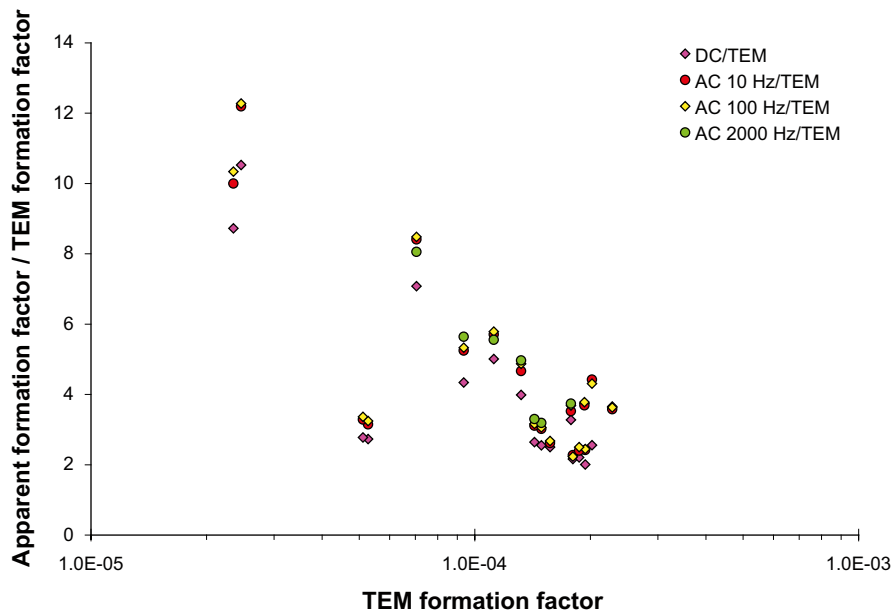


Figure 7-11. Ratio of apparent formation factor and TEM formation factor.

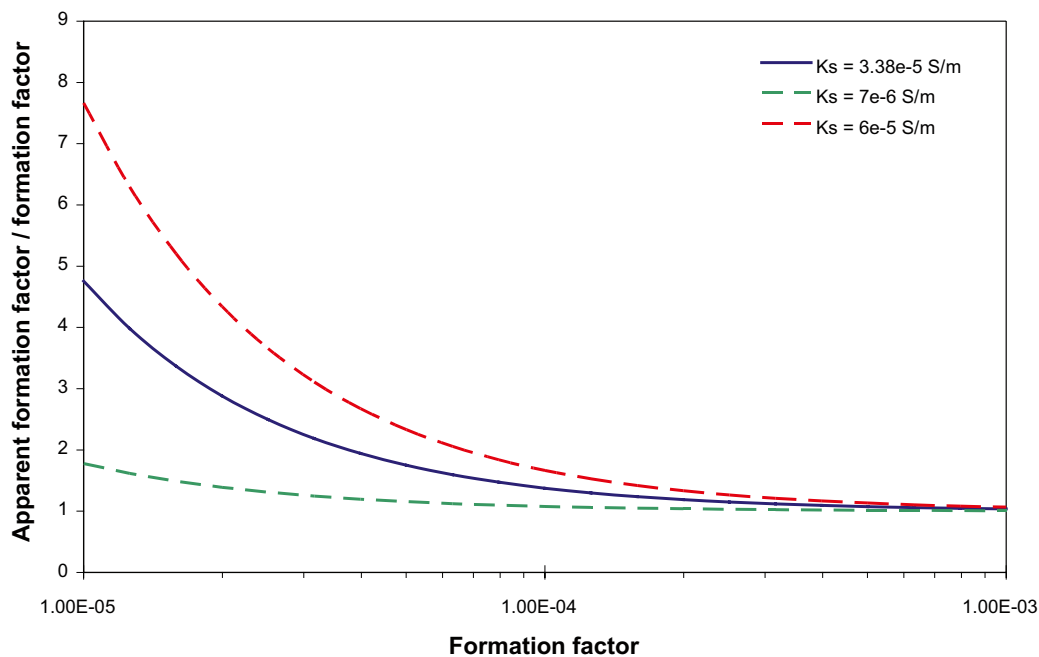


Figure 7-12. Modelled overestimation of the formation factor, if directly estimated from the apparent formation factor, for a typical groundwater κ_w of 0.9 S/m and surface conductivities of $7 \cdot 10^{-6}$, $3.38 \cdot 10^{-5}$, and $6 \cdot 10^{-5}$ S/m.

There is the option to choose the above approach, based on Equation 3-9, to correct in situ apparent formation factors obtained in the site investigations. Each of these apparent formation factors is associated with a κ_w , and there are data on κ_s that can be used as generic data /e.g. Löfgren 2004/. For the Forsmark site the in situ formation factor is thought to be on the order of $1 \cdot 10^{-5}$ /Table 4-24, Crawford 2008/. Figure 7-12 would imply large correction factors for in situ data. However, it is not without associated uncertainty to extrapolate the information to in situ conditions. It should be remembered that samples that in the laboratory feature low formation factors, as de-stressed, may differ in geology from rock of the same in situ formation factor.

7.10.4 Studying the effect of anion exclusion

The effect of anion exclusion can be studied by two approaches. The first approach is to compare the TEM formation factors with the through diffusion (TD) formation factors previously obtained within the site investigation program. This is a direct approach but the drawback is that it assumes that the methods are directly comparable, and that the accuracy in both studies is good. Also, it assumes that the samples have not been altered between measurements, and that the degree of saturation is similar in both studies.

The second approach is correcting the apparent formation factors by Equation 3-9, and then directly comparing the obtained formation factors with the obtained TEM formation factors. This is problematic as the κ_s of the individual samples has not been measured.

Comparing TEM formation factors and TD formation factors

In Figure 7-13, the TEM formation factors obtained in part 2 are displayed together with the formation factors obtained by through diffusion measurements using HTO as the tracer (see Table 4-1).

Due to anion exclusion, one would expect the TEM formation factors to be slightly lower than the TD formation factors. However, as can be seen this is not always the case. Whether the difference seen is due to some physical property or due to data uncertainty in any of the tracer test methods is not known. What can be seen is that for none of the samples, a major effect of anion exclusion can be seen. On average, for the Forsmark site (samples 2 to 5), the TEM formation factors are 96% of the TD formation factors. For the Oskarshamn site (samples 6 to 9), the TEM formation factors are larger than the TD formation factors, indicating that there is little ground for using these data for estimating the effect of anions exclusion.

Correcting apparent formation factors and comparing with TEM formation factors

There are no sample specific data that would make this approach possible in a formal scene. However, from comparing and Figure 7-11 and Figure 7-12, a few things can be said.

1. If there was no anion exclusion effect, one would not expect the $F_f^{app}/TEM F_f$ ratios in Figure 7-11 to be larger than the modeled ones in Figure 7-12.
2. If the anion exclusion factor was major, say a factor of 10, one would expect the $F_f^{app}/TEM F_f$ ratios in Figure 7-11 to be much larger than the modeled ones in Figure 7-12.

A subjective estimate based on this comparison, and also on the comparison in Figure 7-13, is that anion exclusion reduces the effective diffusivity by a few factors at the most. It is recognized that from the laboratory results at hand, conclusions reaching further cannot be drawn.

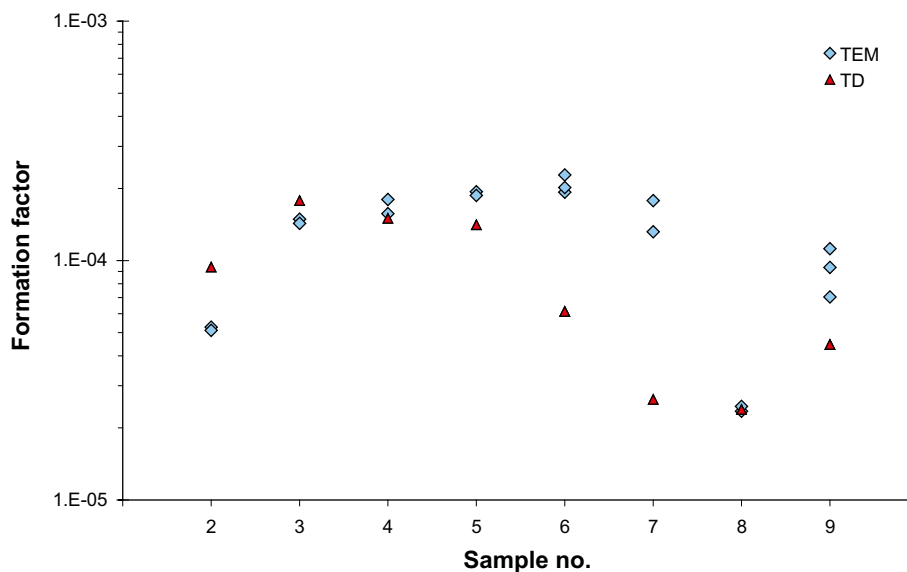


Figure 7-13. Comparing the TEM formation factors and HTO through diffusion formation factors.

8 Conclusions

In this report the geometric formation factor, as obtained in tracer tests, is compared with the apparent formation factor, as obtained by electrical methods. This is done by performing measurements with different methods on nine drill core samples from the Forsmark and Oskarshamn sites.

One of the overall objectives of this study was to investigate how much the apparent formation factor overestimates the formation factor, for different pore water electrolytes and for different samples. This objective is generally met and it is shown that the apparent formation factor in general overestimates the formation factor. For samples saturated by an electrolyte of low ionic strength, the main reason for such an overestimation is suggested to be surface conduction. This is especially shown in part 1 where the apparent formation factor, as measured on a sample saturated by a 0.001 M NaCl electrolyte, is at least one order of magnitude larger than the through diffusion formation factor, as previously measured on the same sample.

We have suggested a method of how to account for surface conduction, enabling correction of the apparent formation factor into the formation factor. This method may be adapted for correcting previously obtained in situ apparent formation factors. This should reduce data uncertainty and provide a better tool of performing the correction. The method can be compared to that of Forsmark SDM-Site /Crawford 2008/ where the apparent formation factor was corrected to the formation factor by simply dividing it by a factor of two. Based on the current experience from performing these new and more elaborate corrections, however, it appears that the approach taken in Forsmark SDM-Site on average would give about the same results as with the new correction.

In this report, it is shown that there is significant data uncertainty associated with estimating the formation factor based on electrical measurements. Therefore, one may wonder if it would not be easier to exclusively use the laboratory through diffusion method for determining the formation factor. However, doing this may be a mistake as it is thought that the laboratory formation factor may overestimate the in situ formation by up to one order of magnitude. The main reasons given for this is that laboratory samples are stress released and affected by excavation induced damage /e.g. Skagius and Neretnieks 1986b, Crawford 2008/. In this respect, it would be non-conservative to base the formation factor exclusively on laboratory through diffusion experiments.

The second objective of the study was to gain information on anion exclusion. One way of doing this is to compare the measured TEM formation factors with those previously obtained with the through diffusion method on the same samples, using HTO as the tracer. However, this comparison indicated no or little anion exclusion and it is suspected that data from the two studies cannot be directly compared. Three explanations provided are that 1) the samples have been altered between measurements, 2) the degree of saturation differs in the two studies, where incomplete saturation in the through diffusion measurements would explain the results, 3) the Fickian theory and equations used are not accurate enough to properly resolve the relatively small differences in the results from two methods.

By comparing the TEM formation factor with formation factors estimated from the electrical methods, the anion exclusion could be suggested to reduce the effective diffusivity by a few factors at the most. However, it is conceivable that this effect is larger in situ, as the porous system is compressed.

Finally it should be said that although there were some problems with the utilised methodology, much has been learned in this study and many flaws in the original methodology have been corrected. Some results of this study are unprecedented and if one has an interest to further investigate the formation factor, much can be done by using the methods discussed in this report. Perhaps the most important aspect of this method is that tracer tests can be repeated under different conditions. This facilitates measurements using different pore water chemistries and, after modifications, perhaps different ambient pressures. This is something that is not possible with the time consuming through diffusion method. It should also be feasible to, within a reasonable time frame, perform long-range tracer tests (on the metre scale) in the in situ rock matrix by adapting this method.

References

- Atkins P W, 1999.** Physical chemistry, 6th ed. Oxford University Press. ISBN 0 19 850102 1.
- Byegård J, Gustavsson E, Tullborg E-L, Berglund S, 2005.** Bedrock transport properties. Preliminary site description Simpevarp subarea – version 1.2. SKB R-05-05, Svensk Kärnbränslehantering AB.
- Byegård J, Gustavsson E, Tullborg E-L, 2006.** Bedrock transport properties. Data evaluation and retardation model. Preliminary site description Laxemar subarea – version 1.2. SKB R-06-27, Svensk Kärnbränslehantering AB.
- Crawford J, 2008.** Bedrock transport properties Forsmark. Site descriptive modelling, SDM-Site Forsmark. SKB R-08-48, Svensk Kärnbränslehantering AB.
- Crawford J, Sidborn M, 2009.** Bedrock transport properties Laxemar. Site descriptive modelling, SDM-Site Laxemar. SKB R-08-94, Svensk Kärnbränslehantering AB.
- CRC, 2008.** CRC Handbook of Chemistry and Physics. 88th ed. Boca Raton, FL: CRC Press, 2007/2008.
- Gascoyne M (ed), Laaksoharju M (ed), 2008.** High-level radioactive waste disposal in Sweden: Hydrogeochemical characterisation and modelling of two potential sites. Applied geochemistry, vol. 23(7), pp. 1745–2020 (July 2008)
- Krishna R, Wesselingh JA, 1997.** The Maxwell-Stefan approach to mass transfer. Review article no. 50, Chemical Engineering Science, Vol. 52(6), pp. 861–911.
- Löfgren M, 2004.** Diffusive properties of granitic rock as measured by in situ electrical methods. Doctoral thesis at the Royal Institute of Technology, Stockholm, Sweden. ISBN 91-7283-935-X.
- Löfgren M, Neretnieks I, 2005.** Formation factor logging in situ and in the laboratory by electrical methods in KSH01A and KSH02: Measurements and evaluation of methodology. Oskarshamn site investigation. SKB P-05-27, Svensk Kärnbränslehantering AB.
- Löfgren M, Neretnieks I, 2006.** Through-electromigration: A new method of investigating pore connectivity and obtaining formation factors. J. Contam. Hydrol, Vol. 87(3–4), pp. 237–252.
- Löfgren M, 2007.** Formation factor logging in situ by electrical methods in KFM01D and KFM08C. Forsmark site investigation. SKB P-07-138, Swedish Nuclear Fuel and Waste Management Co, Stockholm, Sweden.
- Melnyk T W, Skeet A M M, 1986.** An improved technique for the determination of rock porosity. Can. J. Earth Sc. Vol 23, pp. 1068–1074.
- Ohlsson Y, 2000.** Studies of Ionic Diffusion in Crystalline Rock. Doctoral thesis at the Royal Institute of Technology, Stockholm, Sweden. ISBN 91-7283-025-5.
- Revil A, Glover P W J, 1997.** Theory of ionic-surface electrical conduction in porous media. Physical review B. Vol 55 (3), pp. 1757–1773.
- Schön J H, 1996.** Physical properties of rock: Fundamentals and principles of petrophysics. Pergamon Press. ISBN 0-08-04-1008-1.
- Selnert E, Byegård J, Widestrand H, 2008.** Laboratory measurements within the site investigation programme for the transport properties of the rock. Final report. Forsmark site investigation. SKB P-07-139, Svensk Kärnbränslehantering AB.
- Selnert E, Byegård J, Widestrand H, 2009.** Laboratory measurements within the site investigation programme for the transport properties of the rock. Final report. Oskarshamn site investigation. SKB P-07-179, Svensk Kärnbränslehantering AB.
- Skagius K, Neretnieks I, 1986a.** Porosities and diffusivities of some nonsorbing species in crystalline rock. Water Resources Research, vol. 22(3), pp. 389–398.

Skagius K, Neretnieks I, 1986b. Diffusivity measurements and electrical-resistivity measurements in rock samples under mechanical-stress. *Water Resources Research*. Vol. 22(4), pp. 570–580.

SKB, 2006. Data report for the safety assessment SR-Can. SKB TR-06-25. Svensk Kärnbränslehantering AB

Stumm W, Morgan J J, 1996. *Aquatic chemistry. Chemical equilibria and rates in natural waters*, 3rd ed. John Wiley & Sons, Inc. ISBN 0-471-51184-6.

Thunehed H, 2007a. Resistivity measurements on samples from KSH01, KSH02, KLX02, KLX04 and KLX11A. Oskarshamn site investigation. SKB P-07-51, Svensk Kärnbränslehantering AB.

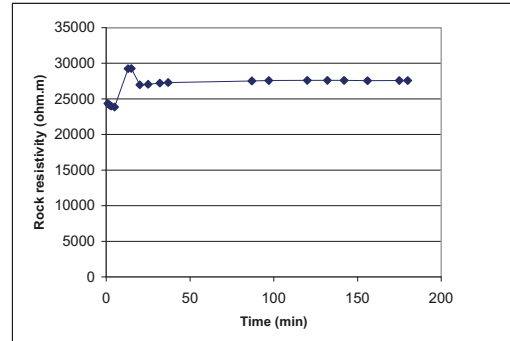
Thunehed H, 2007b. Resistivity measurements on samples from KFM01A, KFM01B, KFM02A, KFM05A and KFM06A. Forsmark site investigation. SKB P-06-289, Svensk Kärnbränslehantering AB.

