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85-19

Evaluation of single-hole hydraulic tests in fractured crystalline rock by steady-state and transient methods.

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Swedish Geological Company, Uppsala

December 1985

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SWEDISH GEOLOGICAL COMPANY
Division of Engineering Geology
Client: SKB

REPORT
ID-no: IRAP 85251
Date: December 1985

EVALUATION OF SINGLE-HOLE HYDRAULIC TESTS IN FRACTURED CRYSTALLINE ROCK BY STEADY-STATE AND TRANSIENT METHODS

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ABSTRACT

The results from a large number of single-hole packer tests in crystalline rock from three test sites in Sweden have been analysed statistically. Average hydraulic conductivity values for 25 m long test intervals along boreholes with a maximal length of about 700 m are used in this study. A comparison between steady state and transient analysis of the same test data has been performed.

The mean vaule of the hydraulic conductivity determined from steady state analysis was found to be about two to three times higher compared to values obtained in transient analysis. However, in some cases the steady state analysis resulted in 10 to 20 times higher values compared to the transient analysis. Such divergence between the two analysis methods may be caused by deviations from the assumed flow pattern, borehole skin effects and influence of hydraulic boundaries.

CONTENTS

1. INTRODUCTION

Site investigations in Sweden for a repository for spent nuclear fuel started 1977. Since then eight sites have been investigated. During recent years investigations of four sites have been performed according to a standard program adapted to the local conditions.

In the investigation phase deep boreholes down to 500-700 m have been drilled as core boreholes with a diameter of 56 mm. Up to 15 such holes have been drilled within each study site. The core boreholes have been located and directed in such a manner as to obtain the best possible information on the geological and hydrogeological properties of the deep sited rock mass and on the character and water content of fracture zones.

The hydraulic conductivity of the rock has been determined by means of single-hole water injection tests, by which water is injected into sealed-off sections in the boreholes. The sections are sealed off by expanding rubber packers against the borehole walls.

Data on hydraulic conductivity from single-hole double-packer tests from three sites in crystalline rock in Sweden have been used in the current study. The studied test sites are Fjällveden, Gideå and Kamlunge (Fig. 1).

At the Fjällveden test site the main type of rock is a veined gneiss with a northeast-southwest strike of foliation. The fracture frequency is 4 fractures per meter within the upper 100 m and 1.8 fractures per meter below 300 m /1/. The Gideå test site consists of a veined gneiss of northeast-southwest strike of foliation. The fracture frequency is more than 4.0 fracture per meter to a depth of 400 m. Below the 500 m level the frequency is 2.0 fractures per meter /1/.

At the Kamlunge test site the most common rock types are gneisses and red granite. The fracture frequency is more than 4.0 fractures per meter down to 200 m level. Below 300 m level the fracture frequency is approximately 2.0 /1/.