Raw data from part 1

Appendix A1

Sample 1: Surface conductivity 0.001 M, first run
 Borehole and borehole length: KFM01A 312.66-312.67

TEM event / feature	Value	Units
start experiment	18.8. 11:23	date:time
end experiment	18.8.14:23	date:time
DC main voltage	25	V
TEM Sample potential drop	16.17	V
initial porewater concentration	0.001	mol/l
initial el. conductivity of porewater	0.0197	S/m
temperature of porewater	23.2	°C
tracer concentration	--	mol/l
time of injection	--	date:time
Volume of low concentration tracer cell	1.90E-04	m3
surrounding electrolyte concentration	0.001	mol/l
initial el. conductivity of electrolyte	1.14E-02	S/m
initial temperature of electrolyte	--	°C
length of water column 1	0.133	m
length of water column 2	0.133	m
inner diameter of cell	0.0405	m
inner cell area	1.29E-03	m2
sample length	0.01025	m
sample diameter	0.05	m
sample area	1.96E-03	m2



el. conductivity of electrolyte high conc. cell	1.14E-02	S/m
pH of electrolyte high conc. cell	--	
temperature of electrolyte high conc. Cell	--	°C
el. conductivity of electrolyte low conc. cell	1.14E-02	S/m
pH of electrolyte low conc. cell	--	
temperature of electrolyte low conc.cell	--	°C
Mean el. conductivity of electrolytes	0.0114	S/m

Time (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)
1	17.42	1.20E-04	24339
2	17.28	1.20E-04	24115
3	17.19	1.20E-04	23971
5	17.12	1.20E-04	23860
13	17.07	1.00E-04	29230
15	17.09	1.00E-04	29268
20	15.89	1.00E-04	26969
25	15.93	1.00E-04	27046
32	16.02	1.00E-04	27218
37	16.06	1.00E-04	27295
87	16.17	1.00E-04	27506
97	16.2	1.00E-04	27563
120	16.21	1.00E-04	27582
132	16.22	1.00E-04	27601
142	16.21	1.00E-04	27582
156	16.19	1.00E-04	27544
175	16.2	1.00E-04	27563
180	16.2	1.00E-04	27563

Potential drop (V)	7.03	Current (A)	8.00E-05	Cor. resistivity (ohm.m)	13364	AC formation factor 10 Hz	6.56E-03
Potential drop (V)	7.13	Current (A)	9.05E-05	Cor. resistivity (ohm.m)	11622	AC formation factor 100 Hz	7.55E-03
Mean 3 corrected resistivity (ohm.m)	27557					DC Formaion factor	3.18E-03
Slope (mol/(m3 s))		De (m2/s)				TEM Formation factor	

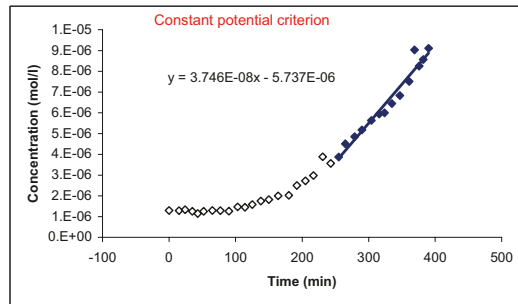
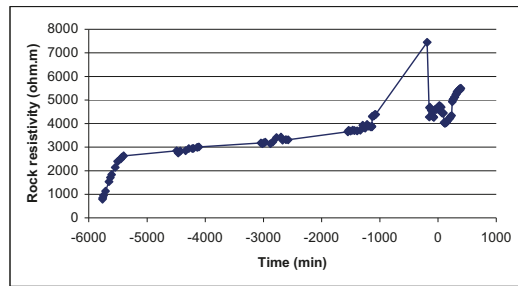
A guide how to read the spreadsheets in Appendix A is found in Appendix C.

Appendix A2

Sample 1: TEM 0.03 M, first run

Borehole and borehole length: KFM01A 312.66-312.67

TEM event / feature	Value	units
Start experiment	14/11/2008 11:39	date:time
End experiment	14/11/2008 17:40	date:time
DC main voltage	~ 25	V
TEM Sample potential drop	13.28	V
Initial porewater concentration	0.03	mol/l
Initial el. conductivity of porewater	0.3	S/m
Temperature of porewater	24	°C
Tracer concentration	0.003	mol/l
Time of injection	11:10	date:time
Volume of low concentration tracer cell	1.90E-04	m3
Surrounding electrolyte concentration	0.03	mol/l
Initial el. conductivity of electrolyte	0.336	S/m
Initial temperature of electrolyte		°C
Length of water column 1	0.133	m
Length of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m2
Sample length	0.01025	m
Sample diameter	0.05	m
Sample area	1.96E-03	m2
El. conductivity of electrolyte high conc. cell	0.361	S/m
pH of electrolyte high conc. cell	6.08	
Temperature of electrolyte high conc. cell	23.3	°C
El. conductivity of electrolyte low conc. cell	0.395	S/m
pH of electrolyte low conc. cell	5.93	
Temperature of electrolyte low conc. cell	23.3	°C
Mean el. conductivity of electrolytes	0.378	S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)
-5764	10.82	0.00224	793	
-5761	10.76	0.0021	850	

Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)	
0	12.56	5.02E-04	4688	1.30E-06	← Injection
15	12.6	4.98E-04	4742	1.29E-06	
24	12.65	4.98E-04	4761	1.33E-06	
35	12.58	5.00E-04	4715	1.25E-06	
43	12.58	5.00E-04	4715	1.15E-06	
52	12.57	5.02E-04	4692	1.25E-06	
65	12.28	5.16E-04	4454	1.30E-06	
77	12.26	5.16E-04	4447	1.29E-06	
90	12.26	5.16E-04	4447	1.26E-06	
103	11.75	5.42E-04	4048	1.47E-06	
114	11.68	5.44E-04	4008	1.45E-06	
125	11.71	5.42E-04	4034	1.58E-06	
138	11.72	5.42E-04	4038	1.75E-06	
150	11.77	5.40E-04	4071	1.82E-06	
164	11.84	5.36E-04	4127	2.00E-06	
180	11.92	5.32E-04	4187	2.03E-06	
192	11.97	5.32E-04	4205	2.50E-06	
205	12.02	5.30E-04	4240	2.72E-06	
217	12.1	5.26E-04	4302	2.98E-06	
231	12.15	5.24E-04	4337	3.88E-06	
243	12.88	4.90E-04	4931	3.56E-06	
255	13	4.86E-04	5019	3.87E-06	
265	13.03	4.84E-04	5052	4.51E-06	
279	13.09	4.80E-04	5119	4.85E-06	
290	13.11	4.80E-04	5127	5.18E-06	
304	13.2	4.74E-04	5230	5.63E-06	
316	13.23	4.72E-04	5265	5.94E-06	
324	13.3	4.68E-04	5339	6.00E-06	
335	13.33	4.66E-04	5375	6.45E-06	
347	13.35	4.64E-04	5407	6.83E-06	
361	13.36	4.62E-04	5435	7.51E-06	
369	13.4	4.60E-04	5476	9.03E-06	
376	13.4	4.64E-04	5427	8.25E-06	
382	13.41	4.60E-04	5480	8.57E-06	
390	13.4	4.58E-04	5500	9.11E-06	

AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	2.37	2.70E-04	1577	1.68E-03
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	2.54	2.28E-04	2029	1.30E-03
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formation factor
	5469			4.84E-04
TEM formation factor	Slope (mol/(m3 s))	De (m2/s)		TEM Formation factor
	6.24E-07	3.97E-13		1.99E-04

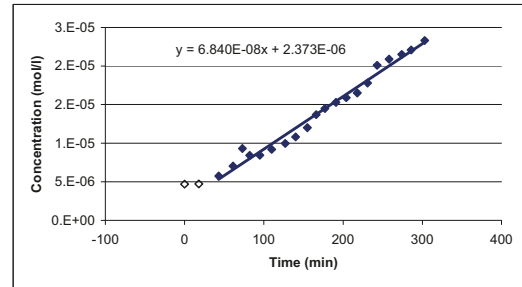
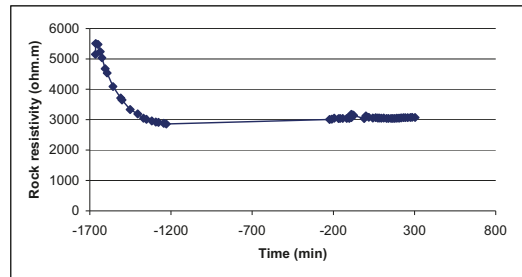
Appendix A3

Sample 1: TEM 0.05 M, first run

Borehole and borehole length: KFM01A 312.66-312.67

TEM event / feature	Value	Units
Start experiment	19/11/2008 11:50	date:time
End experiment	19/11/2008 18:23	date:time
DC main voltage	~ 25	V
TEM Sample potential drop	11.27	V
Initial porewater concentration	0.05	mol/l
Initial el. conductivity of porewater	0.544	S/m
Temperature of porewater	23.8	°C
Tracer concentration	0.005	mol/l
Time of injection	13:20	date:time
Volume of low concentration tracer cell	1.90E-04	m3
Surrounding electrolyte concentration	0.05	mol/l
Initial el. conductivity of electrolyte	0.538	S/m
Initial temperature of electrolyte	23.6	°C
Length of water column 1	0.133	m
Length of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m2
Sample length	0.01025	m
Sample diameter	0.05	m
Sample area	1.96E-03	m2

El. conductivity of electrolyte high conc. cell	0.577	S/m
pH of electrolyte high conc. cell	5.83	
Temperature of electrolyte high conc. cell	22.8	°C
El. conductivity of electrolyte low conc. cell	0.579	S/m
pH of electrolyte low conc. cell	6.51	
Temperature of electrolyte low conc. cell	22.8	°C
Mean el. conductivity of electrolytes	0.578	S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)
-1666	13.2	0.000484	5152	
-1663	12.46	0.000428	5504	
-1650	11.64	0.000402	5474	

0	11.4	6.84E-04	3124	4.70E-06	← Injection
18	11.34	6.90E-04	3080	4.72E-06	
43	11.28	6.92E-04	3054	5.75E-06	
61	11.29	6.90E-04	3066	7.04E-06	
73	11.27	6.92E-04	3051	9.32E-06	
82	11.27	6.92E-04	3051	8.41E-06	
95	11.26	6.92E-04	3049	8.45E-06	
110	11.27	6.92E-04	3051	9.20E-06	
127	11.26	6.94E-04	3040	9.97E-06	
140	11.27	6.94E-04	3042	1.08E-05	
155	11.27	6.94E-04	3042	1.20E-05	
166	11.26	6.94E-04	3040	1.37E-05	
177	11.27	6.94E-04	3042	1.45E-05	
191	11.26	6.92E-04	3049	1.53E-05	
204	11.26	6.92E-04	3049	1.59E-05	
218	11.27	6.90E-04	3060	1.65E-05	
231	11.28	6.90E-04	3063	1.78E-05	
243	11.29	6.90E-04	3066	2.01E-05	
258	11.28	6.90E-04	3063	2.09E-05	
274	11.28	6.88E-04	3072	2.15E-05	
286	11.29	6.88E-04	3075	2.21E-05	
303	11.28	6.88E-04	3072	2.33E-05	

AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	6.68	4.72E-04	2643	6.55E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	6.82	4.94E-04	2576	6.72E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formaion factor
	3073			5.63E-04
TEM formation factor	Slope (mol/(m3 s)) De (m2/s)			TEM Formation factor
	1.14E-06	5.12E-13		2.56E-04

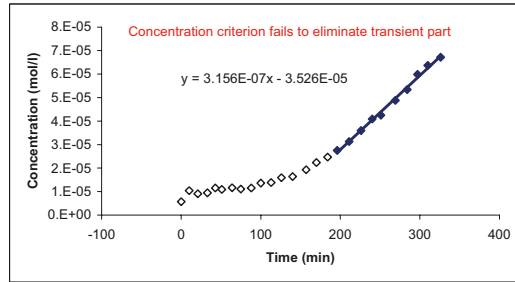
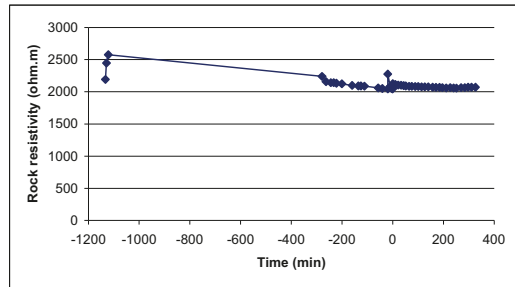
Appendix A4

Sample 1: TEM 0.1 M, first run

Borehole and borehole length: KFM01A 312.66-312.67

TEM event / feature	Value	Units
Start experiment	20/11/2008 13:40	date:time
End experiment	20/11/2008 19:26	date:time
DC main voltage	~ 25	V
TEM Sample potential drop	11.69	V
Initial porewater concentration	0.1	mol/l
Initial el. conductivity of porewater	0.544	S/m
Temperature of porewater	23.8	°C
Tracer concentration	0.01	mol/l
Time of injection	14:00	date:time
Volume of low concentration tracer cell	1.90E-04	m3
Surrounding electrolyte concentration	0.1	mol/l
Initial el. conductivity of electrolyte	1.085	S/m
Initial temperature of electrolyte	23.2	°C
Length of water column 1	0.133	m
Length of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m2
Sample length	0.01025	m
Sample diameter	0.05	m
Sample area	1.96E-03	m2

El. conductivity of electrolyte high conc. cell	1.117	S/m
pH of electrolyte high conc. cell	4.63	
Temperature of electrolyte high conc. cell	23.1	°C
El. conductivity of electrolyte low conc. cell	1.074	S/m
pH of electrolyte low conc. cell	6.8	
Temperature of electrolyte low conc. cell	23.1	°C
Mean el. conductivity of electrolytes	1.0955	S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)
-1133	12.8	0.0011	2192	
-1129	12.01	0.000926	2448	
-1122	11.92	0.000874	2576	

0	11.72	1.038E-03	2127	5.70E-06	<-- Injection
10	11.69	1.042E-03	2113	1.04E-05	
21	11.67	1.044E-03	2105	9.08E-06	
33	11.67	1.046E-03	2101	9.48E-06	
43	11.66	1.048E-03	2095	1.15E-05	
51	11.66	1.050E-03	2091	1.09E-05	
64	11.63	1.050E-03	2086	1.16E-05	
75	11.63	1.050E-03	2086	1.11E-05	
88	11.64	1.052E-03	2083	1.15E-05	
100	11.64	1.052E-03	2083	1.36E-05	
113	11.62	1.054E-03	2076	1.38E-05	
126	11.63	1.054E-03	2078	1.59E-05	
140	11.63	1.054E-03	2078	1.64E-05	
157	11.64	1.058E-03	2071	1.93E-05	
170	11.64	1.060E-03	2067	2.24E-05	
184	11.67	1.062E-03	2069	2.47E-05	
196	11.67	1.064E-03	2065	2.75E-05	
211	11.67	1.066E-03	2061	3.13E-05	
226	11.69	1.066E-03	2065	3.60E-05	
240	11.68	1.068E-03	2059	4.09E-05	
251	11.67	1.068E-03	2057	4.25E-05	
269	11.69	1.066E-03	2065	4.88E-05	
284	11.7	1.066E-03	2066	5.34E-05	
297	11.71	1.064E-03	2072	5.99E-05	
310	11.71	1.064E-03	2072	6.37E-05	
326	11.7	1.064E-03	2070	6.72E-05	

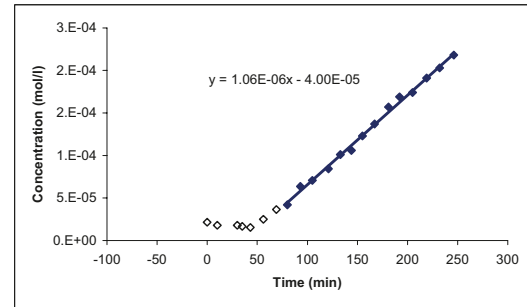
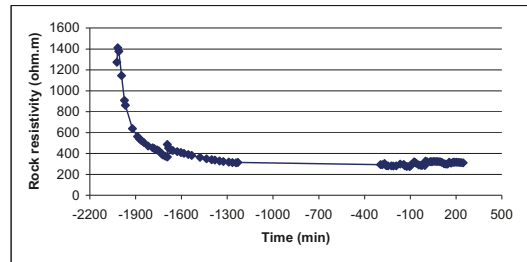
AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	6.45	6.76E-04	1792	5.09E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	6.53	7.10E-04	1726	5.29E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formation factor
	2072			4.41E-04
TEM formation factor	Slope (mol/(m3 s)) De (m2/s)			TEM Formation factor
	5.26E-06	1.14E-12		5.70E-04

Appendix A5

Sample 1: TEM 1 M, first run

Borehole and borehole length: KFM01A 312.66-312.67

TEM event / feature	Value	Units
Start experiment	25/11/2008 12:50	date:time
End experiment	25/11/2008 18:41	date:time
DC main voltage	~ 25	V
TEM Sample potential drop	6.36	V
Initial porewater concentration	1	mol/l
Initial el. conductivity of porewater	8.85	S/m
Temperature of porewater	23.9	°C
Tracer concentration	0.1	mol/l
Time of injection	14:35	date:time
Volume of low concentration tracer cell	1.90E-04	m3
Surrounding electrolyte concentration	1	mol/l
Initial el. conductivity of electrolyte	8.25	S/m
Initial temperature of electrolyte	23.3	°C
Length of water column 1	0.133	m
Length of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m2
Sample length	0.01025	m
Sample diameter	0.05	m
Sample area	1.96E-03	m2
El. conductivity of electrolyte high conc. cell	8.3	S/m
pH of electrolyte high conc. cell	6.56	
Temperature of electrolyte high conc. cell	23	°C
El. conductivity of electrolyte low conc. cell	8.69	S/m
pH of electrolyte low conc. cell	5.62	
Temperature of electrolyte low conc. cell	23.4	°C
Mean el. conductivity of electrolytes	8.495	S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)
-2023	10.8	0.00162	1272	
-2018	11.98	0.00162	1412	
-2010	11.69	0.00162	1377	

0	6.37	3.70E-03	325	2.15E-05	← Injection
10	6.31	3.72E-03	320	1.78E-05	
30	6.42	3.78E-03	321	1.79E-05	
35	6.41	3.78E-03	320	1.66E-05	
43	6.43	3.78E-03	321	1.53E-05	
56	6.46	3.76E-03	324	2.49E-05	
69	6.49	3.80E-03	323	3.63E-05	
80	6.49	3.80E-03	323	4.20E-05	
93	6.47	3.82E-03	320	6.36E-05	
105	6.39	3.82E-03	316	7.06E-05	
121	6.15	3.84E-03	302	8.43E-05	
133	6.08	3.86E-03	297	1.01E-04	
144	6.08	3.86E-03	297	1.06E-04	
155	6.47	3.88E-03	315	1.23E-04	
167	6.31	3.88E-03	307	1.37E-04	
181	6.47	3.88E-03	315	1.57E-04	
192	6.48	3.88E-03	315	1.69E-04	
205	6.47	3.88E-03	315	1.74E-04	
219	6.44	3.88E-03	313	1.91E-04	
232	6.41	3.88E-03	312	2.03E-04	
246	6.38	3.88E-03	310	2.18E-04	

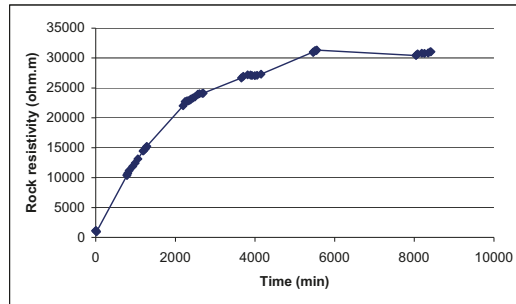
AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	3.556	3.08E-03	217	5.44E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	3.765	3.20E-03	221	5.33E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formaion factor
	312			3.78E-04
TEM formation factor	Slope (mol/(m3 s))	De (m2/s)		TEM Formation factor
	1.77E-05	7.03E-13		3.52E-04

Appendix A6

Sample 1: Surface conductivity 0.001 M, second run

Borehole and borehole length: KFM01A 312.66-312.67

TEM event / feature	Value	Units
Start experiment	25/11/2008 19:15	date:time
End experiment	01/12/2008 15:33	date:time
DC main voltage	~ 25	V
TEM Sample potential drop		V
Initial porewater concentration	1	mol/l
Initial el. conductivity of porewater		S/m
Temperature of porewater		°C
Tracer concentration		mol/l
Time of injection		date:time
Volume of low concentration tracer cell	1.90E-04	m3
Surrounding electrolyte concentration	0.001	mol/l
Initial el. conductivity of electrolyte	0.01108	S/m
Initial temperature of electrolyte	22.6	°C
Length of water column 1	0.133	m
Length of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m2
Sample length	0.01025	m
Sample diameter	0.05	m
Sample area	1.96E-03	m2



El. conductivity of electrolyte high conc. cell	0.01781	S/m
pH of electrolyte high conc. cell		
Temperature of electrolyte high conc. cell	24.4	°C
El. conductivity of electrolyte low conc. cell	0.02692	S/m
pH of electrolyte low conc. cell		
Temperature of electrolyte low conc. cell	24.1	°C
Mean el. conductivity of electrolytes	0.022365	S/m

Time (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)
1	17.1	1.120E-03	1156
6	15.71	1.040E-03	1125
12	15.01	1.020E-03	1050
21	14.06	1.000E-03	925
786	16.51	2.606E-04	10368
3886	17.73	1.174E-04	27161
3921	17.73	1.176E-04	27112
3994	17.73	1.178E-04	27063
4055	17.74	1.176E-04	27128
4151	17.76	1.170E-04	27309
5458	18.04	1.054E-04	31018
5464	18	1.054E-04	30946
5505	17.99	1.044E-04	31241
5531	18	1.044E-04	31259
5549	18	1.042E-04	31323
8044	17.72	1.054E-04	30437
8051	17.73	1.052E-04	30516
8082	17.76	1.048E-04	30694
8187	17.8	1.046E-04	30830
8256	17.82	1.048E-04	30804
8351	17.82	1.046E-04	30866
8399	17.83	1.040E-04	31073
8419	17.83	1.040E-04	31073

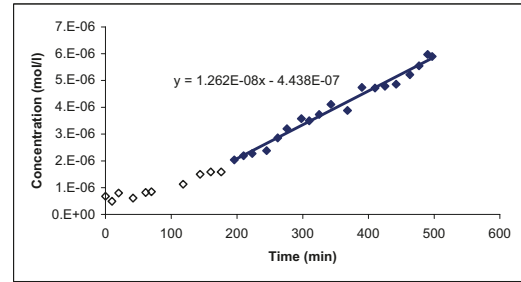
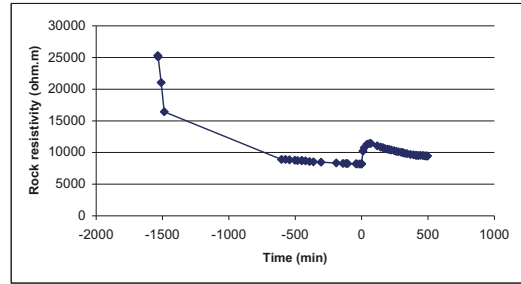
AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	2.201	4.88E-05	6871	6.51E-03
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	2.361	5.32E-05	6733	6.64E-03
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formation factor
	31004			1.44E-03
TEM formation factor	Slope (mol/(m3 s))	De (m2/s)		TEM Formation factor

Appendix A7

Sample 1: TEM 0.03 M, second run

Borehole and borehole length: KFM01A 312.66-312.67

TEM event / feature	Value	Units
Start experiment	20/01/2009 10:50	date:time
End experiment	20/01/2009 19:07	date:time
DC main voltage	~25	V
TEM Sample potential drop	14.10	V
Initial porewater concentration	0.03	mol/l
Initial el. conductivity of porewater	0.3	S/m
Temperature of porewater	22	°C
Tracer concentration	0.003	mol/l
Time of injection	20/01/2009 10:50	date:time
Volume of low concentration tracer cell	1.90E-04	m ³
Surrounding electrolyte concentration	0.03	mol/l
Initial el. conductivity of electrolyte	0.338	S/m
Initial temperature of electrolyte		°C
Length of water column 1	0.133	m
Length of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m ²
Sample length	0.01025	m
Sample diameter	0.05	m
Sample area	1.96E-03	m ²
El. conductivity of electrolyte high conc. cell	0.361	S/m
pH of electrolyte high conc. cell	6.08	
Temperature of electrolyte high conc. cell	23.3	°C
El. conductivity of electrolyte low conc. cell	0.395	S/m
pH of electrolyte low conc. cell	5.93	
Temperature of electrolyte low conc. cell	23.3	°C
Mean el. conductivity of electrolytes	0.378	S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)
-1536	18.31	0.000138	25298	
-1533	18.2	0.0001384	25072	
-1510	17.36	0.0001572	21036	

Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)	
0	14.1	3.260E-04	8181	6.80E-07	← Injection
10	14.09	2.612E-04	10229	4.90E-07	
20	14.11	2.482E-04	10785	8.00E-07	
42	14.1	2.366E-04	11311	6.10E-07	
61	14.08	2.336E-04	11441	8.20E-07	
70	14.1	2.342E-04	11428	8.50E-07	
118	14.08	2.414E-04	11068	1.13E-06	
144	14.09	2.458E-04	10876	1.50E-06	
160	14.07	2.480E-04	10763	1.59E-06	
176	14.05	2.508E-04	10627	1.59E-06	
196	14.12	2.546E-04	10519	2.04E-06	
210	14.11	2.560E-04	10454	2.19E-06	
223	14.11	2.572E-04	10404	2.27E-06	
245	14.09	2.596E-04	10292	2.38E-06	
262	14.09	2.622E-04	10189	2.86E-06	
276	14.09	2.638E-04	10127	3.20E-06	
298	14.09	2.664E-04	10027	3.58E-06	
310	14.09	2.678E-04	9974	3.50E-06	
325	14.12	2.710E-04	9876	3.73E-06	
343	14.09	2.720E-04	9818	4.11E-06	
368	14.1	2.752E-04	9710	3.88E-06	
390	14.09	2.772E-04	9632	4.74E-06	
410	14.09	2.792E-04	9563	4.72E-06	
425	14.09	2.802E-04	9528	4.79E-06	
442	14.12	2.802E-04	9549	4.86E-06	
463	14.13	2.812E-04	9521	5.22E-06	
477	14.12	2.822E-04	9480	5.55E-06	
490	14.12	2.828E-04	9460	5.97E-06	
497	14.13	2.836E-04	9440	5.90E-06	

AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	5.46	1.46E-04	7059	3.75E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	5.58	1.53E-04	6882	3.84E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formation factor
	9460			2.80E-04
TEM formation factor	Slope (mol/(m ³ s))	De (m ² /s)		TEM Formation factor
	2.10E-07	1.26E-13		6.30E-05

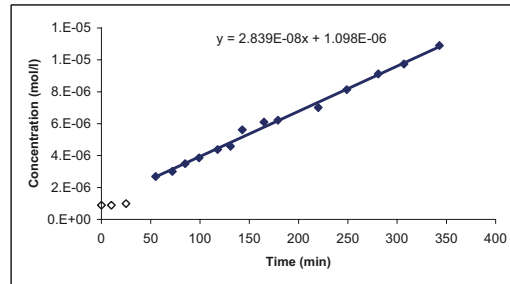
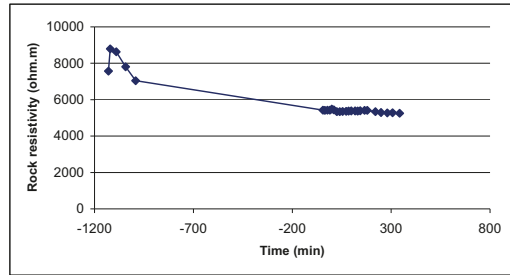
Appendix A8

Sample 1: TEM 0.05 M, second run

Borehole and borehole length: KFM01A 312.66-312.67

TEM event / feature	Value	Units
Start experiment	21/01/2009 date:time	
End experiment	22/01/2009 date:time	
DC main voltage	~ 25 V	
TEM Sample potential drop	13.61 V	
Initial porewater concentration	0.03 mol/l	
Initial el. conductivity of porewater	0.378 S/m	
Temperature of porewater	23 °C	
Tracer concentration	0.005 mol/l	
Time of injection	22/1/09 9:05 date:time	
Volume of low concentration tracer cell	1.90E-04 m3	
Surrounding electrolyte concentration	0.05 mol/l	
Initial el. conductivity of electrolyte	0.623 S/m	
Initial temperature of electrolyte	23.2 °C	
Length of water column 1	0.133 m	
Length of water column 2	0.133 m	
Inner diameter of cell	0.0405 m	
Inner cell area	1.29E-03 m2	
Sample length	0.01025 m	
Sample diameter	0.05 m	
Sample area	1.96E-03 m2	

El. conductivity of electrolyte high conc. cell	0.664 S/m
pH of electrolyte high conc. cell	4.58
Temperature of electrolyte high conc. cell	23.2 °C
El. conductivity of electrolyte low conc. cell	0.635 S/m
pH of electrolyte low conc. cell	6.09
Temperature of electrolyte low conc. cell	23.3 °C
Mean el. conductivity of electrolytes	0.6495 S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)
-1130	14.06	3.530E-04	7569	
-1120	14.02	3.036E-04	8785	
-1090	13.91	3.066E-04	8630	
-1043	13.55	3.300E-04	7805	
-992	13.05	3.518E-04	7045	
-45	13.45	4.700E-04	5421	
-35	13.44	4.700E-04	5417	
-22	13.45	4.700E-04	5421	
-10	13.45	4.700E-04	5421	
0	13.66	4.720E-04	5483	8.90E-07 <-- Injection
10	13.61	4.740E-04	5439	8.80E-07
25	13.6	4.820E-04	5344	9.90E-07
40	13.59	4.820E-04	5340	
55	13.61	4.820E-04	5348	2.69E-06
72	13.64	4.820E-04	5360	3.01E-06
85	13.62	4.800E-04	5375	3.49E-06
99	13.63	4.800E-04	5379	3.86E-06
118	13.64	4.800E-04	5383	4.38E-06
131	13.62	4.800E-04	5375	4.58E-06
143	13.6	4.780E-04	5389	5.62E-06
165	13.6	4.760E-04	5412	6.10E-06
179	13.6	4.760E-04	5412	6.22E-06
220	13.6	4.820E-04	5344	7.01E-06
249	13.59	4.860E-04	5296	8.13E-06
281	13.58	4.880E-04	5270	9.12E-06
307	13.61	4.880E-04	5282	9.74E-06
343	13.59	4.900E-04	5252	1.09E-05

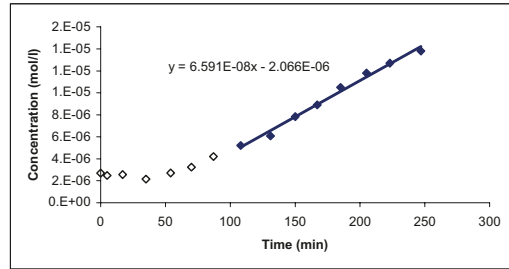
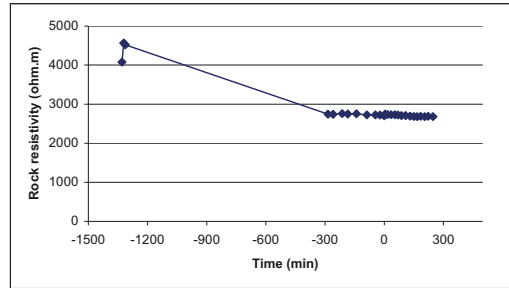
AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	5.67	2.50E-04	4284	3.59E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	5.79	2.65E-04	4125	3.73E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formation factor
	5268			2.92E-04
TEM formation factor	Slope (mol/(m3 s))	De (m2/s)		TEM Formation factor
	4.73E-07	1.76E-13		8.81E-05

Appendix A9

Sample 1: TEM 0.1 M, second run

Borehole and borehole length: KFM01A 312.66-312.67

TEM event / feature	Value	units
Start experiment	22/01/2009	date:time
End experiment	23/01/2009	date:time
DC main voltage	~ 25	V
TEM Sample potential drop	11.60	V
Initial porewater concentration	0.05	mol/l
Initial el. conductivity of porewater	0.6495	S/m
Temperature of porewater	23.3	°C
Tracer concentration	0.01	mol/l
Time of injection	23/01/2009 13:35	date:time
Volume of low concentration tracer cell	1.90E-04	m3
Surrounding electrolyte concentration	0.1	mol/l
Initial el. conductivity of electrolyte	1.246	S/m
Initial temperature of electrolyte	22	°C
Length of water column 1	0.133	m
Length of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m2
Sample length	0.01025	m
Sample diameter	0.05	m
Sample area	1.96E-03	m2
El. conductivity of electrolyte high conc. cell	1.315	S/m
pH of electrolyte high conc. cell	4.63	
Temperature of electrolyte high conc. cell	22.9	°C
El. conductivity of electrolyte low conc. cell	1.269	S/m
pH of electrolyte low conc. cell	6.77	
Temperature of electrolyte low conc. cell	22.7	°C
Mean el. conductivity of electrolytes	1.292	S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)
-1330	13.5	6.300E-04	4074	
-1321	13.1	5.460E-04	4565	
-1312	13.01	5.480E-04	4517	
-285	11.44	7.900E-04	2743	
-259	11.42	7.900E-04	2739	
-213	11.44	7.860E-04	2757	
-185	11.44	7.880E-04	2750	
-141	11.48	7.900E-04	2753	
-88	11.46	7.960E-04	2727	
-45	11.45	7.960E-04	2725	
-22	11.43	7.960E-04	2720	
0	11.41	8.000E-04	2702	2.70E-06
5	11.6	8.000E-04	2747	2.48E-06
17	11.58	8.020E-04	2735	2.57E-06
35	11.59	8.040E-04	2731	2.16E-06
54	11.6	8.040E-04	2733	2.71E-06
70	11.61	8.080E-04	2722	3.23E-06
87	11.61	8.120E-04	2708	4.21E-06
108	11.6	8.120E-04	2706	5.20E-06
131	11.61	8.160E-04	2695	6.07E-06
150	11.6	8.180E-04	2686	7.83E-06
167	11.58	8.180E-04	2681	8.90E-06
185	11.59	8.160E-04	2690	1.05E-05
205	11.6	8.200E-04	2679	1.18E-05
223	11.58	8.160E-04	2688	1.27E-05
247	11.57	8.180E-04	2679	1.38E-05

AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	3.32	4.14E-04	1506	5.14E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	3.52	4.38E-04	1509	5.13E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formaion factor
	2682			2.89E-04
TEM formation factor	Slope (mol/(m3 s)) De (m2/s)			TEM Formation factor
	1.10E-06	2.40E-13		1.20E-04

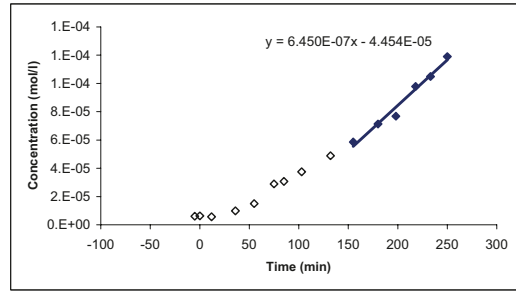
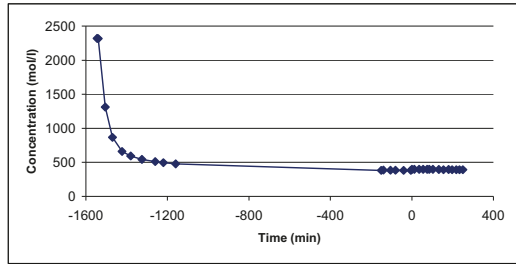
Appendix A10

Sample 1: TEM 1 M, second run

Borehole and borehole length: KFM01A 312.66-312.67

TEM event / feature	Value	Units
Start experiment	26/01/2009 date:time	
End experiment	27/01/2009 date:time	
DC main voltage	~ 25 V	
TEM Sample potential drop	6.52 V	
Initial porewater concentration	0.1 mol/l	
Initial el. conductivity of porewater	1.292 S/m	
Temperature of porewater	22.7 °C	
Tracer concentration	0.1 mol/l	
Time of injection	27/01/2009 11:50 date:time	
Volume of low concentration tracer cell	1.90E-04 m3	
Surrounding electrolyte concentration	1 mol/l	
Initial el. conductivity of electrolyte	9.09 S/m	
Initial temperature of electrolyte	23 °C	
Length of water column 1	0.133 m	
Length of water column 2	0.133 m	
Inner diameter of cell	0.0405 m	
Inner cell area	1.29E-03 m2	
Sample length	0.01025 m	
Sample diameter	0.05 m	
Sample area	1.96E-03 m2	

El. conductivity of electrolyte high conc. cell	8.81 S/m
pH of electrolyte high conc. cell	5.82
Temperature of electrolyte high conc. cell	23.4 °C
El. conductivity of electrolyte low conc. cell	8.92 S/m
pH of electrolyte low conc. cell	5.46
Temperature of electrolyte low conc. cell	23.7 °C
Mean el. conductivity of electrolytes	8.865 S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)
-1545	11.4	9.400E-04	2319	
-1540	10.66	8.800E-04	2316	
-1505	7.97	1.160E-03	1312	
-1470	6.45	1.420E-03	866	
-1423	5.83	1.680E-03	660	
-1380	5.75	1.840E-03	594	
-1325	5.77	2.020E-03	543	
-1260	5.88	2.180E-03	512	
-1220	5.95	2.280E-03	495	