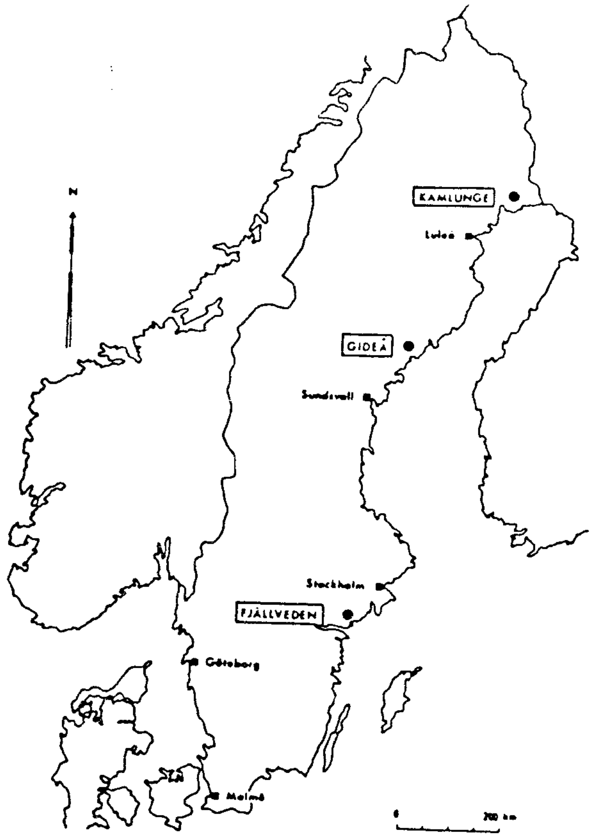

Figure 1. Map showing the studied sites

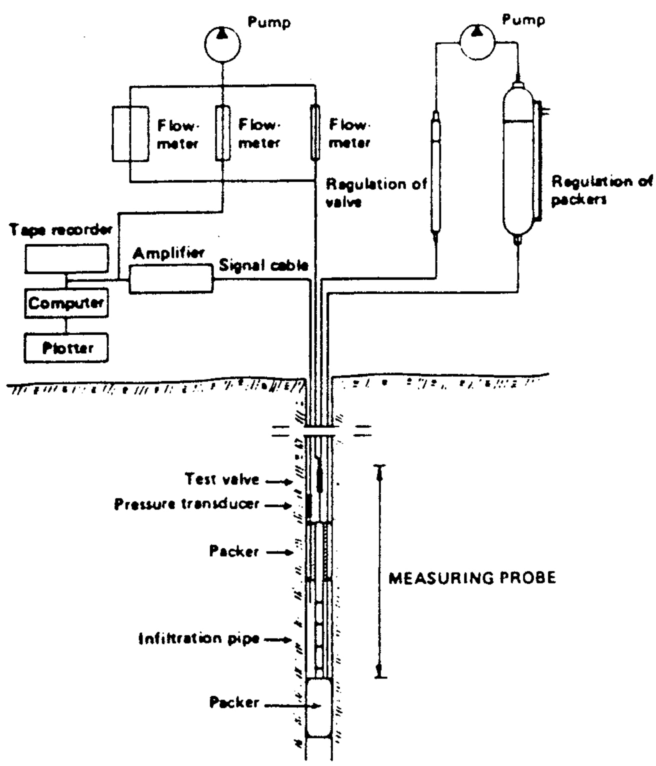

Figure 2. General configuration of the test equipment

2. HYDRAULIC TESTS

In the Swedish standard program for site investigation for disposal of nuclear waste, single-hole packer tests are performed in all deep boreholes /1/. The borehole length normally ranges from 600 m to 800 m and the diameter is 56 mm. The standard test intervals (packer spacing) are 20 or 25 m long. These tests are followed by detailed tests of intervals with high hydraulic conductivity using a packer spacing of 5 or 10 m.

Water injection tests with constant head followed by a fall-off phase are performed. The injection and fall-off phase normally have a duration of 2 hours each. During the injection phase the decline in flow rate is monitored continously.

During the fall-off phase the pressure decline after shut-in is monitored. The equipment assembly is schematically shown in Fig. 2.

3. ANALYSIS METHODS

3.1 Steady-state analysis

The hydraulic conductivity can be calculated from steady-state tests using an equation of the form /2/.

$$K = \frac{Q}{L \cdot H_o} \times C \qquad (1)$$

where K = hydraulic conductivity (m/s)
Q = flow rate (m^3/s)
L = length of test interval (m)
H_o = injection head (m)

C is a dimensionless constant which varies depending on the assumed flow pattern in the test interval and the estimated radius of influence of the test. The flow pattern can either be elliptical, radial or alternatively radial near the borehole becoming spherical at a certain distance from the active borehole. The relevance of the factor C in testing of fractured non-porous rock is questionable /3/.

In this study approximative values of the hydraulic conductivity have been calculated according to equation (1) assuming a steady flow rate by the end of the injection tests and assuming C is equal to one /4/. Two different conductivity values are calculated from each test by using the actual flow rate at two different times on the transient flow rate curve, see Fig 3. The hydraulic conductivity (KPR) corresponding to the flow rate at 2 hours of injection is defined as

$$KPR = \frac{Q\ (2\ hrs)}{L \cdot H_o} \qquad (2)$$

To compare the results with those obtained from shorter injection times the hydraulic conductivity (K15) corresponding to 15 minutes of injection is defined:

$$K15 = \frac{Q(15\ mins)}{L \cdot H_o} \qquad (3)$$

3.2 Transient analysis

The theoretical decline in flow rate during a constant head test is shown in Fig. 4. If the tested interval has an infinite extent in the radial direction the response will follow the curve marked $r_{eD} = \infty$ (infinite dimensionless outer radius). This curve corresponds to the Jacob and Lohman solution /5/. If the interval is of finite extent the flow rate will decline rapidly. If leakage occurs into the fracture system or rock matrix the flow rate will tend to stabilize.

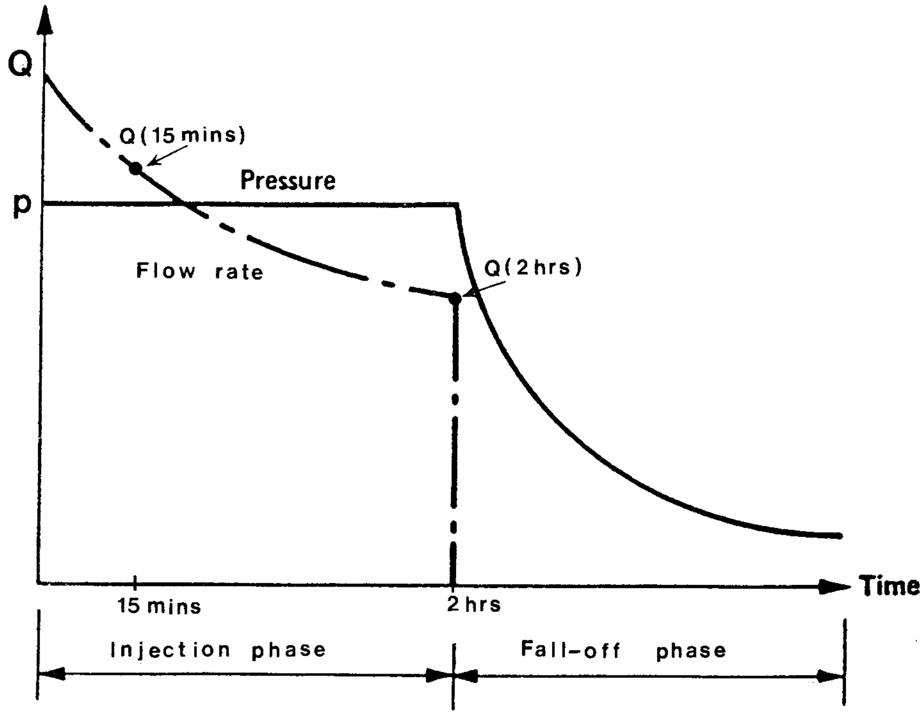

Figure 3 Different phases in single-hole hydraulic testing.