-5	6.54	3.240E-03	382	6.04E-06
0	6.5	3.100E-03	397	6.30E-06
12	6.51	3.100E-03	398	5.65E-06
36	6.51	3.100E-03	398	9.83E-06
55	6.51	3.100E-03	398	1.49E-05
75	6.51	3.100E-03	398	2.89E-05
85	6.52	3.100E-03	398	3.07E-05
103	6.53	3.120E-03	396	3.75E-05
132	6.52	3.120E-03	396	4.88E-05
155	6.52	3.140E-03	393	5.86E-05
180	6.51	3.120E-03	395	7.13E-05
198	6.52	3.140E-03	393	7.68E-05
218	6.52	3.140E-03	393	9.80E-05
233	6.51	3.140E-03	393	1.05E-04
250	6.52	3.140E-03	393	1.19E-04

AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	3.05	1.82E-03	317	3.56E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	3.18	1.92E-03	313	3.61E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formation factor
	393			2.87E-04
TEM formation factor	Slope (mol/(m3 s))	De (m2/s)		TEM Formation factor
	1.08E-05	4.18E-13		2.09E-04

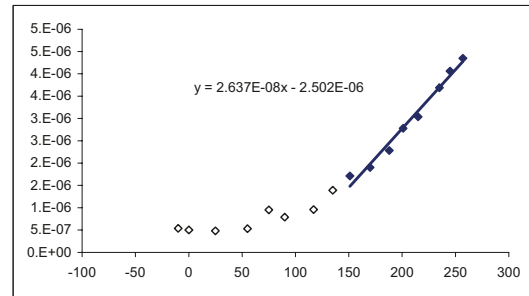
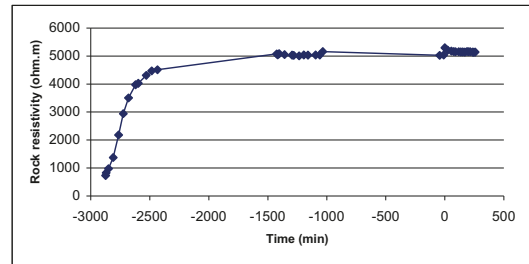
Appendix A11

Sample 1: TEM 0.03 M, third run

Borehole and borehole length: KFM01A 312.66-312.67

TEM event / feature	Value	Units
Start experiment	28/01/2009 date:time	
End experiment	30/01/2009 date:time	
DC main voltage	~ 25 V	
TEM Sample potential drop	13.40 V	
Initial porewater concentration	1 mol/l	
Initial el. conductivity of porewater	8.865 S/m	
Temperature of porewater	23.7 °C	
Tracer concentration	0.003 mol/l	
Time of injection	30/01/2009 09:25 date:time	
Volume of low concentration tracer cell	1.90E-04 m3	
Surrounding electrolyte concentration	0.03 mol/l	
Initial el. conductivity of electrolyte	0.337 S/m	
Initial temperature of electrolyte	21.9 °C	
Length of water column 1	0.133 m	
Length of water column 2	0.133 m	
Inner diameter of cell	0.0405 m	
Inner cell area	1.29E-03 m2	
Sample length	0.01025 m	
Sample diameter	0.05 m	
Sample area	1.96E-03 m2	

El. conductivity of electrolyte high conc. cell	0.393 S/m
pH of electrolyte high conc. cell	4.46
Temperature of electrolyte high conc. cell	21.8 °C
El. conductivity of electrolyte low conc. cell	0.389 S/m
pH of electrolyte low conc. cell	5.98
Temperature of electrolyte low conc. cell	21.9 °C
Mean el. conductivity of electrolytes	0.391 S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)
-2875	10.52	2.420E-03	732	
-2870	10.43	2.150E-03	828	
-2850	10.21	1.820E-03	973	
-2810	11.22	1.460E-03	1371	
-2765	13.33	1.120E-03	2179	
-10	12.93	4.820E-04	5038	5.40E-07
0	13.53	4.800E-04	5298	5.00E-07
25	13.43	4.840E-04	5214	4.80E-07
55	13.4	4.860E-04	5181	5.30E-07
75	13.4	4.880E-04	5159	9.50E-07
90	13.39	4.880E-04	5155	7.90E-07
117	13.39	4.880E-04	5155	9.60E-07
135	13.37	4.880E-04	5147	1.39E-06
151	13.43	4.900E-04	5149	1.71E-06
170	13.41	4.900E-04	5141	1.90E-06
188	13.4	4.880E-04	5159	2.28E-06
201	13.39	4.880E-04	5155	2.78E-06
215	13.39	4.880E-04	5155	3.04E-06
235	13.41	4.900E-04	5141	3.69E-06
245	13.4	4.900E-04	5137	4.06E-06
257	13.41	4.900E-04	5141	4.35E-06

AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	5.11	1.56E-04	6174	4.14E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	5.21	1.64E-04	5984	4.27E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formation factor
	5140			4.98E-04
TEM formation factor	Slope (mol/(m3 s)) De (m2/s)			TEM Formation factor
	4.40E-07	2.76E-13		1.38E-04

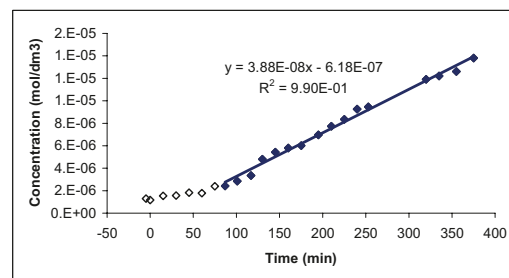
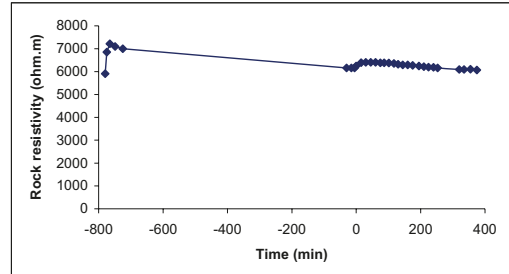
Raw data from part 2

Appendix B1

Sample 2: TEM 0.1 M, first run

Borehole and borehole length: KFM01A 312.54-312.55

TEM event / feature	Value	Units
Start experiment	03/02/2009 18:45	date:time
End experiment	04/02/2009 14:00	date:time
DC main voltage	-25	V
TEM Sample potential drop	15.50	V
Initial porewater concentration	0.1	mol/l
Initial el. conductivity of porewater	1.064	S/m
Temperature of porewater	22.1	°C
Tracer concentration	0.01	mol/l
Time of injection	04/02/2009 07:45	date:time
Volume of low concentration tracer cell	1.90E-04	m3
Surrounding electrolyte concentration	0.1	mol/l
Initial el. conductivity of electrolyte	1.078	S/m
Initial temperature of electrolyte	22.3	°C
Length of water column 1	0.133	m
Length of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m2
Sample length	0.01018	m
Sample diameter	0.05	m
Sample area	1.96E-03	m2
El. conductivity of electrolyte high conc. cell	1.18	S/m
pH of electrolyte high conc. cell	6.28	
Temperature of electrolyte high conc. cell	24.4	°C
El. conductivity of electrolyte low conc. cell	1.102	S/m
pH of electrolyte low conc. cell	6.34	
Temperature of electrolyte low conc.cell	24.6	°C
Mean el. conductivity of electrolytes	1.141	S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)
-780	15.90	5.16E-04	5908	
-775	16.06	4.50E-04	6849	
-765	16.02	4.26E-04	7218	
-749	15.98	4.32E-04	7100	
-725	15.90	4.36E-04	6999	
-30	15.43	4.80E-04	6165	
-15	15.42	4.80E-04	6161	
-5	15.43	4.80E-04	6165	1.30E-06
0	15.96	4.90E-04	6247	1.17E-06
15	15.53	4.66E-04	6393	1.55E-06
30	15.50	4.64E-04	6408	1.57E-06
45	15.49	4.64E-04	6404	1.82E-06
60	15.50	4.64E-04	6408	1.77E-06
75	15.51	4.66E-04	6385	2.40E-06
87	15.51	4.66E-04	6385	2.42E-06
101	15.50	4.66E-04	6381	2.85E-06
117	15.50	4.68E-04	6353	3.35E-06
130	15.50	4.70E-04	6326	4.80E-06
145	15.49	4.72E-04	6295	5.42E-06
160	15.49	4.72E-04	6295	5.80E-06
175	15.49	4.74E-04	6268	6.02E-06
195	15.50	4.76E-04	6246	6.96E-06
210	15.49	4.78E-04	6215	7.73E-06
225	15.50	4.80E-04	6193	8.35E-06
240	15.49	4.80E-04	6189	9.26E-06
253	15.48	4.82E-04	6160	9.46E-06
320	15.51	4.88E-04	6095	1.19E-05
335	15.50	4.88E-04	6091	1.22E-05
355	15.52	4.88E-04	6099	1.26E-05
375	15.51	4.90E-04	6070	1.38E-05

← Tracer injection

AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	5.67	2.06E-04	5274	1.66E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	5.79	2.16E-04	5135	1.71E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formaion factor
	6087			1.44E-04
TEM formation factor	Slope (mol/(m3 s))	De (m2/s)		TEM Formation factor
	6.47E-07	1.05E-13		5.27E-05

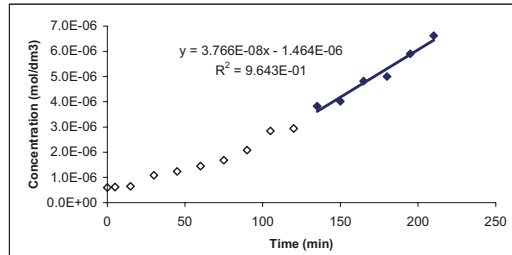
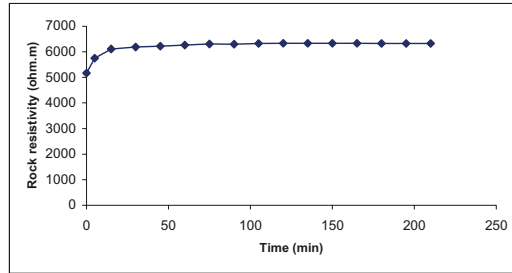
A guide how to read the spreadsheets in Appendix B is found in Appendix C.

Appendix B2

Sample 2: TEM 0.1 M, second run

Borehole and borehole length: KFM01A 312.54-312.55

TEM event / feature	Value	Units
Start experiment	04/02/2009 14:45	date:time
End experiment	04/02/2009 18:15	date:time
DC main voltage	-25	V
TEM Sample potential drop	15.51	V
Initial porewater concentration	0.1	mol/l
Initial el. conductivity of porewater	1.064	S/m
Temperature of porewater	22.1	°C
Tracer concentration	0.01	mol/l
Time of injection	04/02/2009 14:45	date:time
Volume of low concentration tracer cell	1.90E-04	m3
Surrounding electrolyte concentration	0.1	mol/l
Initial el. conductivity of electrolyte	1.078	S/m
Initial temperature of electrolyte	22.3	°C
Length of water column 1	0.133	m
Length of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m2
Sample length	0.01018	m
Sample diameter	0.05	m
Sample area	1.96E-03	m2
El. conductivity of electrolyte high conc. cell	1.12	S/m
pH of electrolyte high conc. cell	6.22	
Temperature of electrolyte high conc. cell	24.3	°C
El. conductivity of electrolyte low conc. cell	1.105	S/m
pH of electrolyte low conc. cell	6.41	
Temperature of electrolyte low conc. cell	24.3	°C
Mean el. conductivity of electrolytes	1.1125	S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)
0	15.92	5.900E-04	5169	6.00E-07
5	15.54	5.180E-04	5751	6.20E-07
15	15.49	4.860E-04	6112	6.50E-07
30	15.49	4.800E-04	6189	1.08E-06
45	15.51	4.780E-04	6223	1.24E-06
60	15.48	4.740E-04	6263	1.45E-06
75	15.52	4.720E-04	6306	1.68E-06
90	15.51	4.720E-04	6302	2.08E-06
105	15.51	4.700E-04	6329	2.84E-06
120	15.52	4.700E-04	6333	2.94E-06
135	15.52	4.700E-04	6333	3.83E-06
150	15.52	4.700E-04	6333	4.02E-06
165	15.52	4.700E-04	6333	4.82E-06
180	15.51	4.700E-04	6329	5.00E-06
195	15.5	4.700E-04	6325	5.90E-06
210	15.5	4.700E-04	6325	6.62E-06

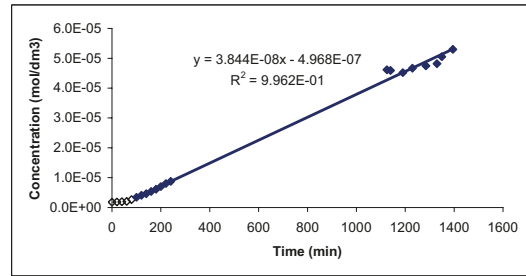
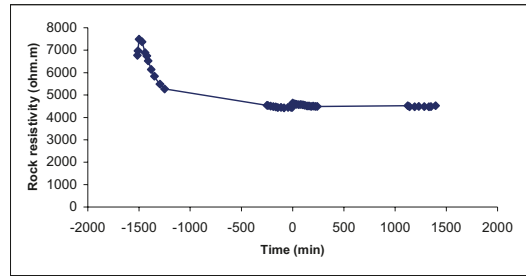
AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	5.7	2.04E-04	5353	1.68E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	5.81	2.13E-04	5225	1.72E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formaion factor
	6326			1.42E-04
TEM formation factor	Slope (mol/(m3 s)) De (m2/s)			TEM Formation factor
	6.28E-07	1.02E-13		5.11E-05

Appendix B3

Sample 3: TEM 0.05 M, first run

Borehole and borehole length: KFM02A 554.60-554.61

TEM event / feature	Value	units
Start experiment	24/02/2009 12:15	date:time
End experiment	26/02/2009 12:45	date:time
DC main voltage	-25	V
TEM Sample potential drop	13.39	V
Initial porewater concentration	0.05	mol/l
Initial el. conductivity of porewater	0.543	S/m
Temperature of porewater	22.1	°C
Tracer concentration	0.005	mol/l
Time of injection	25/02/2009 13:30	date:time
Volume of low concentration tracer cell	1.90E-04	m3
Surrounding electrolyte concentration	0.05	mol/l
Initial el. conductivity of electrolyte	0.564	S/m
Initial temperature of electrolyte	23	°C
Lenght of water column 1	0.133	m
Lenght of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m2
Sample length	0.01264	m
Sample diameter	0.05	m
Sample area	1.96E-03	m2
El. conductivity of electrolyte high conc. cell	0.593	S/m
pH of electrolyte high conc. cell	6.67	
Temperature of electrolyte high conc. cell	22.3	°C
El. conductivity of electrolyte low conc. cell	0.578	S/m
pH of electrolyte low conc. cell	6.74	
Temperature of electrolyte low conc. cell	22.3	°C
Mean el. conductivity of electrolytes	0.5855	S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)
-1515	14.62	3.326E-04	6773	
-1510	14.48	3.200E-04	6974	
-1500	14.36	2.956E-04	7491	
-1470	14.11	2.950E-04	7375	
-1440	13.84	3.096E-04	6889	
-1425	13.74	3.136E-04	6751	
-1410	13.6	3.212E-04	6522	
-1380	13.39	3.356E-04	6143	
-1350	13.19	3.476E-04	5840	
-1295	13	3.642E-04	5490	
-1250	12.8	3.730E-04	5276	
-250	13.72	4.640E-04	4538	
-240	13.35	4.520E-04	4533	
-215	13.32	4.540E-04	4503	
-190	13.31	4.560E-04	4479	
-165	13.32	4.580E-04	4463	
-145	13.32	4.600E-04	4443	
-115	13.33	4.600E-04	4447	
-85	13.33	4.620E-04	4427	
-45	13.33	4.600E-04	4447	
-15	13.35	4.600E-04	4453	
-5	13.35	4.600E-04	4453	
0	13.91	4.600E-04	4643	1.78E-06
20	13.91	4.640E-04	4602	1.88E-06
40	13.93	4.660E-04	4589	1.94E-06
60	13.88	4.660E-04	4572	2.02E-06
80	13.89	4.660E-04	4575	2.62E-06
100	13.9	4.680E-04	4559	3.39E-06
120	13.89	4.700E-04	4536	4.06E-06
140	13.89	4.720E-04	4517	4.61E-06
160	13.89	4.720E-04	4517	5.37E-06
180	13.88	4.740E-04	4494	6.12E-06
200	13.92	4.740E-04	4507	7.01E-06
220	13.92	4.760E-04	4488	8.03E-06
240	13.92	4.760E-04	4488	8.74E-06
1125	14.45	4.900E-04	4526	4.61E-05
1140	13.94	4.780E-04	4475	4.59E-05
1190	13.89	4.760E-04	4478	4.52E-05
1230	13.93	4.760E-04	4491	4.67E-05
1285	13.91	4.760E-04	4485	4.75E-05
1330	13.89	4.760E-04	4478	4.82E-05
1350	13.9	4.760E-04	4481	5.06E-05
1395	13.9	4.720E-04	4520	5.30E-05

← Injection

AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	6.86	2.77E-04	3798	4.50E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	7.01	2.86E-04	3747	4.56E-04
AC formation factor 2000 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 2000 Hz
	7.02	2.99E-04	3597	4.75E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formaion factor
	4493			3.80E-04
TEM formation factor	Slope (mol/(m3 s))	De (m2/s)		TEM Formation factor
	6.41E-07	2.98E-13		1.49E-04

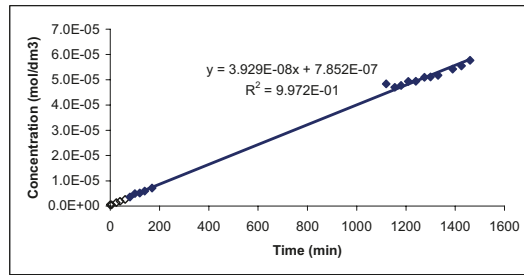
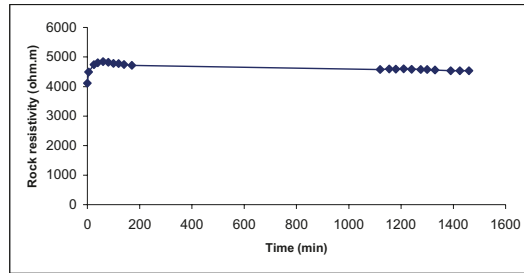
Appendix B4

Sample 3: TEM 0.05 M, second run

Borehole and borehole length: KFM02A 554.60-554.61

TEM event / feature	Value	units
Start experiment	26/02/2009 13:40	date:time
End experiment	27/02/2009 14:00	date:time
DC main voltage	-25	V
TEM Sample potential drop	14.30	V
Initial porewater concentration	0.05	mol/l
Initial el. conductivity of porewater	0.543	S/m
Temperature of porewater	22.1	°C
Tracer concentration	0.005	mol/l
Time of injection	26/02/2009 13:40	date:time
Volume of low concentration tracer cell	1.90E-04	m3
Surrounding electrolyte concentration	0.05	mol/l
Initial el. conductivity of electrolyte	0.564	S/m
Initial temperature of electrolyte	23	°C
Length of water column 1	0.133	m
Length of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m2
Sample length	0.01264	m
Sample diameter	0.05	m
Sample area	1.96E-03	m2

El. conductivity of electrolyte high conc. cell	0.604	S/m
pH of electrolyte high conc. cell	5.77	
Temperature of electrolyte high conc. cell	22.4	°C
El. conductivity of electrolyte low conc. cell	0.563	S/m
pH of electrolyte low conc. cell	6.04	
Temperature of electrolyte low conc. cell	22.3	°C
Mean el. conductivity of electrolytes	0.5835	S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)	
0	14.54	5.420E-04	4112	5.07E-07	← Injection
5	14.29	4.880E-04	4494	5.12E-07	
25	14.33	4.640E-04	4742	1.37E-06	
40	14.34	4.580E-04	4809	1.91E-06	
60	14.32	4.540E-04	4845	2.60E-06	
80	14.32	4.560E-04	4823	3.59E-06	
100	14.33	4.600E-04	4784	4.92E-06	
120	14.32	4.600E-04	4781	5.20E-06	
140	14.29	4.620E-04	4750	5.91E-06	
170	14.31	4.660E-04	4715	7.17E-06	
1120	14.2	4.760E-04	4579	4.83E-05	
1155	14.31	4.780E-04	4595	4.70E-05	
1180	14.3	4.780E-04	4592	4.77E-05	
1210	14.28	4.760E-04	4605	4.94E-05	
1240	14.28	4.780E-04	4586	4.94E-05	
1275	14.32	4.800E-04	4579	5.09E-05	
1300	14.31	4.800E-04	4576	5.11E-05	
1330	14.32	4.820E-04	4560	5.17E-05	
1390	14.31	4.840E-04	4538	5.43E-05	
1425	14.3	4.840E-04	4535	5.55E-05	
1460	14.3	4.840E-04	4535	5.77E-05	

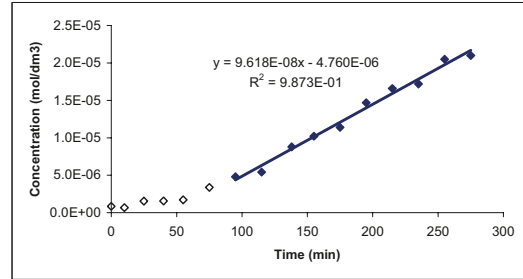
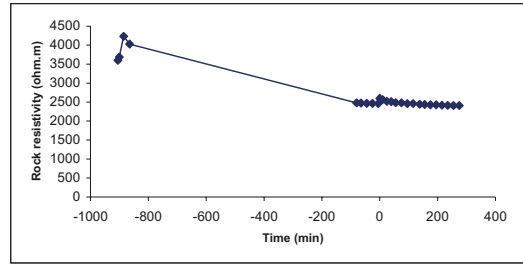
AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	6.8	2.704E-04	3852	4.45E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	6.92	2.796E-04	3790	4.52E-04
AC formation factor 2000 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 2000 Hz
	6.93	2.922E-04	3629	4.72E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formation factor
	4536			3.78E-04
TEM formation factor	Slope (mol/(m3 s))	De (m2/s)		TEM Formation factor
	6.55E-07	2.85E-13		1.43E-04

Appendix B5

Sample 4: TEM 0.1 M, first run

Borehole and borehole length: KFM01A 554.71-554.72

TEM event / feature	Value	units
Start experiment	11/02/2009 18:00	date:time
End experiment	12/02/2009 13:40	date:time
DC main voltage	-25 V	
TEM Sample potential drop	12.80 V	
Initial porewater concentration	0.1 mol/l	
Initial el. conductivity of porewater	1.064 S/m	
Temperature of porewater	22.1 °C	
Tracer concentration	0.01 mol/l	
Time of injection	12/02/2009 09:05	date:time
Volume of low concentration tracer cell	1.90E-04 m3	
Surrounding electrolyte concentration	0.1 mol/l	
Initial el. conductivity of electrolyte	~1 S/m	
Initial temperature of electrolyte	°C	
Length of water column 1	0.133 m	
Length of water column 2	0.133 m	
Inner diameter of cell	0.0405 m	
Inner cell area	1.29E-03 m2	
Sample length	0.01166 m	
Sample diameter	0.05 m	
Sample area	1.96E-03 m2	
El. conductivity of electrolyte high conc. cell	1.093 S/m	
pH of electrolyte high conc. cell	6.52	
Temperature of electrolyte high conc. cell	22.1 °C	
El. conductivity of electrolyte low conc. cell	1.041 S/m	
pH of electrolyte low conc. cell	6.32	
Temperature of electrolyte low conc. cell	22 °C	
Mean el. conductivity of electrolytes	1.067 S/m	



Time from injection (min)	potential drop (V)	current (A)	cor. resistivity (ohm.m)	iodide concentration (mol/l)
-905	15.75	7.300E-04	3601	
-900	15.25	6.900E-04	3689	
-885	15.21	6.000E-04	4236	
-865	15	6.220E-04	4028	
-80	12.41	8.320E-04	2479	
-65	12.39	8.320E-04	2475	
-45	12.38	8.340E-04	2467	
-25	12.34	8.320E-04	2465	
-5	12.37	8.360E-04	2459	8.30E-07
0	12.98	8.300E-04	2601	8.50E-07
10	12.83	8.320E-04	2564	6.70E-07
25	12.81	8.460E-04	2517	1.54E-06
40	12.8	8.460E-04	2515	1.57E-06
55	12.81	8.560E-04	2487	1.71E-06
75	12.8	8.580E-04	2480	3.36E-06
95	12.77	8.620E-04	2462	4.80E-06
115	12.82	8.660E-04	2460	5.42E-06
138	12.79	8.700E-04	2443	8.80E-06
155	12.77	8.700E-04	2439	1.02E-05
175	12.83	8.780E-04	2428	1.14E-05
195	12.82	8.780E-04	2426	1.47E-05
215	12.78	8.780E-04	2419	1.66E-05
235	12.79	8.800E-04	2415	1.72E-05
255	12.83	8.840E-04	2411	2.05E-05
275	12.81	8.840E-04	2408	2.10E-05

← Injection

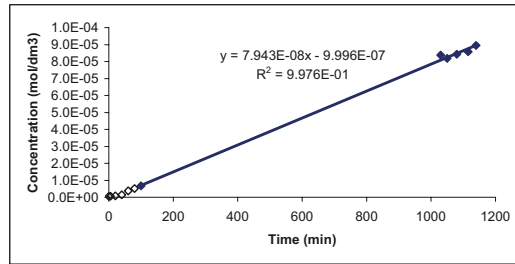
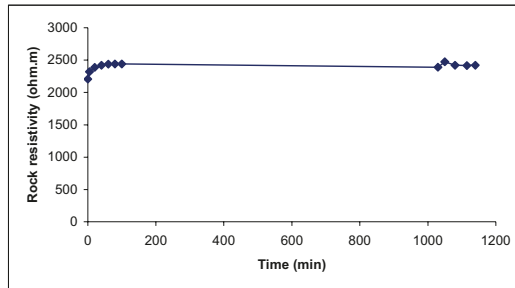
AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	5.71	4.14E-04	2290	4.09E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	5.95	4.24E-04	2331	4.02E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formaion factor
	2411			3.89E-04
TEM formation factor	Slope (mol/(m3 s))	De (m2/s)		TEM Formation factor
	1.60E-06	3.59E-13		1.80E-04

Appendix B6

Sample 4: TEM 0.1 M, second run

Borehole and borehole length: KFM01A 554.71-554.72

TEM event / feature	Value	Units
Start experiment	12/02/2009 15:00	date:time
End experiment	13/02/2009 10:00	date:time
DC main voltage	-25	V
TEM Sample potential drop	12.16	V
Initial porewater concentration	0.1	mol/l
Initial el. conductivity of porewater	1.064	S/m
Temperature of porewater	22.1	°C
Tracer concentration	0.01	mol/l
Time of injection	12/02/2009 15:00	date:time
Volume of low concentration tracer cell	1.90E-04	m3
Surrounding electrolyte concentration	0.1	mol/l
Initial el. conductivity of electrolyte	~1	S/m
Initial temperature of electrolyte		°C
Length of water column 1	0.133	m
Length of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m2
Sample length	0.01166	m
Sample diameter	0.05	m
Sample area	1.96E-03	m2
El. conductivity of electrolyte high conc. cell	1.074	S/m
pH of electrolyte high conc. cell	6.56	
Temperature of electrolyte high conc. cell	23.1	°C
El. conductivity of electrolyte low conc. cell	1.031	S/m
pH of electrolyte low conc. cell	6.33	
Temperature of electrolyte low conc. cell	22.9	°C
Mean el. conductivity of electrolytes	1.0525	S/m



time (min)	potential drop (V)	current (A)	cor. resistivity (ohm.m)	iodide concentration (mol/l)	
0	12.5	9.400E-04	2206	5.00E-07	← Injection
5	12.19	8.720E-04	2321	6.00E-07	
20	12.19	8.480E-04	2388	8.30E-07	
40	12.21	8.380E-04	2421	1.49E-06	
60	12.17	8.300E-04	2436	3.80E-06	
80	12.19	8.300E-04	2440	5.17E-06	
100	12.22	8.320E-04	2440	6.74E-06	
1030	11.71	8.140E-04	2389	8.38E-05	
1050	12.2	8.200E-04	2472	8.19E-05	
1080	12.21	8.380E-04	2421	8.43E-05	
1115	12.24	8.420E-04	2415	8.58E-05	
1140	12.26	8.420E-04	2419	8.95E-05	

AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	5.58	4.01E-04	2310	4.11E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	5.51	4.04E-04	2264	4.20E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formation factor
	2418			3.93E-04
TEM formation factor	Slope (mol/(m3 s))	De (m2/s)		TEM Formation factor
	1.32E-06	3.13E-13		1.57E-04

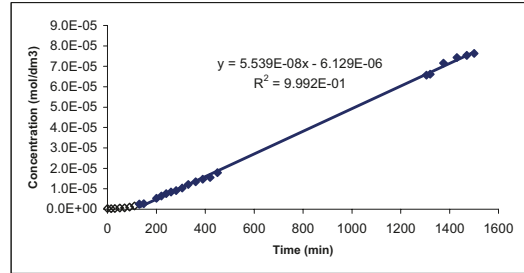
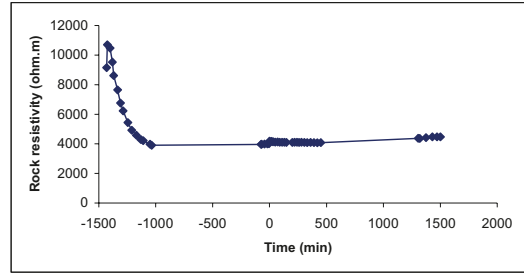
Appendix B7

Sample 5: TEM 0.05 M, first run

Borehole and borehole length: KFM02A 554.84-554.85

TEM event / feature	Value	Units
Start experiment	16/02/2009 09:40	date:time
End experiment	18/02/2009 10:30	date:time
DC main voltage	-25	V
TEM Sample potential drop	13.35	V
Initial porewater concentration	0.05	mol/l
Initial el. conductivity of porewater	0.543	S/m
Temperature of porewater	22.1	°C
Tracer concentration	0.005	mol/l
Time of injection	17/02/2009 09:30	date:time
Volume of low concentration tracer cell	1.90E-04	m3
Surrounding electrolyte concentration	0.05	mol/l
Initial el. conductivity of electrolyte	0.545	S/m
Initial temperature of electrolyte	22.3	°C
Length of water column 1	0.133	m
Length of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m2
Sample length	0.01138	m
Sample diameter	0.05	m
Sample area	1.96E-03	m2

El. conductivity of electrolyte high conc. cell	0.583	S/m
pH of electrolyte high conc. cell	6.67	
Temperature of electrolyte high conc. cell	23.1	°C
El. conductivity of electrolyte low conc. cell	0.567	S/m
pH of electrolyte low conc. cell	6.35	
Temperature of electrolyte low conc. cell	23.2	°C
Mean el. conductivity of electrolytes	0.575	S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)
-1430	15.8	2.960E-04	9148	
-1425	15.69	2.516E-04	10698	
-1400	15.27	2.500E-04	10477	
-1380	14.78	2.660E-04	9525	
-1370	14.45	2.874E-04	8613	
-1335	13.78	3.084E-04	7647	
-1310	13.25	3.352E-04	6758	
-1285	12.9	3.536E-04	6233	
-1245	12.39	3.880E-04	5448	
-1210	11.78	4.080E-04	4920	
-1170	11.57	4.300E-04	4581	
-1130	11.45	4.540E-04	4290	
-1110	11.4	4.600E-04	4214	
-1050	11.36	4.860E-04	3971	
-1035	11.34	4.940E-04	3899	
-75	12.83	5.500E-04	3963	
-70	12.74	5.440E-04	3979	
-45	12.76	5.440E-04	3985	
-20	12.77	5.420E-04	4003	
-5	12.8	5.420E-04	4013	
0	13.38	5.440E-04	4182	3.40E-07
15	13.3	5.420E-04	4172	3.00E-07
30	13.27	5.440E-04	4147	3.10E-07
50	13.29	5.480E-04	4122	5.80E-07
70	13.32	5.480E-04	4132	7.20E-07
90	13.29	5.500E-04	4107	1.04E-06
110	13.3	5.500E-04	4110	1.58E-06
130	13.29	5.500E-04	4107	2.51E-06
148	13.31	5.520E-04	4098	2.75E-06
200	13.35	5.540E-04	4096	5.38E-06
220	13.29	5.500E-04	4107	6.51E-06
240	13.3	5.500E-04	4110	7.63E-06
260	13.32	5.520E-04	4101	8.40E-06
280	13.3	5.500E-04	4110	9.17E-06
305	13.32	5.520E-04	4101	1.04E-05
330	13.33	5.540E-04	4090	1.21E-05
360	13.34	5.540E-04	4093	1.34E-05
390	13.32	5.540E-04	4086	1.47E-05
420	13.32	5.560E-04	4072	1.55E-05
450	13.33	5.540E-04	4090	1.79E-05
1305	13.95	5.420E-04	4379	6.57E-05
1320	13.29	5.180E-04	4365	6.61E-05
1375	13.33	5.120E-04	4430	7.16E-05
1430	13.34	5.080E-04	4469	7.43E-05
1470	13.31	5.060E-04	4477	7.53E-05
1500	13.3	5.060E-04	4473	7.63E-05

AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	6.75	3.09E-04	3707	4.69E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	6.89	3.19E-04	3665	4.75E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formaion factor
	4473			3.89E-04
TEM formation factor	Slope (mol/(m3 s))	De (m2/s)		TEM Formation factor
	9.23E-07	3.89E-13		1.94E-04

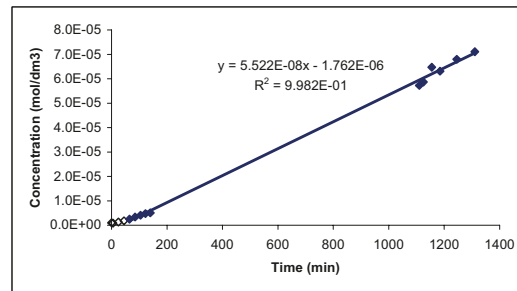
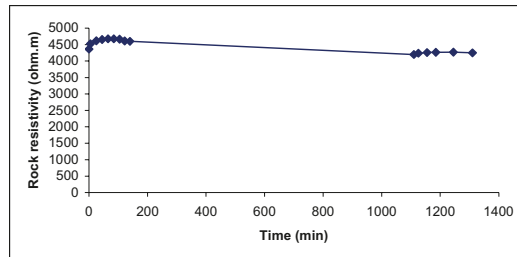
Appendix B8

Sample 5: TEM 0.05 M, second run

Borehole and borehole length: KFM02A 554.84-554.85

TEM event / feature	Value	units
Start experiment	18/02/2009 13:15	date:time
End experiment	19/02/2009 11:05	date:time
DC main voltage	-25	V
TEM Sample potential drop	13.80	V
Initial porewater concentration	0.05	mol/l
Initial el. conductivity of porewater	0.543	S/m
Temperature of porewater	22.1	°C
Tracer concentration	0.005	mol/l
Time of injection	18/02/2009 13:15	date:time
Volume of low concentration tracer cell	1.90E-04	m3
Surrounding electrolyte concentration	0.05	mol/l
Initial el. conductivity of electrolyte	0.558	S/m
Initial temperature of electrolyte	23.3	°C
Length of water column 1	0.133	m
Length of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m2
Sample length	0.01138	m
Sample diameter	0.05	m
Sample area	1.96E-03	m2

El. conductivity of electrolyte high conc. cell	0.586	S/m
pH of electrolyte high conc. cell	5.78	
Temperature of electrolyte high conc. cell	22.8	°C
El. conductivity of electrolyte low conc. cell	0.552	S/m
pH of electrolyte low conc. cell	5.99	
Temperature of electrolyte low conc. cell	22.9	°C
Mean el. conductivity of electrolytes	0.569	S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)	
0	14.17	5.520E-04	4367	1.00E-06	<-- Injection
5	13.82	5.200E-04	4523	8.50E-07	
25	13.78	5.080E-04	4618	1.33E-06	
45	13.83	5.060E-04	4653	1.83E-06	
65	13.85	5.040E-04	4679	2.51E-06	
85	13.85	5.040E-04	4679	3.42E-06	
105	13.81	5.040E-04	4665	4.14E-06	
122	13.81	5.100E-04	4609	4.81E-06	
140	13.84	5.120E-04	4601	5.08E-06	
1110	13.53	5.480E-04	4197	5.73E-05	
1125	13.8	5.540E-04	4235	5.87E-05	
1155	13.83	5.520E-04	4260	6.47E-05	
1185	13.84	5.520E-04	4263	6.31E-05	
1245	13.81	5.500E-04	4270	6.80E-05	
1310	13.79	5.520E-04	4248	7.11E-05	