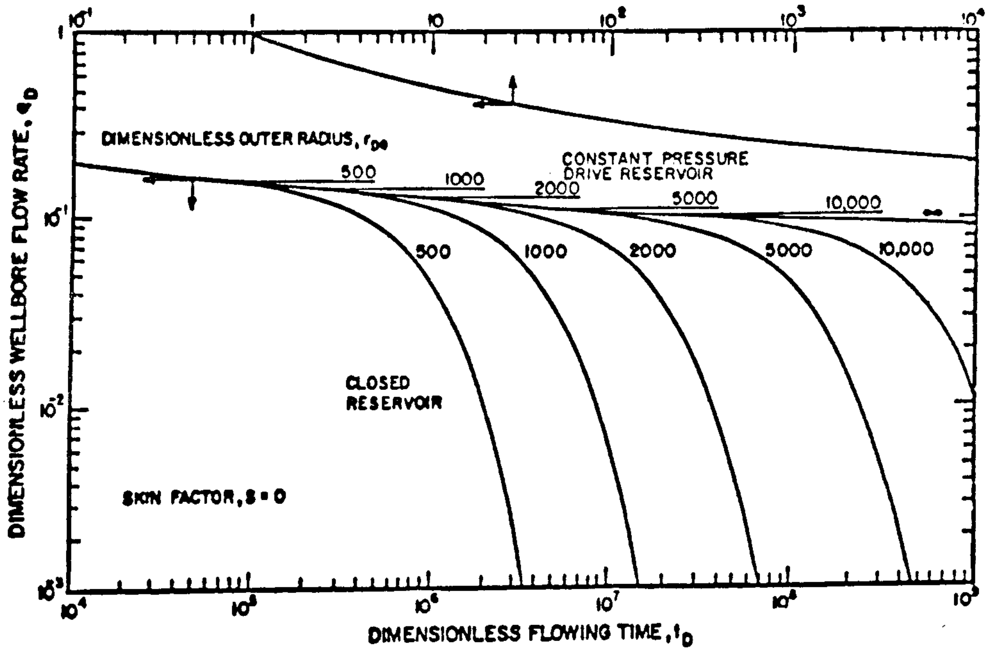

Figure 4 Type curves for radial flow in aquifers with infinite, open and closed boundaries. Constant-head tests.

The test data are plotted on various graphs to identify different flow regimes, i.e. linear, radial and spherical flow /6/. The problems of identifying the actual flow regime during a test are discussed by Ershaghi and Woodbury /7/. The reciprocal flow rate 1/Q(t) and flow rate Q (t) during injection is plotted versus time t in semilogarithmic and logarithmic graphs. Also 1/Q(t) is plotted versus the root of time in linear graphs to detect linear flow periods. During the fall-off phase, the residual pressure is plotted in a Horner-diagram. Also the pressure change related to the actual pressure at injection stop is plotted versus time in a logarithmic diagram.

The transient analysis of the single-hole tests is based on the continuum approach using porous media assumptions. The hydraulic conductivity of the rock mass is generally determined from the slope of the straight line in the semilogarithmic diagrams assuming radial or pseudoradial flow. If the radial flow regime is not reached during the test, the hydraulic conductivity is estimated by type curve matching in the logarithmic diagram. From the injection phase, the conductivity is calculated from the following equation assuming radial flow /8/:

$$KI = \frac{0.183}{L \cdot H_0 \Delta(1/Q)} \qquad (4)$$

where KI = hydraulic conductivity from injection phase (m/s)
L = length of test interval (m)
H_0 = injection head (m)
$\Delta(1/Q)$ = change of reciprocal flow rate per log cycle (s/m^3)

From the fall-off phase the hydraulic conductivity is generally calculated from the Horner-diagram assuming radial flow by the following equation /9/:

$$KU = \frac{0.183\ Q_p}{L \cdot \Delta H} \tag{5}$$

where KU = hydraulic conductivity from fall-off phase (m/s)
Q_p = flow rate at injection stop (m^3/s)
ΔH = change in head per log cycle (m)

In addition, the effective borehole radius or alternatively the specific storage coefficient is estimated for each test and also the static head from the Horner-diagram. Due considerations are taken to wellbore storage effects in low-permeability test intervals during the fall-off phase.

It should be pointed out that the transient analysis is more based on simple rules of thumb than a rigorous analysis in each case due to the large number of tests.

3.3 Comparison of analysis methods

The simplified steady-state analysis used in this study is based on the assumptions of steady-state flow conditions and the factor C = 1. For infinite aquifers and fractures, steady conditions are never reached in practice. In Moye´s equation for steady-state flow the factor C is defined /10/:

$$C = \frac{1 + \ln(L/2r_w)}{2\pi} \tag{6}$$

For a test interval of 25 m length and a borehole diameter of 56 mm the factor C is close to 1. Moye´s equation assumes radial flow near the well becoming spherical at a distance of L/2.

The transient analysis of hydraulic conductivity is mainly based on the slope of a straight line through many data points assuming radial or pseudoradial flow. Also tests with linear or spherical flow can be analysed by transient methods.

In addition, transient analysis allows identification of different flow regimes and outer boundary conditions from the test response c.f Appendix I. From this information the fracture geometry may be deduced.

Doe and Remer /3/ made a theoretical comparison of steady-state and transient analyses. They found that the error in the steady-state analysis generally increases with lower hydraulic conductivity. The calculated hydraulic conductivity will in general be a factor of two or three higher by steady-state analysis compared to transient and occasionally an order of magnitude higher. A similar study was made by Almén et al /11/. These studies did not consider the borehole skin effect /12/.