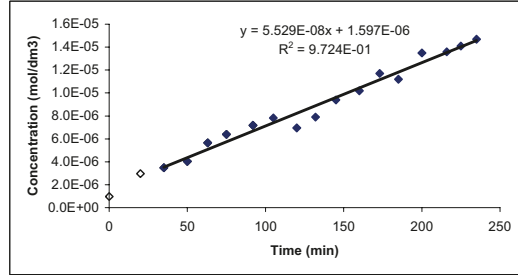
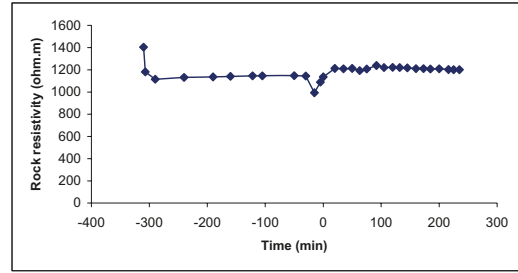
AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	6.77	2.94E-04	3910	4.49E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	6.91	3.12E-04	3759	4.68E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formation factor
	4260			4.13E-04
TEM formation factor	Slope (mol/(m3 s)) De (m2/s)			TEM Formation factor
	9.20E-07	3.75E-13		1.87E-04

Appendix B9

Sample 6: TEM 0.1 M, first run

Borehole and borehole length: KLX04 489.49-489.50

TEM event / feature	Value	Units
Start experiment	02/02/2009 09:30	date:time
End experiment	02/02/2009 18:35	date:time
DC main voltage	-25	V
TEM Sample potential drop	5.72	V
Initial porewater concentration	0.1	mol/l
Initial el. conductivity of porewater	1.064	S/m
Temperature of porewater	22.1	°C
Tracer concentration	0.01	mol/l
Time of injection	02/02/2009 14:00	date:time
Volume of low concentration tracer cell	1.90E-04	m ³
Surrounding electrolyte concentration	0.1	mol/l
Initial el. conductivity of electrolyte	1.07	S/m
Initial temperature of electrolyte	22.1	°C
Length of water column 1	0.133	m
Length of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m ²
Sample length	0.00968	m
Sample diameter	0.05	m
Sample area	1.96E-03	m ²
El. conductivity of electrolyte high conc. cell	1.197	S/m
pH of electrolyte high conc. cell	6.23	
Temperature of electrolyte high conc. cell	23.8	°C
El. conductivity of electrolyte low conc. cell	1.105	S/m
pH of electrolyte low conc. cell	6.04	
Temperature of electrolyte low conc. cell	24.1	°C
Mean el. conductivity of electrolytes	1.151	S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)
-310	4.8	6.760E-04	1404	
-307	4.01	6.680E-04	1181	
-290	3.667	6.460E-04	1115	
-240	4.02	6.980E-04	1132	
-190	4.3	7.440E-04	1136	
-160	4.49	7.740E-04	1140	
-122	4.71	8.080E-04	1146	
-105	4.79	8.220E-04	1146	
-50	5.1	8.740E-04	1147	
-30	5.17	8.880E-04	1145	
-15	4.7	9.260E-04	993	
-5	5.07	9.140E-04	1089	5.70E-07
0	5.4	9.350E-04	1135	9.60E-07
20	5.7	9.260E-04	1212	2.96E-06
35	5.72	9.320E-04	1209	3.48E-06
50	5.7	9.260E-04	1212	4.03E-06
63	5.68	9.380E-04	1192	5.65E-06
75	5.7	9.300E-04	1207	6.38E-06
92	5.73	9.120E-04	1238	7.18E-06
105	5.71	9.220E-04	1220	7.82E-06
120	5.73	9.240E-04	1221	6.95E-06
132	5.71	9.220E-04	1220	7.90E-06
145	5.7	9.220E-04	1218	9.40E-06
160	5.72	9.300E-04	1211	1.02E-05
173	5.72	9.300E-04	1211	1.17E-05
185	5.73	9.340E-04	1208	1.12E-05
200	5.72	9.320E-04	1209	1.35E-05
216	5.74	9.400E-04	1202	1.36E-05
225	5.73	9.400E-04	1200	1.41E-05
235	5.71	9.360E-04	1201	1.47E-05

AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	4.61	7.44E-04	1220	7.12E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	4.69	7.76E-04	1190	7.30E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formation factor
	1201			7.23E-04
TEM formation factor	Slope (mol/(m ³ s))	De (m ² /s)		TEM Formation factor
	9.22E-07	3.87E-13		1.93E-04

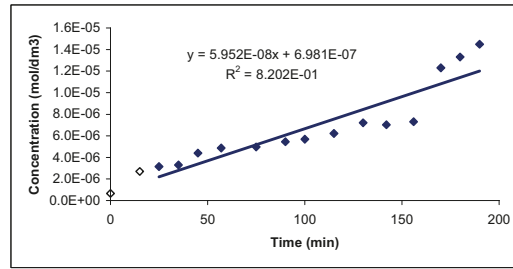
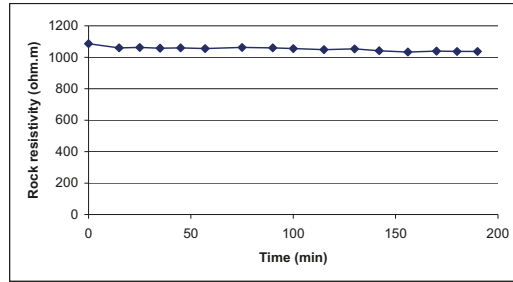
Appendix B10

Sample 6: TEM 0.1 M, second run

Borehole and borehole length: KLX04 489.49-489.50

TEM event / feature	Value	Units
Start experiment	03/02/2009 15:00	date:time
End experiment	03/02/2009 18:10	date:time
DC main voltage	-25	V
TEM Sample potential drop	5.20	V
Initial porewater concentration	0.1	mol/l
Initial el. conductivity of porewater	1.064	S/m
Temperature of porewater	22.1	°C
Tracer concentration	0.01	mol/l
Time of injection	03/02/2009 15:00	date:time
Volume of low concentration tracer cell	1.90E-04	m3
Surrounding electrolyte concentration	0.1	mol/l
Initial el. conductivity of electrolyte	1.07	S/m
Initial temperature of electrolyte	22.1	°C
Length of water column 1	0.133	m
Length of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m2
Sample length	0.00968	m
Sample diameter	0.05	m
Sample area	1.96E-03	m2

El. conductivity of electrolyte high conc. cell	1.19	S/m
pH of electrolyte high conc. cell	5.87	
Temperature of electrolyte high conc. cell	23.1	°C
El. conductivity of electrolyte low conc. cell	1.118	S/m
pH of electrolyte low conc. cell	5.91	
Temperature of electrolyte low conc. cell	22.6	°C
Mean el. conductivity of electrolytes	1.154	S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)	
0	5.7	1.030E-03	1086	6.60E-07	<-- Injection
15	5.22	9.660E-04	1060	2.70E-06	
25	5.19	9.580E-04	1063	3.15E-06	
35	5.2	9.640E-04	1058	3.29E-06	
45	5.23	9.680E-04	1060	4.39E-06	
57	5.19	9.640E-04	1056	4.86E-06	
75	5.2	9.600E-04	1062	4.97E-06	
90	5.2	9.620E-04	1060	5.45E-06	
100	5.2	9.660E-04	1056	5.68E-06	
115	5.18	9.680E-04	1049	6.22E-06	
130	5.21	9.700E-04	1053	7.21E-06	
142	5.19	9.760E-04	1042	7.03E-06	
156	5.21	9.880E-04	1033	7.30E-06	
170	5.22	9.840E-04	1040	1.23E-05	
180	5.2	9.820E-04	1038	1.33E-05	
190	5.2	9.820E-04	1038	1.45E-05	

AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	4.44	8.20E-04	1062	8.16E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	4.52	8.46E-04	1047	8.27E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formation factor
	1038			8.34E-04
TEM formation factor	Slope (mol/(m3 s))	De (m2/s)		TEM Formation factor
	9.92E-07	4.56E-13		2.28E-04

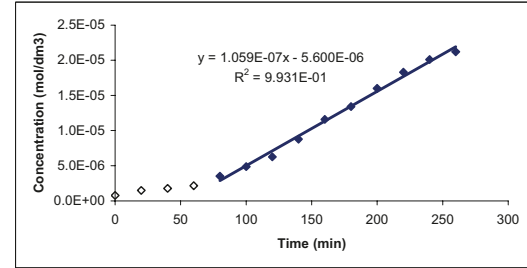
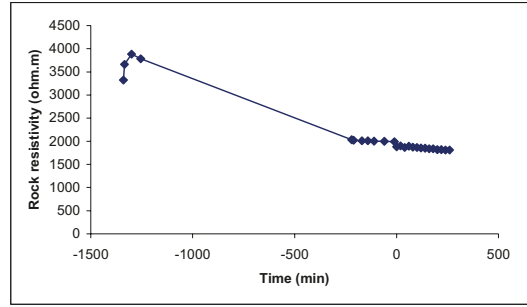
Appendix B11

Sample 6: TEM 0.1 M, third run

Borehole and borehole length: KLX04 489.49-489.50

TEM event / feature	Value	units
Start experiment	10/02/2009 14:40	date:time
End experiment	11/02/2009 17:20	date:time
DC main voltage	-25	V
TEM Sample potential drop	10.39	V
Initial porewater concentration	0.1	mol/l
Initial el. conductivity of porewater	1.064	S/m
Temperature of porewater	22.1	°C
Tracer concentration	0.01	mol/l
Time of injection	11/02/2009 13:00	date:time
Volume of low concentration tracer cell	1.90E-04	m3
Surrounding electrolyte concentration	0.1	mol/l
Initial el. conductivity of electrolyte	~1	S/m
Initial temperature of electrolyte		°C
Length of water column 1	0.133	m
Length of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m2
Sample length	0.00968	m
Sample diameter	0.05	m
Sample area	1.96E-03	m2

El. conductivity of electrolyte high conc. cell	1.101	S/m
pH of electrolyte high conc. cell	6.39	
Temperature of electrolyte high conc. cell	22.1	°C
El. conductivity of electrolyte low conc. cell	1.031	S/m
pH of electrolyte low conc. cell	6.25	
Temperature of electrolyte low conc. cell	22.3	°C
Mean el. conductivity of electrolytes	1.066	S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)
-1340	13.6	8.200E-04	3325	
-1335	13.58	7.440E-04	3663	
-1300	13.31	6.880E-04	3885	
-1255	13.16	6.980E-04	3785	
-220	10.54	1.032E-03	2032	
-210	10.49	1.032E-03	2023	
-170	10.45	1.034E-03	2011	
-140	10.44	1.034E-03	2009	
-110	10.42	1.036E-03	2001	
-60	10.41	1.036E-03	1999	
-10	10.41	1.040E-03	1991	8.20E-07
0	10.12	1.068E-03	1883	7.60E-07
20	10.39	1.086E-03	1901	1.48E-06
40	10.4	1.106E-03	1868	1.76E-06
60	10.38	1.090E-03	1892	2.15E-06
80	10.36	1.098E-03	1875	3.51E-06
100	10.39	1.106E-03	1866	4.88E-06
120	10.39	1.112E-03	1856	6.25E-06
140	10.42	1.118E-03	1851	8.78E-06
160	10.4	1.122E-03	1841	1.16E-05
180	10.37	1.120E-03	1839	1.34E-05
200	10.4	1.134E-03	1821	1.60E-05
220	10.4	1.134E-03	1821	1.83E-05
240	10.38	1.138E-03	1811	2.01E-05
260	10.39	1.138E-03	1813	2.12E-05

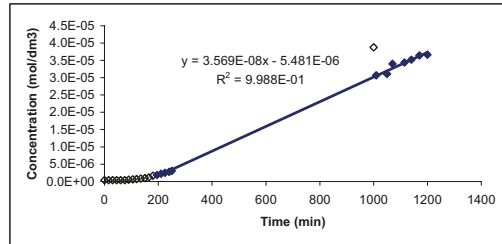
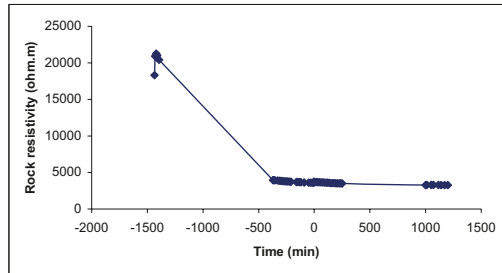
AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	3.33	6.20E-04	1050	8.93E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	3.56	6.46E-04	1079	8.70E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formaion factor
	1815			5.17E-04
TEM formation factor	Slope (mol/(m3 s)) De (m2/s)			TEM Formation factor
	1.77E-06	4.05E-13		2.02E-04

Appendix B12

Sample 7: TEM 0.05 M, first run

Borehole and borehole length: KLX04 489.61-489.62

TEM event / feature	Value	units
Start experiment	09/03/2009 15:35	date:time
End experiment	11/03/2009 11:30	date:time
DC main voltage	-25	V
TEM Sample potential drop	11.30	V
Initial porewater concentration	0.05	mol/l
Initial el. conductivity of porewater	0.543	S/m
Temperature of porewater		°C
Tracer concentration	0.005	mol/l
Time of injection	10/03/2009 15:30	date:time
Volume of low concentration tracer cell	1.90E-04	m3
Surrounding electrolyte concentration	0.05	mol/l
Initial el. conductivity of electrolyte	0.558	S/m
Initial temperature of electrolyte	24.3	°C
Length of water column 1	0.133	m
Length of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m2
Sample length	0.00985	m
Sample diameter	0.05	m
Sample area	1.96E-03	m2
El. conductivity of electrolyte high conc. cell	0.602	S/m
pH of electrolyte high conc. cell	6.94	
Temperature of electrolyte high conc. cell	24.5	°C
El. conductivity of electrolyte low conc. cell	0.565	S/m
pH of electrolyte low conc. cell	6.64	
Temperature of electrolyte low conc. cell	24.5	°C
Mean el. conductivity of electrolytes	0.5835	S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)
-1435	18.02	1.953E-04	18322	
-1430	18.28	1.736E-04	20920	
-1420	18.25	1.704E-04	21279	
-1410	18.15	1.716E-04	21013	
-1395	18	1.750E-04	20433	
-370	11.66	5.780E-04	3951	
-365	11.49	5.700E-04	3948	
-355	11.45	5.720E-04	3920	
-330	11.42	5.760E-04	3882	
-315	11.41	5.760E-04	3878	
-300	11.4	5.800E-04	3848	
-285	11.39	5.820E-04	3831	
-270	11.37	5.860E-04	3797	
-255	11.36	5.880E-04	3781	
-240	11.35	5.900E-04	3764	
-225	11.34	5.920E-04	3748	
-210	11.33	5.940E-04	3732	
-160	11.23	5.960E-04	3685	
-150	11.26	5.980E-04	3683	
-135	11.28	6.000E-04	3677	
-120	11.27	6.020E-04	3661	
-90	11.24	6.080E-04	3615	
-50	11.21	6.120E-04	3581	
-30	11.22	6.120E-04	3584	
-15	11.21	6.120E-04	3581	
-5	11.2	6.140E-04	3566	3.51E-07
0	11.75	6.180E-04	3719	4.15E-07
15	11.29	6.000E-04	3680	4.12E-07
30	11.31	6.040E-04	3662	3.72E-07
45	11.31	6.060E-04	3650	3.95E-07
60	11.3	6.080E-04	3634	4.18E-07
75	11.29	6.080E-04	3631	4.09E-07
90	11.27	6.120E-04	3600	4.83E-07
105	11.31	6.160E-04	3589	5.89E-07
120	11.29	6.160E-04	3583	6.94E-07
135	11.27	6.180E-04	3565	8.35E-07
150	11.3	6.220E-04	3551	1.01E-06
165	11.28	6.220E-04	3544	1.20E-06
180	11.3	6.240E-04	3539	1.70E-06
195	11.3	6.260E-04	3528	1.87E-06
210	11.34	6.300E-04	3518	2.20E-06
225	11.33	6.300E-04	3514	2.53E-06
240	11.32	6.300E-04	3511	2.79E-06
250	11.31	6.320E-04	3497	3.07E-06
1000	11.3	6.760E-04	3262	3.87E-05
1010	11.29	6.720E-04	3278	3.07E-05
1050	11.3	6.700E-04	3291	3.11E-05
1070	11.3	6.700E-04	3291	3.40E-05
1115	11.3	6.720E-04	3281	3.44E-05
1140	11.28	6.740E-04	3266	3.52E-05
1170	11.31	6.780E-04	3255	3.65E-05
1200	11.29	6.780E-04	3249	3.66E-05

← Injection

Calibration error

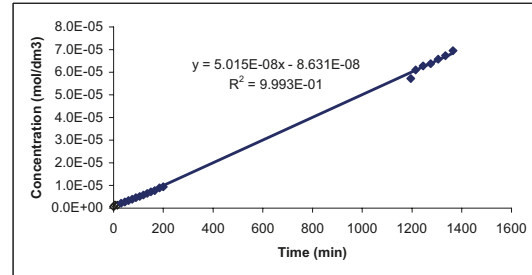
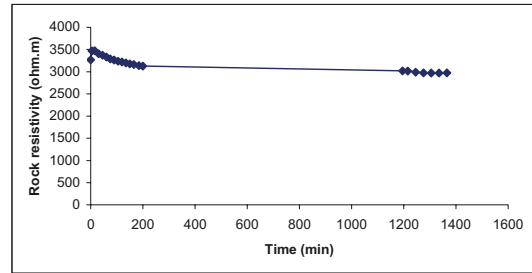
	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor
AC formation factor 10 Hz	6.5	4.540E-04	2783	6.16E-04
AC formation factor 100 Hz	6.56	4.780E-04	2665	6.43E-04
AC formation factor 2000 Hz	6.62	4.920E-04	2612	6.56E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)	3256		5.26E-04
TEM formation factor	Slope (mol/(m3 s))	6.16E-07	De (m2/s)	2.66E-13
				TEM Formation factor
				1.33E-04