4. FLOW REGIMES

In hydraulic borehole testing the type of response in the rock may vary from one test to another. The actual bedrock geometry adjacent to the test section and the ratio Kz/Kr (the vertical and radial hydraulic conductivity, respectively) are the two major factors controlling the nature of the flow. In general, three different flow regimes can be separated; radial flow, linear flow and spherical flow. Each of these flow regimes has its own characteristic flow pattern and flow equations. Test data plotted according to the solution of the appropriate flow equation should in the ideal case result in a well-defined straight line in one of the flow regime graphs.

4.1 Radial flow

The radial flow regime is the most common regime observed in the water injection tests performed. If the flow is radial from the test section into the rock the response will show a straight line in a 1/Q vs log t plot as shown in Figure 5.

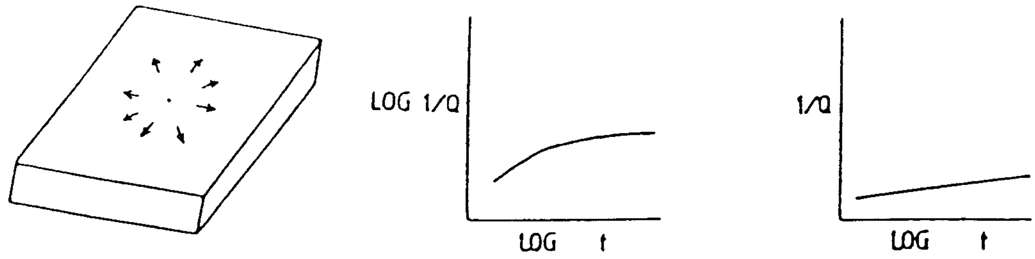

Figure 5 Radial flow and typical data curves in different plots.

4.2 Linear flow

The linear flow regime may be developed when a single (vertical) fracture intersects the test section. The linear flow regime may be divided into four different phases during the test time /13/. In the very early phase a fracture linear flow regime is developed changing into bilinear flow when flow occurs both in the fracture and the host rock. This phase is followed by formation linear flow at which the fracture can be regarded as an extended borehole section. After some time the flow may on a large scale be regarded as a pseudo-radial flow. Linear flow can also result from channeling effects when flow takes place in interconnected channels in fracture planes.

The various linear flow regimes all exhibit straight lines (in the absence of wellbore storage and skin effects) but with different slopes. Bilinear flow shows a quarter slope and formation linear flow a half slope in a log-log plot of 1/Q vs t, see Figure 6.

Both flow regimes should result in straight lines in linear plots of 1/Q vs $\sqrt[4]{t}$ and $\sqrt{t}$, respectively. Figure 6 shows a formation linear flow pattern and typical data curves.

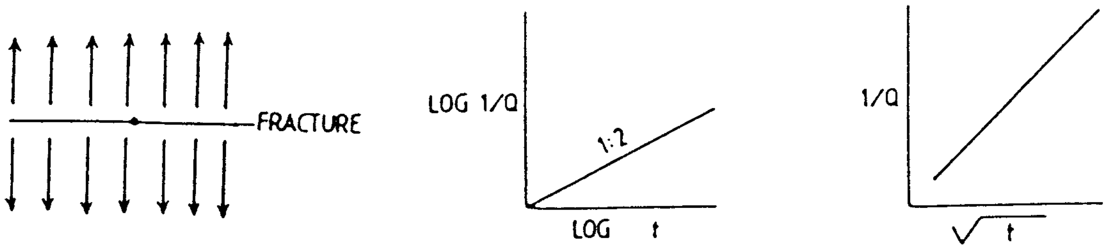

Figure 6 Formation linear flow and typical data curves in different plots.

4.3 Spherical flow

The spherical flow regime may be developed when the test interval is short and/or when Kz is in the same order as Kr. In the spherical flow regime the flow is spherical around the test section. The spherical flow regime can be analysed in a Q vs $1/\sqrt{t}$ plot where a straight line will develop as shown in Figure 7.

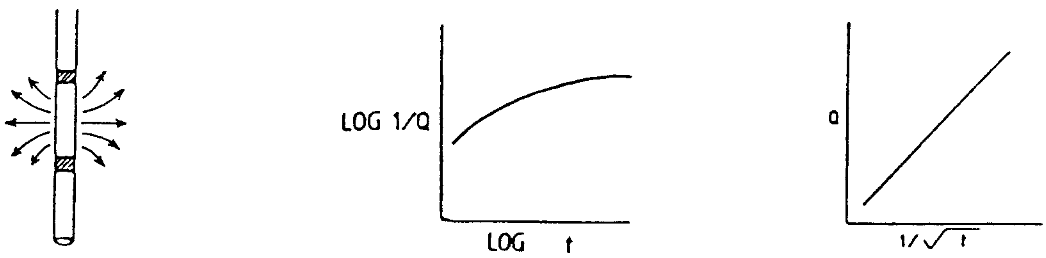

Figure 7 Spherical flow and typical data curves.

In Appendix I:a-d field examples of radial, bilinear, formation-linear and spherical flow regimes, respectively are shown. Also the response of a test section with a negative (closed) hydraulic boundary is shown in Appendix I:e.

5. CROSSPLOTS OF HYDRAULIC CONDUCTIVITY

To compare transient analysis results with steady-state analysis results the following crossplots of hydraulic conductivity were prepared using values from each test site and also for all sites together:

log KPR versus log KI
log K15 versus log KI
log KPR versus log KU
log K15 versus log KU
log KI versus log KU
log K15 versus log KPR

In addition, the ratios of KPR/KI, K15/KI, KPR/KU, K15/KU, KI/KU and K15/KPR are calculated and plotted versus KI and KU respectively in a semilogarithmic diagram. The following crossplots are prepared:

- KPR/KI versus log KI
- K15/KI versus log KI
- KPR/KU versus log KU
- K15/KU versus log KU
- KI/KU versus log KU
- K15/KPR versus log KPR

The lower measurement limit for hydraulic conductivity with the actual equipment configuration can for practical purposes be considered to be 5.10^{-12} m/s. Hydraulic conductivities below this limit are omitted from this study. All conductivity values used are calculated from tests with 25 m packer spacing.

6. RESULTS

Selected crossplots are shown in Appendix II. The first group of crossplots show a very good correlation between different hydraulic conductivity values. Statistical data for the different conductivity ratios described above are shown in Table 1.

Comparing mean values from steady-state analysis with transient analysis of injection test data (ratios K15/KI and KPR/KI) it is concluded that the conductivity KPR, calculated from steady-state analysis after 2 hours of injection, generally is about a factor of 2 higher than the corresponding transient value, see Table 1 (total). This is to be expected considering the assumption of a true steady-state involved in the steady-state analysis which is generally not achieved during the tests. The deviation increases as the injection time decreases as shown from the mean values of the ratio K15/KI. The same conclusions can be drawn from the comparison of the steady-state analysis results with the results from transient analysis of the fall-off tests (the ratios KPR/KU and K15/KU) but the differences in mean values are somewhat larger in this case.

In a few cases the conductivity value from the steady-state analysis is lower than that from the transient analysis, c.f. Appendix II (K15/KI vs log KI). This may be due to a positive skin in the tested section which will result in a too low conductivty value from the steady-state analysis because of a reduced flow rate due to skin damage. On the other hand, a negative skin factor will improve the flow rate and the hydraulic conductivity will thus be further overestimated compared to transient analysis. The hydraulic conductivity value determined from the latter analysis should be unaffected by the skin effect unless the fractures are completely plugged.

A comparison of the standard deviation and the 95 % confidence interval for steady state and transient analysis methods shows that the scatter in the results increase significantly with decreasing test time, which also could be expected. The crossplots of the ratio KPR/KI versus log KI and the ratio KPR/KU versus KU show that the preliminary conductivity KPR may sometimes be up to an order of magnitude higher than the values KI and KU from the transient analysis. The K15 values may occasionally be 10-20 times higher compared to the transient analysis. However, data points showing such great deviation between steady state and transient analysis are relatively few, c.f. Appendix II.

Comparing the results in different hydraulic conductivity intervals no firm conclusions regarding the intervals in which large deviations occur most frequently can be drawn from the present material although there is a tendency towards larger deviations in lower conductivity intervals. In such intervals the deviation may also be due to inaccuracies in either test data or analysis, regardless of the analysis method used.

Table 1 Statistical parameters for the hydraulic conductivity from different test sites

Fjällveden

	N	MEAN	STDEV	SE MEAN	95.0 PERCENT C.I.
KPR/KI	154	2.03	1.36	0.11	(1.81, 2.24)
KPR/KU	126	2.67	1.73	0.15	(2.36, 2.97)
K15/KPR	159	1.35	0.63	0.05	(1.25 1.45)
KI/KU	126	1.51	0.98	0.09	(1.34 1.68)
K15/KI	150	2.83	2.57	0.21	(2.41 3.24)
K15/KU	125	3.68	2.71	0.24	(3.20 4.16)

Gideå

	N	MEAN	STDEV	SE MEAN	95.0 PERCENT C.I.
KPR/KI	186	1.83	1.12	0.082	(1.664, 1.988)
KPR/KU	147	2.36	1.54	0.13	(2.11, 2.61)
K15/KPR	191	1.43	0.85	0.06	(1.31, 1.55)
KI/KU	131	1.32	0.82	0.07	(1.17, 1.46)
K15/KI	161	2.54	2.06	0.16	(2.22, 2.86)
K15/KU	130	3.26	2.85	0.25	(2.77, 3.76)

Kamlunge

	N	MEAN	STDEV	SE MEAN	95.0 PERCENT C.I.
KPR/KI	124	1.647	0.791	0.071	(1.506, 1.787)
KPR/KU	91	2.34	1.43	0.15	(2.05, 2.64)
K15/KPR	118	1.61	1.17	0.11	(1.40, 1.82)
KI/KU	81	1.41	0.90	0.10	(1.22, 1.61)
K15/KI	112	2.62	1.74	0.16	(2.30, 2.95)
K15/KU	78	3.70	2.70	0.31	(3.09, 4.31)

All sites

	N	MEAN	STDEV	SE MEAN	95.0 PERCENT C.I.
KPR/KI	463	1.85	1.14	0.053	(1.745, 1.953)
KPR/KU	364	2.46	1.59	0.083	(2.300, 2.627)
K15/KPR	468	1.45	0.88	0.04	(1.37, 1.53)
KI/KU	338	1.42	0.91	0.05	(1.32, 1.51)
K15/KI	423	2.67	2.18	0.11	(2.46, 2.87)
K15/KU	333	3.52	2.76	0.15	(3.22, 3.82)

One reason for large errors in K15 and KPR determined from short-time tests, particularly in higher-conductivity intervals, can be the occurence of linear flow during a substantial part of a test. This causes a large change in flow rate (or head) with time contrary to the assumption of steady-state, c.f Appendix I:b-c. A linear flow response may be caused by flow in high-conductive channels in the rock, c.f. channeling. Another reason for an increased change in flow rate can be effects of (closed) boundaries during the test, c.f. Appendix I:e. Such effects are generally not considered in the analysis of steady-state tests. With transient analysis methods such effects can be identified and taken into account by the interpretation. On the other hand, if spherical flow occurs during a test, the change in head is much smaller and the steady-state analysis should be more accurate, c.f Appendix I:d.