Appendix B13

Sample 7: TEM 0.05 M, second run

Borehole and borehole length: KLX04 489.61-489.62

TEM event / feature	Value	units
Start experiment	11/03/2009 13:15	date:time
End experiment	12/03/2009 12:00	date:time
DC main voltage	-25	V
TEM Sample potential drop	11.47	V
Initial porewater concentration	0.05	mol/l
Initial el. conductivity of porewater	0.543	S/m
Temperature of porewater		°C
Tracer concentration	0.005	mol/l
Time of injection	11/03/2009 13:15	date:time
Volume of low concentration tracer cell	1.90E-04	m3
Surrounding electrolyte concentration	0.05	mol/l
Initial el. conductivity of electrolyte	0.558	S/m
Initial temperature of electrolyte	24.3	°C
Lenght of water column 1	0.133	m
Lenght of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m2
Sample length	0.00985	m
Sample diameter	0.05	m
Sample area	1.96E-03	m2
El. conductivity of electrolyte high conc. cell	0.604	S/m
pH of electrolyte high conc. cell	6.65	
Temperature of electrolyte high conc. cell	24.3	°C
El. conductivity of electrolyte low conc. cell	0.55	S/m
pH of electrolyte low conc. cell	6.35	
Temperature of electrolyte low conc. cell	24.3	°C
Mean el. conductivity of electrolytes	0.577	S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)	
0	12.4	7.400E-04	3269	6.02E-04	<-- Injection
5	12.01	6.760E-04	3470	1.35E-06	
15	11.56	6.500E-04	3474	1.26E-06	
30	11.33	6.500E-04	3403	2.17E-06	
45	11.3	6.540E-04	3373	2.67E-06	
60	11.3	6.620E-04	3331	3.33E-06	
75	11.33	6.720E-04	3290	3.85E-06	
90	11.28	6.740E-04	3265	4.59E-06	
105	11.31	6.820E-04	3234	5.13E-06	
120	11.29	6.840E-04	3219	5.80E-06	
135	11.32	6.900E-04	3199	6.50E-06	
150	11.3	6.940E-04	3174	7.18E-06	
165	11.29	6.960E-04	3162	7.76E-06	
185	11.33	7.040E-04	3137	8.90E-06	
200	11.32	7.060E-04	3125	9.37E-06	
1195	11.34	7.320E-04	3017	5.72E-05	
1215	11.33	7.320E-04	3014	6.10E-05	
1245	11.31	7.360E-04	2992	6.28E-05	
1275	11.31	7.400E-04	2975	6.38E-05	
1305	11.29	7.400E-04	2970	6.57E-05	
1335	11.29	7.400E-04	2970	6.73E-05	
1365	11.28	7.380E-04	2975	6.95E-05	

AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	5.75	4.040E-04	2766	6.27E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	5.85	4.300E-04	2641	6.56E-04
AC formation factor 2000 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 2000 Hz
	5.82	4.340E-04	2602	6.66E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formaion factor
	2972			5.83E-04
TEM formation factor	Slope (mol/(m3 s))	De (m2/s)		TEM Formation factor
	8.36E-07	3.56E-13		1.78E-04

Appendix B14

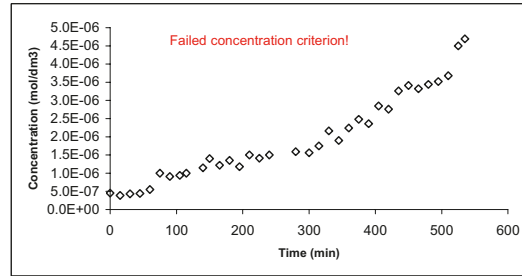
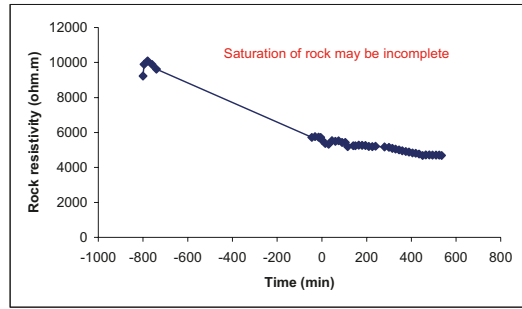
Sample 8: TEM 0.1 M, first run

Borehole and borehole length: KSH02 474.47-474.48

TEM event / feature	Value	Units
Start experiment	04/02/2009 18:40	date:time
End experiment	05/02/2009 16:55	date:time
DC main voltage	-25	V
TEM Sample potential drop	15.30	V
Initial porewater concentration	0.1	mol/l
Initial el. conductivity of porewater	1.064	S/m
Temperature of porewater	22.1	°C
Tracer concentration	0.01	mol/l
Time of injection	05/02/2009 08:00	date:time
Volume of low concentration tracer cell	1.90E-04	m3
Surrounding electrolyte concentration	0.1	mol/l
Initial el. conductivity of electrolyte	1.078	S/m **
Initial temperature of electrolyte	22.3	°C
Length of water column 1	0.133	m
Length of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m2
Sample length	0.01029	m
Sample diameter	0.05	m
Sample area	1.96E-03	m2

El. conductivity of electrolyte high conc. cell	~1	S/m
pH of electrolyte high conc. cell	not measured	
Temperature of electrolyte high conc. cell	not measured	
El. conductivity of electrolyte low conc. cell	~1	S/m
pH of electrolyte low conc. cell	not measured	
Temperature of electrolyte low conc. cell	not measured	°C
Mean el. conductivity of electrolytes	1	S/m

** Electrical conductivity used in DC formation factor



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)
-800	18.45	3.800E-04	9228	
-795	18.3	3.514E-04	9901	
-780	18.08	3.404E-04	10098	
-760	17.95	3.450E-04	9891	
-740	17.87	3.530E-04	9623	
-45	15.27	5.060E-04	5722	
-30	15.25	5.020E-04	5760	
-15	15.24	5.040E-04	5733	
-5	15.22	5.040E-04	5726	4.00E-07
0	15.5	5.280E-04	5565	4.50E-07
15	15.31	5.400E-04	5373	3.90E-07
30	15.3	5.440E-04	5330	4.30E-07
45	15.31	5.240E-04	5539	4.40E-07
60	15.31	5.280E-04	5496	5.50E-07
75	15.32	5.260E-04	5521	1.00E-06
90	15.31	5.340E-04	5434	9.10E-07
105	15.3	5.340E-04	5431	9.40E-07
115	15.29	5.580E-04	5192	1.00E-06
140	15.29	5.520E-04	5249	1.15E-06
150	15.29	5.520E-04	5249	1.40E-06
165	15.31	5.500E-04	5275	1.22E-06
180	15.33	5.520E-04	5263	1.35E-06
195	15.31	5.520E-04	5256	1.18E-06
210	15.27	5.560E-04	5204	1.50E-06
225	15.28	5.580E-04	5189	1.41E-06
240	15.31	5.560E-04	5218	1.50E-06
280	15.24	5.580E-04	5175	1.59E-06
300	15.29	5.620E-04	5155	1.56E-06
315	15.27	5.680E-04	5093	1.75E-06
330	15.29	5.740E-04	5046	2.16E-06
345	15.28	5.780E-04	5008	1.90E-06
360	15.29	5.840E-04	4959	2.24E-06
375	15.31	5.900E-04	4915	2.48E-06
390	15.3	5.940E-04	4878	2.36E-06
405	15.32	6.000E-04	4836	2.85E-06
420	15.3	6.020E-04	4813	2.76E-06
435	15.32	6.080E-04	4772	3.26E-06
450	15.31	6.180E-04	4691	3.41E-06
465	15.34	6.160E-04	4715	3.32E-06
480	15.33	6.160E-04	4712	3.44E-06
495	15.32	6.160E-04	4709	3.52E-06
510	15.31	6.160E-04	4706	3.68E-06
525	15.3	6.160E-04	4703	4.50E-06
535	15.31	6.180E-04	4691	4.69E-06

AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	not measured			
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	not measured			
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formation factor
	4700			1.97E-04
TEM formation factor	Slope (mol/(m3 s))	De (m2/s)		TEM Formation factor
	failed measurement			

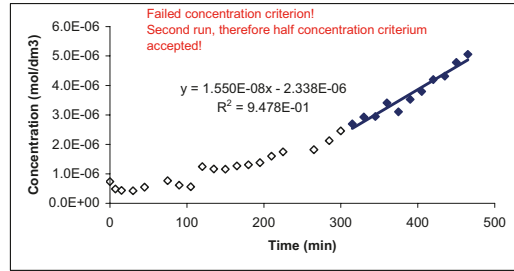
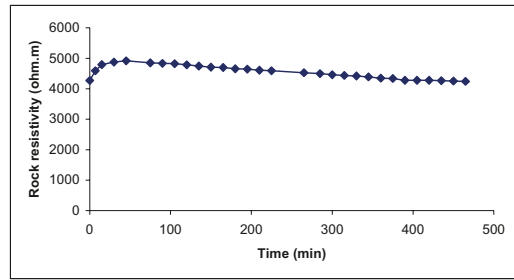
Appendix B15

Sample 8: TEM 0.1 M, second run

Borehole and borehole length: KSH02 474.47-474.48

TEM event / feature	Value	Units
Start experiment	06/02/2009 08:15	date:time
End experiment	06/02/2009 18:00	date:time
DC main voltage	-25	V
TEM Sample potential drop	14.01	V
Initial porewater concentration	0.1	mol/l
Initial el. conductivity of porewater	1.064	S/m
Temperature of porewater	22.1	°C
Tracer concentration	0.01	mol/l
Time of injection	06/02/2009 08:15	date:time
Volume of low concentration tracer cell	1.90E-04	m3
Surrounding electrolyte concentration	0.1	mol/l
Initial el. conductivity of electrolyte	1.063	S/m
Initial temperature of electrolyte	22.7	°C
Length of water column 1	0.133	m
Length of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m2
Sample length	0.01029	m
Sample diameter	0.05	m
Sample area	1.96E-03	m2

El. conductivity of electrolyte high conc. cell	1.192	S/m
pH of electrolyte high conc. cell	6.05	
Temperature of electrolyte high conc. cell	23.1	°C
El. conductivity of electrolyte low conc. cell	1.104	S/m
pH of electrolyte low conc. cell	6.04	
Temperature of electrolyte low conc. cell	24	°C
Mean el. conductivity of electrolytes	1.148	S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)
0	14	6.200E-04	4274	7.40E-07
7	14.01	5.780E-04	4591	4.90E-07
15	14.02	5.540E-04	4795	4.40E-07
30	14.003	5.440E-04	4877	4.30E-07
45	14.02	5.400E-04	4920	5.50E-07
75	14.03	5.480E-04	4851	7.70E-07
90	14.03	5.500E-04	4833	6.20E-07
105	14.05	5.520E-04	4822	5.60E-07
120	14.04	5.560E-04	4784	1.25E-06
135	14.02	5.600E-04	4743	1.17E-06
150	14.03	5.640E-04	4712	1.16E-06
165	14.03	5.660E-04	4696	1.27E-06
180	14.02	5.700E-04	4659	1.31E-06
195	14.03	5.720E-04	4646	1.38E-06
210	14.01	5.760E-04	4607	1.60E-06
225	14.01	5.780E-04	4591	1.75E-06
265	14	5.860E-04	4524	1.82E-06
285	14.01	5.900E-04	4497	2.13E-06
300	14	5.940E-04	4463	2.46E-06
315	14.02	5.980E-04	4439	2.70E-06
330	14.01	6.000E-04	4421	2.93E-06
345	14.01	6.040E-04	4392	2.95E-06
360	13.97	6.080E-04	4350	3.41E-06
375	14.02	6.120E-04	4337	3.11E-06
390	13.97	6.180E-04	4279	3.53E-06
405	14.02	6.200E-04	4281	3.80E-06
420	14.02	6.200E-04	4281	4.20E-06
435	14.02	6.220E-04	4267	4.32E-06
450	14.03	6.240E-04	4256	4.78E-06
465	14.03	6.260E-04	4242	5.06E-06

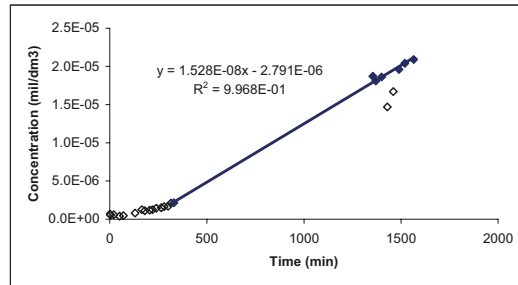
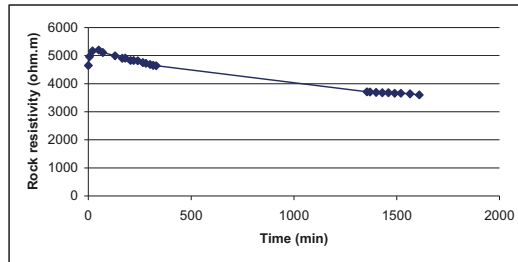
AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	5.23	2.67E-04	3703	2.35E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	5.34	2.82E-04	3579	2.43E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formaion factor
	4255			2.05E-04
TEM formation factor	Slope (mol/(m3 s))	De (m2/s)		TEM Formation factor
	2.58E-07	4.69E-14		2.35E-05

Appendix B16

Sample 8: TEM 0.1 M, third run

Borehole and borehole length: KSH02 474.47-474.48

TEM event / feature	Value	units
Start experiment	09/02/2009 10:40	date:time
End experiment	10/02/2009 13:30	date:time
DC main voltage	-25	V
TEM Sample potential drop	13.13	V
Initial porewater concentration	0.1	mol/l
Initial el. conductivity of porewater	1.064	S/m
Temperature of porewater	22.1	°C
Tracer concentration	0.01	mol/l
Time of injection	09/02/2009 10:40	date:time
Volume of low concentration tracer cell	1.90E-04	m3
Surrounding electrolyte concentration	0.1	mol/l
Initial el. conductivity of electrolyte	1.063	S/m
Initial temperature of electrolyte	22.7	°C
Length of water column 1	0.133	m
Length of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m2
Sample length	0.01029	m
Sample diameter	0.05	m
Sample area	1.96E-03	m2
El. conductivity of electrolyte high conc. cell	1.096	S/m
pH of electrolyte high conc. cell	6.48	
Temperature of electrolyte high conc. cell	22.4	°C
El. conductivity of electrolyte low conc. cell	1.032	S/m
pH of electrolyte low conc. cell	6.38	
Temperature of electrolyte low conc. cell	22.4	°C
Mean el. conductivity of electrolytes	1.064	S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)	
0	13.5	5.500E-04	4647	6.50E-07	
5	13.09	5.000E-04	4959	5.60E-07	
20	13.08	4.800E-04	5163	6.00E-07	
50	13.12	4.780E-04	5200	4.10E-07	
70	13.11	4.860E-04	5110	4.60E-07	
130	13.23	5.020E-04	4992	8.00E-07	
165	13.1	5.060E-04	4903	1.26E-06	
180	13.12	5.060E-04	4911	1.12E-06	
205	13.1	5.140E-04	4826	1.19E-06	
220	13.15	5.160E-04	4826	1.25E-06	
240	13.12	5.160E-04	4815	1.44E-06	
265	13.15	5.240E-04	4752	1.51E-06	
280	13.12	5.260E-04	4722	1.65E-06	
300	13.12	5.300E-04	4687	1.70E-06	
315	13.12	5.340E-04	4651	2.10E-06	
330	13.13	5.360E-04	4637	2.15E-06	
1355	13.36	6.800E-04	3712	1.87E-05	
1370	13.1	6.680E-04	3705	1.81E-05	
1400	13.09	6.700E-04	3691	1.86E-05	
1430	13.07	6.720E-04	3674	1.47E-05	Calibration error
1460	13.13	6.740E-04	3680	1.67E-05	Calibration error
1490	13.09	6.760E-04	3658	1.96E-05	
1520	13.09	6.760E-04	3658	2.04E-05	
1565	13.09	6.800E-04	3636	2.09E-05	
1610	13.12	6.880E-04	3602	2.25E-05	

AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	5.59	3.36E-04	3138	3.00E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	5.72	3.47E-04	3108	3.02E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formation factor
	3632			2.59E-04
TEM formation factor	Slope (mol/(m3 s))	De (m2/s)		TEM Formation factor
	2.55E-07	4.92E-14		2.46E-05

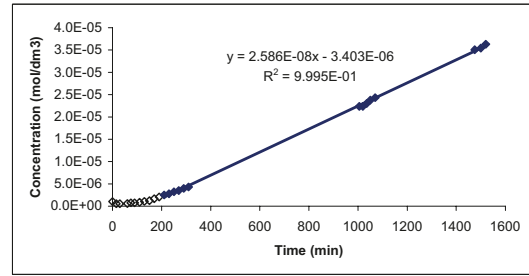
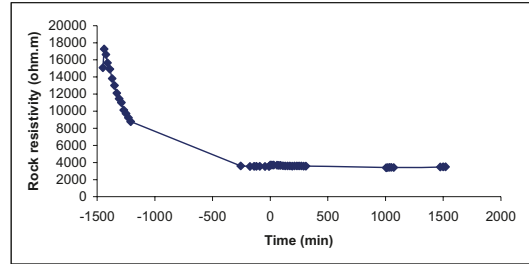
Appendix B17

Sample 9: TEM 0.05 M, first run

Borehole and borehole length: KSH02 474.66-474.67

TEM event / feature	Value	Units
Start experiment	02/03/2009 13:20	date:time
End experiment	04/03/2009 14:50	date:time
DC main voltage	-25	V
TEM Sample potential drop	15.47	V
Initial porewater concentration	0.05	mol/l
Initial el. conductivity of porewater	0.543	S/m
Temperature of porewater		°C
Tracer concentration	0.005	mol/l
Time of injection	03/03/2009 13:30	date:time
Volume of low concentration tracer cell	1.90E-04	m ³
Surrounding electrolyte concentration	0.05	mol/l
Initial el. conductivity of electrolyte	0.564	S/m
Initial temperature of electrolyte		°C
Lenght of water column 1	0.133	m
Lenght of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m ²
Sample length	0.01027	m
Sample diameter	0.05	m
Sample area	1.96E-03	m ²