A comparison of mean values for transient analysis of the injection and fall-off tests shows that the mean value of the previous tests is about a factor of 1.5-2 higher than the latter (ratio KI/KU). The reason for this deviation is not completely known at present. One possible reason is that the fall-off test data sometimes may be less reliable due to insufficient duration of the previous injection period, particularly in test intervals with low conductivity /9/. According to the authors experience from the actual tests, fall-off data are more difficult to interprete than injection test data. The results from the injection tests are in general considered as more reliable. The ratio KI/KU from transient analysis also shows some scatter particularly towards low-conductive intervals.

Comparing mean values for different steady-state analysis methods (ratio K15/KPR), this ratio is relatively constant with the K15-values generally about 50 % higher than the KPR-values. However, a few peak values may occur. As an example, a value of 4.5, caused by linear flow, was determined.

In practice short time constant head injection tests (c. 15 mins) are generally analysed by steady-state methods whereas longer tests (2 hours or more) are analysed by transient methods. From a site investigation point of view the most relevant comparisons of the two test methods should therefore be the ratios K15/KI and K15/KU.

A comparison between the test sites shows that the conductivity ratios between steady-state and transient analysis are greatest for the Fjällveden site and smallest for the Kamlunge site. Also the deviations of the ratios show the same pattern, c.f. Table 1.

7. CONCLUSIONS

A comparison between steady-state analysis and transient analysis of the injection phase show that the steady state analysis in general gives K-values which are about 2-3 times higher, depending on the test duration, and occasionally 10-20 times higher than the transient analysis. This is in good agreement with the conclusions by Doe and Remer /3/. Corresponding maximal deviation for steady-state versus transient fall-off data is a factor of 15-25. The difference between the transient and steady-state analysis will generally increase when linear flow and flow barriers occur. On the other hand, spherical flow and/or effects of recharge boundaries will decrease the difference.

Comparing steady-state analysis using different injection times (K15 and KPR) shows that the shorter test time analysis (K15) results in a higher K-value by about 50 %. Mean values of hydraulic conductivity from the fall-off phase are generally a factor of 1,5 - 2 lower than the conductivity calculated from the injection phase.

Some general reflections regarding the design of a relevant hydraulic test program for investigatons in crystalline rock can be drawn from the present study. In many engineering geology investigations an estimate of the equvalent rock mass hydraulic conductivity within a factor of 2 - 3 of the true conductivity can be accepted. In such cases short-time steady-state tests are quite sufficient. If a large number of such tests are performed along boreholes, these data can be used as input data for various hydrogeological statistical models of an investigated area and for calculations of the hydraulic fracture frequency etc.

If more detailed information of certain hydraulic units is desired, which might be considered important for the groundwater flow conditions, longer transient tests are required. Such tests may either be performed as single-hole tests or interference tests between boreholes. From transient tests, particularly interference tests, a separate determination of the hydraulic properties of both fracture system and rock matrix is possible. From single-hole tests the indentification of different flow regimes, e.g. linear flow, and the opportunity of deducing information on hydraulic characteristics and geometry of individual fractures and boundary conditions may be possible.

With a combination of short-time steady-state tests and longer transient tests a more flexible hydraulic testing program can be obtained which is more sympathetic to the structural geology. For example, steady-state tests can be used in the early phase of an investigation as a hydraulic conductivity log along the full length of a borehole. In intervals and hydraulic units, which are considered as important for further investigations, longer transient tests can then be carried out, preferably as a combination of single-hole- and interference tests. The hydraulic test program should also be combined with geological and geophysical investigations, e.g. borehole radar measurements. Such a flexible program should give a better resolution of the hydraulic testing in crystalline rock.

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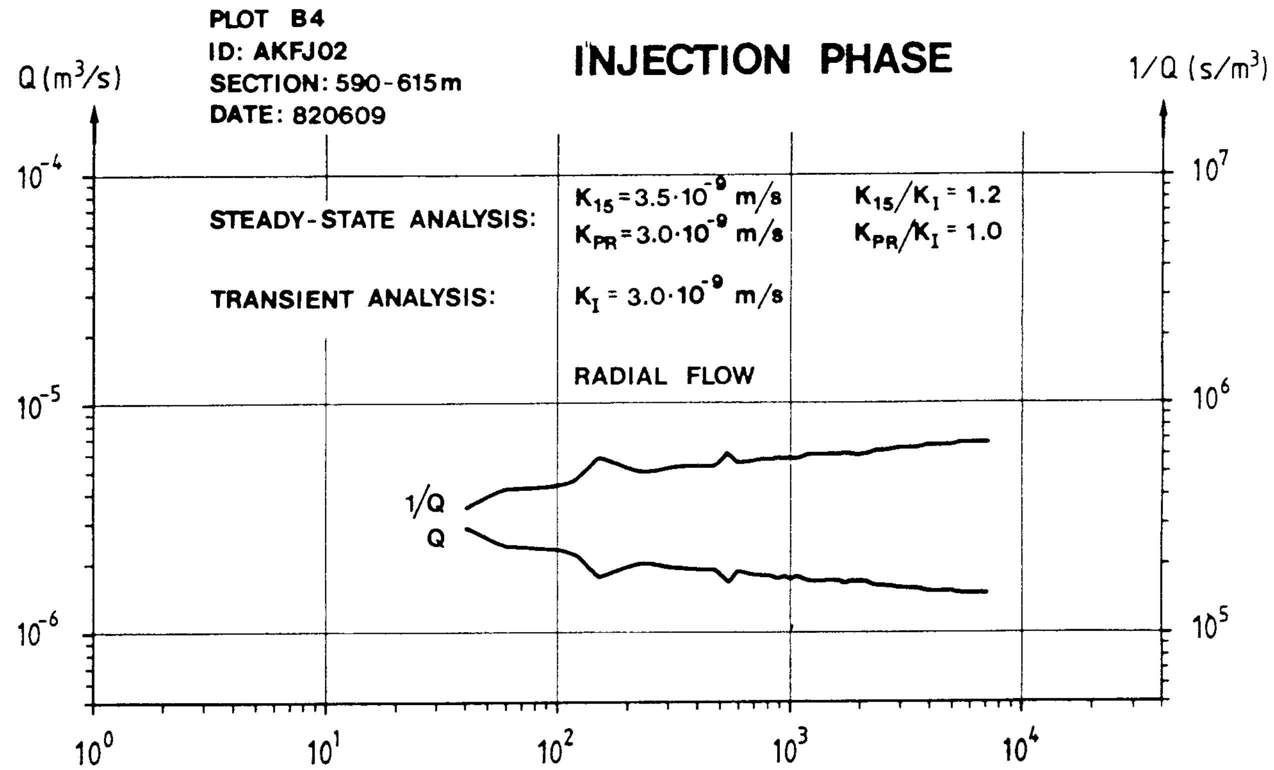
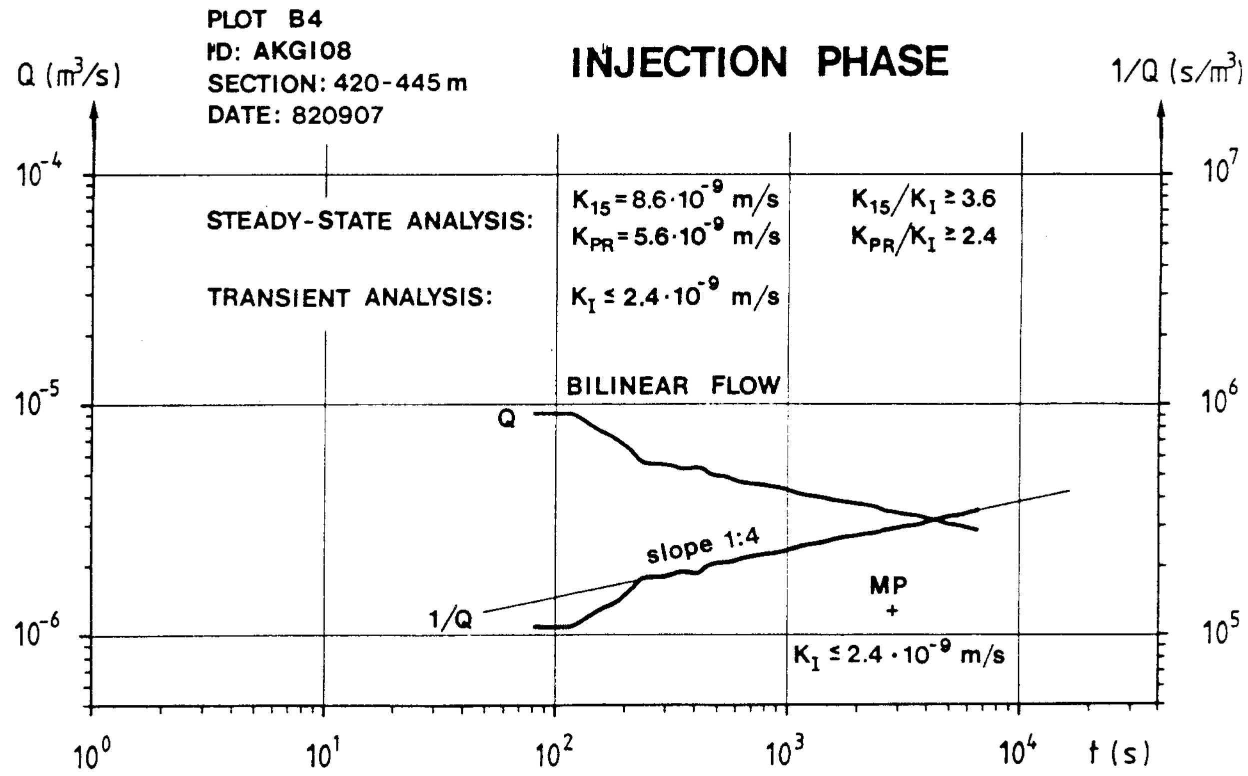
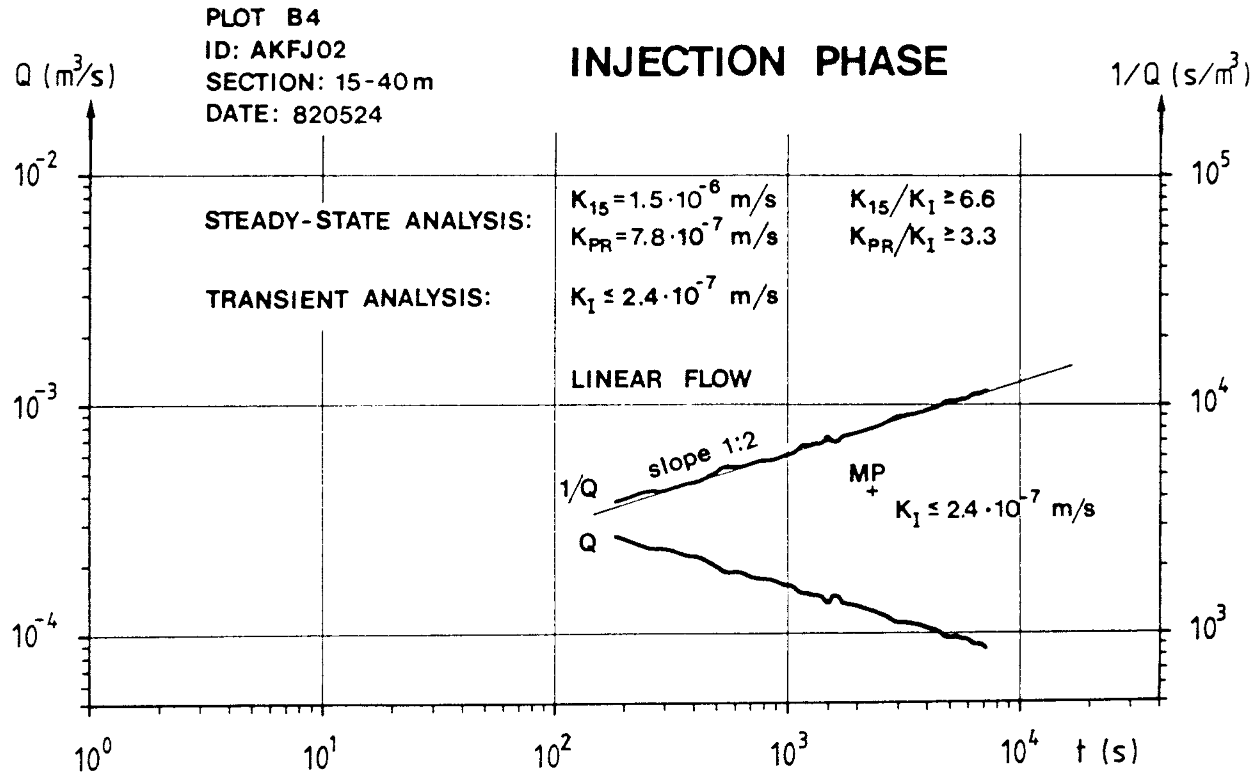
APPENDIX I: FIELD EXAMPLES OF DIFFERENT FLOW REGIMES.