El. conductivity of electrolyte high conc. cell	0.602	S/m
pH of electrolyte high conc. cell	7.09	
Temperature of electrolyte high conc. cell	22.3	°C
El. conductivity of electrolyte low conc. cell	0.546	S/m
pH of electrolyte low conc. cell	6.67	
Temperature of electrolyte low conc. cell	22.3	°C
Mean el. conductivity of electrolytes	0.574	S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)
-1450	17.65	2.226E-04	15091	
-1440	17.19	1.894E-04	17283	
-1425	16.97	1.942E-04	16638	
-1410	16.65	2.024E-04	15659	
-1390	17.01	2.168E-04	14932	
-1370	16.73	2.304E-04	13814	
-1350	16.47	2.408E-04	13008	
-1330	16.16	2.538E-04	12105	
-1310	15.94	2.644E-04	11457	
-1290	15.98	2.756E-04	11017	
-1270	15.42	2.890E-04	10132	
-1250	15.25	2.978E-04	9722	
-1230	15.05	3.094E-04	9231	
-1210	14.82	3.204E-04	8775	
-255	11.3	5.900E-04	3593	
-175	11.29	5.980E-04	3541	
-140	11.28	5.960E-04	3550	
-120	11.3	5.960E-04	3556	
-90	11.32	5.960E-04	3563	
-45	11.32	6.000E-04	3538	
-10	11.32	6.000E-04	3538	
0	11.9	6.020E-04	3711	4.75E-07
15	11.89	6.040E-04	3695	1.02E-06
30	11.89	6.040E-04	3695	5.67E-07
60	11.88	6.060E-04	3679	5.72E-07
75	11.88	6.080E-04	3667	5.79E-07
90	11.88	6.080E-04	3667	7.57E-07
110	11.8	6.100E-04	3630	7.76E-07
130	11.79	6.140E-04	3602	8.90E-07
150	11.81	6.160E-04	3597	1.09E-06
170	11.8	6.160E-04	3594	1.25E-06
190	11.81	6.180E-04	3585	1.67E-06
210	11.79	6.160E-04	3590	2.06E-06
230	11.79	6.160E-04	3590	2.50E-06
250	11.8	6.160E-04	3594	2.78E-06
270	11.8	6.160E-04	3594	3.23E-06
290	11.8	6.180E-04	3582	3.52E-06
310	11.82	6.180E-04	3588	3.98E-06
1005	11.61	6.400E-04	3399	4.31E-06
1020	11.8	6.460E-04	3424	2.24E-05
1035	11.81	6.460E-04	3426	2.24E-05
1050	11.81	6.460E-04	3426	2.30E-05
1070	11.83	6.480E-04	3422	2.38E-05
1475	11.77	6.340E-04	3481	2.43E-05
1500	11.79	6.320E-04	3498	3.50E-05
1520	11.8	6.320E-04	3501	3.54E-05
				3.63E-05

← Injection

AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	6.39	4.060E-04	2940	5.93E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	6.52	4.180E-04	2913	5.98E-04
AC formation factor 2000 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 2000 Hz
	6.53	3.980E-04	3068	5.68E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formaion factor
	3493			4.99E-04
TEM formation factor	Slope (mol/(m ³ s))	De (m ² /s)		TEM Formation factor
	4.31E-07	1.41E-13		7.05E-05

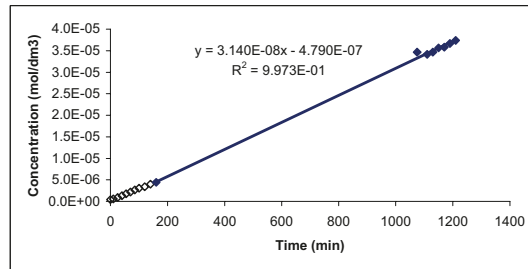
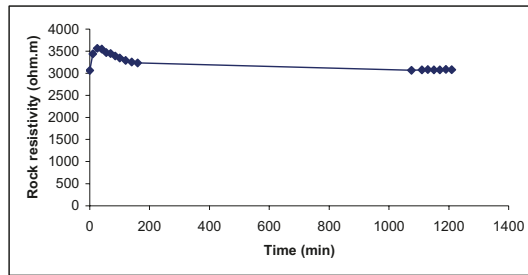
Appendix B18

Sample 9: TEM 0.05 M, second run

Borehole and borehole length: KSH02 474.66-474.67

TEM event / feature	Value	Units
Start experiment	04/03/2009 15:20	date:time
End experiment	05/03/2009 11:30	date:time
DC main voltage	-25	V
TEM Sample potential drop	11.80	V
Initial porewater concentration	0.05	mol/l
Initial el. conductivity of porewater	0.543	S/m
Temperature of porewater		°C
Tracer concentration	0.005	mol/l
Time of injection	04/03/2009 15:20	date:time
Volume of low concentration tracer cell	1.90E-04	m3
Surrounding electrolyte concentration	0.05	mol/l
Initial el. conductivity of electrolyte	0.564	S/m
Initial temperature of electrolyte		°C
Length of water column 1	0.133	m
Length of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m2
Sample length	0.01027	m
Sample diameter	0.05	m
Sample area	1.96E-03	m2

El. conductivity of electrolyte high conc. cell	0.603	S/m
pH of electrolyte high conc. cell	6.52	
Temperature of electrolyte high conc. cell	22.4	°C
El. conductivity of electrolyte low conc. cell	0.554	S/m
pH of electrolyte low conc. cell	6.32	
Temperature of electrolyte low conc. cell	22.4	°C
Mean el. conductivity of electrolytes	0.5785	S/m



time (min)	potential drop (V)	current (A)	cor. resistivity (ohm.m)	iodide concentration (mol/l)	
0	11.79	7.200E-04	3062	4.25E-07	
10	11.81	6.440E-04	3438	5.78E-07	
25	11.82	6.220E-04	3565	9.21E-07	
40	11.76	6.220E-04	3546	1.31E-06	
55	11.8	6.380E-04	3468	1.76E-06	
70	11.81	6.420E-04	3449	2.21E-06	
85	11.8	6.520E-04	3392	2.66E-06	
100	11.79	6.600E-04	3347	3.07E-06	
120	11.77	6.700E-04	3290	3.40E-06	
140	11.81	6.800E-04	3252	4.03E-06	
160	11.77	6.820E-04	3231	4.43E-06	
1075	11.84	7.220E-04	3067	3.46E-05	← Injection
1110	11.81	7.180E-04	3077	3.42E-05	
1130	11.8	7.160E-04	3083	3.46E-05	
1150	11.81	7.180E-04	3077	3.57E-05	
1170	11.81	7.180E-04	3077	3.58E-05	
1190	11.82	7.160E-04	3088	3.67E-05	
1210	11.82	7.180E-04	3079	3.74E-05	

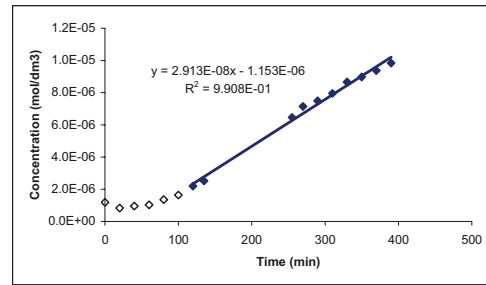
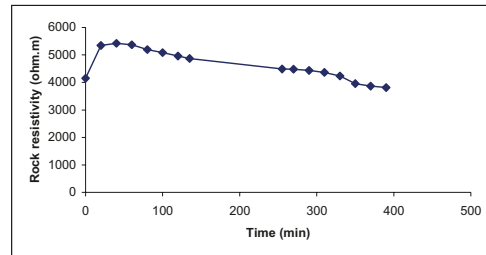
AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	5.83	4.020E-04	2704	6.39E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	5.92	4.140E-04	2666	6.48E-04
AC formation factor 2000 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 2000 Hz
	5.99	4.020E-04	2781	6.22E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formation factor
	3081			5.61E-04
TEM formation factor	Slope (mol/(m3 s))	De (m2/s)		TEM Formation factor
	5.23E-07	2.24E-13		1.12E-04

Appendix B19

Sample 9: TEM 0.05 M, third run

Borehole and borehole length: KSH02 474.66-474.67

TEM event / feature	Value	Units
Start experiment	06/03/2009 08:30	date:time
End experiment	06/03/2009 15:00	date:time
DC main voltage	-25	V
TEM Sample potential drop	13.30	V
Initial porewater concentration	0.05	mol/l
Initial el. conductivity of porewater	0.543	S/m
Temperature of porewater		°C
Tracer concentration	0.005	mol/l
Time of injection	06/03/2009 08:30	date:time
Volume of low concentration tracer cell	1.90E-04	m ³
Surrounding electrolyte concentration	0.05	mol/l
Initial el. conductivity of electrolyte	0.558	S/m
Initial temperature of electrolyte	24.3	°C
Length of water column 1	0.133	m
Length of water column 2	0.133	m
Inner diameter of cell	0.0405	m
Inner cell area	1.29E-03	m ²
Sample length	0.01027	m
Sample diameter	0.05	m
Sample area	1.96E-03	m ²
El. conductivity of electrolyte high conc. cell	0.71	S/m
pH of electrolyte high conc. cell	6.63	
Temperature of electrolyte high conc. cell	24.5	°C
El. conductivity of electrolyte low conc. cell	0.56	S/m
pH of electrolyte low conc. cell	7.58	
Temperature of electrolyte low conc. cell	24.5	°C
Mean el. conductivity of electrolytes	0.635	S/m



Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)
0	13.1	5.940E-04	4154	1.18E-06
20	13.29	4.700E-04	5344	8.27E-07
40	13.26	4.620E-04	5425	9.53E-07
60	13.3	4.680E-04	5371	1.03E-06
80	13.31	4.840E-04	5195	1.35E-06
100	13.3	4.940E-04	5085	1.64E-06
120	13.29	5.060E-04	4959	2.19E-06
135	13.32	5.160E-04	4873	2.52E-06
255	13.28	5.580E-04	4488	6.46E-06
270	13.31	5.600E-04	4482	7.14E-06
290	13.27	5.640E-04	4436	7.49E-06
310	13.29	5.740E-04	4364	7.95E-06
330	13.31	5.920E-04	4236	8.66E-06
350	13.28	6.320E-04	3955	8.98E-06
370	13.32	6.480E-04	3868	9.37E-06
390	13.3	6.560E-04	3814	9.84E-06

AC formation factor 10 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
	5.97	3.490E-04	3208	4.91E-04
AC formation factor 100 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 100 Hz
	6.09	3.620E-04	3154	4.99E-04
AC formation factor 2000 Hz	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 2000 Hz
	6.08	3.820E-04	2981	5.28E-04
DC formation factor	Mean 3 corrected resistivity (ohm.m)			DC Formation factor
	3879			4.06E-04
TEM formation factor	Slope (mol/(m ³ s))	De (m ² /s)		TEM Formation factor
	4.89E-07	1.87E-13		9.36E-05

Guide how to read raw data spread sheet

In the spread sheet below there are explanations helping the reader understanding what data represents and from where data are taken.

Sample no.: NaCl background electrolyte concentration; first, second or third run

Borehole and borehole length sample is taken from:

TEM event / feature	Value	Units
Start experiment		date:time
End experiment		date:time
DC main voltage (potential drop over the entire cell)		V
Potential drop over the studied sample		V
NaCl concentration in pore water at initiation of trace test		mol/l
EC of solution the sample is equilibrated with prior to tracer test		S/m
Temperature of porewater		°C
Iodide tracer concentration in the source electrolyte		mol/l
Time of tracer injection		date:time
Volume of low concentration tracer cell		m3
Surrounding electrolyte NaCl concentration		mol/l
EC of solution the sample prior to the tracer test		S/m
Initial temperature of electrolyte surrounding the sample		°C
Length of water column 1, between potential electrode and sample		m
Length of water column 2, between potential electrode and sample		m
Inner diameter of the TEM cylinder		m
Inner area of the TEM cylinder		m2
Sample length		m
Sample diameter		m
Sample area		m2

Rock resistivity = corrected resistivity

Initial values and circumstances for the experiment	Value	Units
Start experiment		date:time
End experiment		date:time
DC main voltage (potential drop over the entire cell)		V
Potential drop over the studied sample		V
NaCl concentration in pore water at initiation of trace test		mol/l
EC of solution the sample is equilibrated with prior to tracer test		S/m
Temperature of porewater		°C
Iodide tracer concentration in the source electrolyte		mol/l
Time of tracer injection		date:time
Volume of low concentration tracer cell		m3
Surrounding electrolyte NaCl concentration		mol/l
EC of solution the sample prior to the tracer test		S/m
Initial temperature of electrolyte surrounding the sample		°C
Length of water column 1, between potential electrode and sample		m
Length of water column 2, between potential electrode and sample		m
Inner diameter of the TEM cylinder		m
Inner area of the TEM cylinder		m2
Sample length		m
Sample diameter		m
Sample area		m2

TEM tracer test breakthrough curve

$y = 1.206E-07x - 8.090E-06$
 $R^2 = 9.962E-01$

Final values of surrounding electrolytes	Value	Units
El. conductivity of electrolyte high conc. cell		S/m
pH of electrolyte high conc. cell		
Temperature of electrolyte high conc. cell		°C
El. conductivity of electrolyte low conc. cell		S/m
pH of electrolyte low conc. cell		
Temperature of electrolyte low conc. cell		°C
Mean el. conductivity of the two surrounding electrolytes		S/m

Raw data measured during the experiment	Time from injection (min)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	Iodide concentration (mol/l)
The time relative to tracer injection					
The potential drop over the studied sample,					
The current running through the cell					
The rock resistivity, corrected for potential drop in water columns					
Iodide concentration in low concentration tracer compartment					
	-140	10.44	1.034E-03	2009	
	-110	10.42	1.036E-03	2001	
	-60	10.41	1.036E-03	1999	
	-10	10.41	1.040E-03	1991	8.20E-07
	0	10.12	1.068E-03	1883	7.60E-07
	20	10.39	1.086E-03	1901	1.48E-06
	40	10.4	1.106E-03	1868	1.76E-06
	60	10.38	1.096E-03	1892	2.15E-06
	80	10.36	1.058E-03	1875	3.51E-06
	100	10.39	1.106E-03	1866	4.88E-06
	120	10.39	1.112E-03	1856	6.25E-06
	140	10.42	1.118E-03	1851	8.78E-06
	160	10.4	1.122E-03	1841	1.16E-05
	180	10.37	1.120E-03	1839	1.34E-05
	200	10.4	1.134E-03	1821	1.60E-05

Formation factor and apparent formation factor (also raw data)	Potential drop (V)	Current (A)	Cor. resistivity (ohm.m)	AC formation factor 10 Hz
The potential drop over the studied sample,				
The current running through the cell				
The rock resistivity, corrected for potential drop in water columns				
Obtained AC apparent formation factor at 10 or 100 Hz				
AC formation factor 10 Hz	3.33	6.20E-04	1050	8.93E-04
AC formation factor 100 Hz	3.56	6.46E-04	1079	8.70E-04
Mean 3 corrected resistivity (ohm.m)				
Mean value of last three corrected resistivities				
DC Formation factor				
DC formation factor	1815			5.17E-04
Slope (mol/(m3 s)) De (m2/s)				
Slope of steady state part corrected for volume, slope can be used for obtaining N				
De calculated from equation				
TEM formation factor	1.77E-06	4.05E-13		2.02E-04
TEM formation factor calculated from equation				

$$N_{\mu} = - \frac{FzD_{\mu}}{RT} C_p \frac{dU}{dx} = - Ff \cdot \frac{zD_{\mu}}{RT} C_p \frac{dU}{dx}$$

Test with impervious sample

Two studies were made using an impervious Plexiglas slab instead of the central rock sample in the TEM cell. The aims of the studies were:

- 1) To confirm that there is no substantial void space between the rock sample, the sealing ring, and the TEM cylinder. In such void space the electrical current would be conducted and as a result the obtained rock resistivity would be underestimated.
- 2) To confirm that the TEM equipment does not significantly disturb the rock resistivity measurements. Especially for the AC measurements one can expect that capacitance effects in the filter rocks (and possibly other part of the equipment) give rise to an underestimated rock resistivity.

Figure D-1 shows the development of the Plexiglas/sealing ring resistance as measured by direct current. In the measurements the background electrolyte of the TEM equipment was 0.05 M NaCl.

The fact that it takes so long time to stabilise the system may indicate that there are polarisation effects. In any case, the resistance should be compared with that if a typical rock sample placed in the equipment. If using the same background electrolyte, then the rock sample resistance is about 10,000 – 20,000 ohm. From this one can conclude that there is no significant void space between the sealing ring and the TEM equipment.

To test that there is no significant void space between the sealing ring and the rock sample, comparative measurements were made. In these measurements the sealing ring was either fitted normally on the rock sample, or glued to the rock sample. No significant differences in measured rock sample/sealing ring resistance could be seen, and it was thus concluded that there is no significant void space between the sealing ring and rock sample.

When measuring the resistance of the setup using AC, with the power supply connected to the potential electrodes, the resistance decreased with increasing frequency. For 10, 100, and 2,000 Hz, the resistances were $2.2 \cdot 10^6$, $2.0 \cdot 10^6$, and $3.1 \cdot 10^5$ ohm, respectively. This indicates capacitance effects, for example in the filter rocks. In the context of the resistivity of a typical rock sample, the influence from these capacitance effects are insignificant at 10 and 100 Hz, and minor at 2,000 Hz.

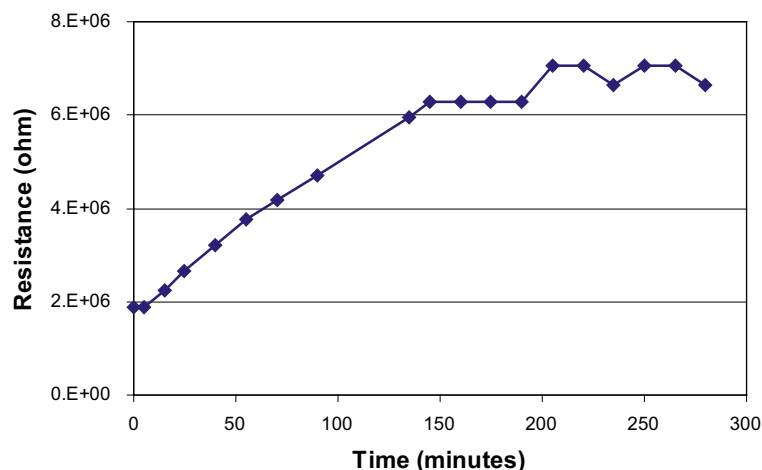


Figure D-1. Development of the Plexiglas/sealing ring resistance as measured by DC.