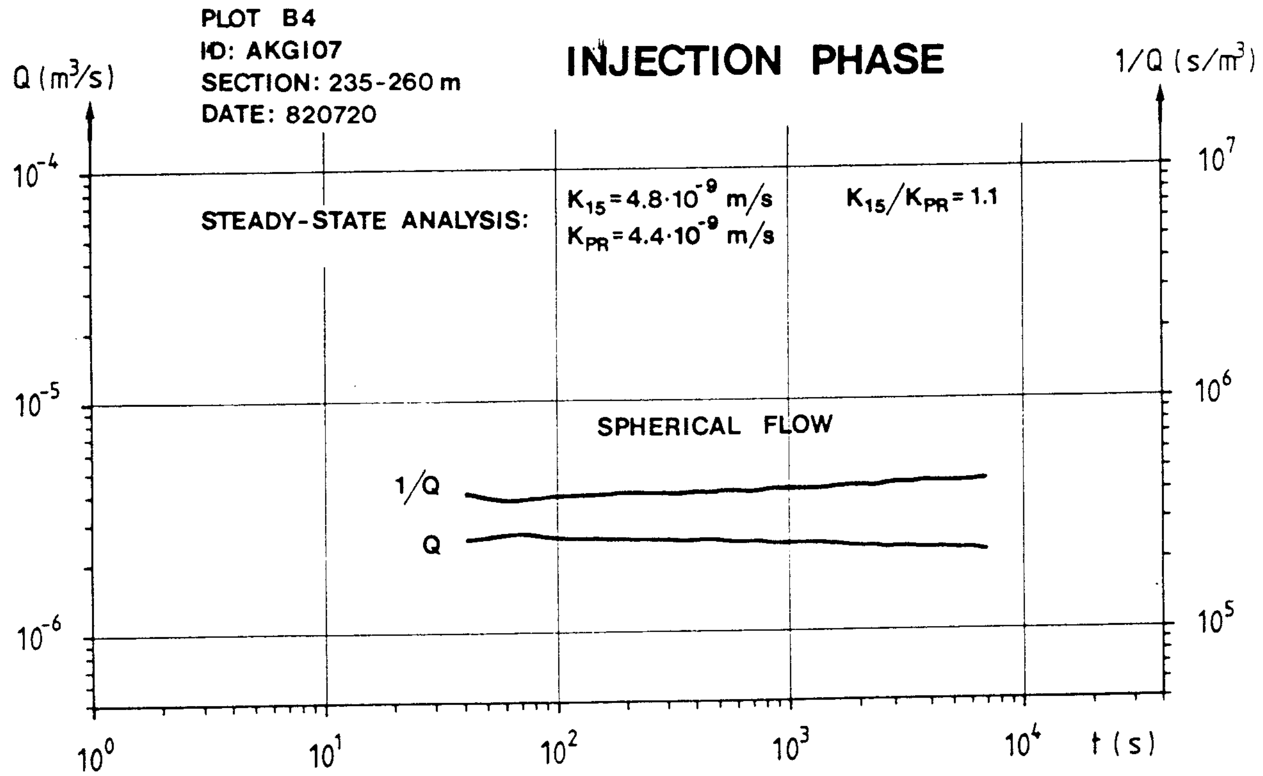
Appendix I:a A log-log plot of test data exhibiting a radial flow regime.



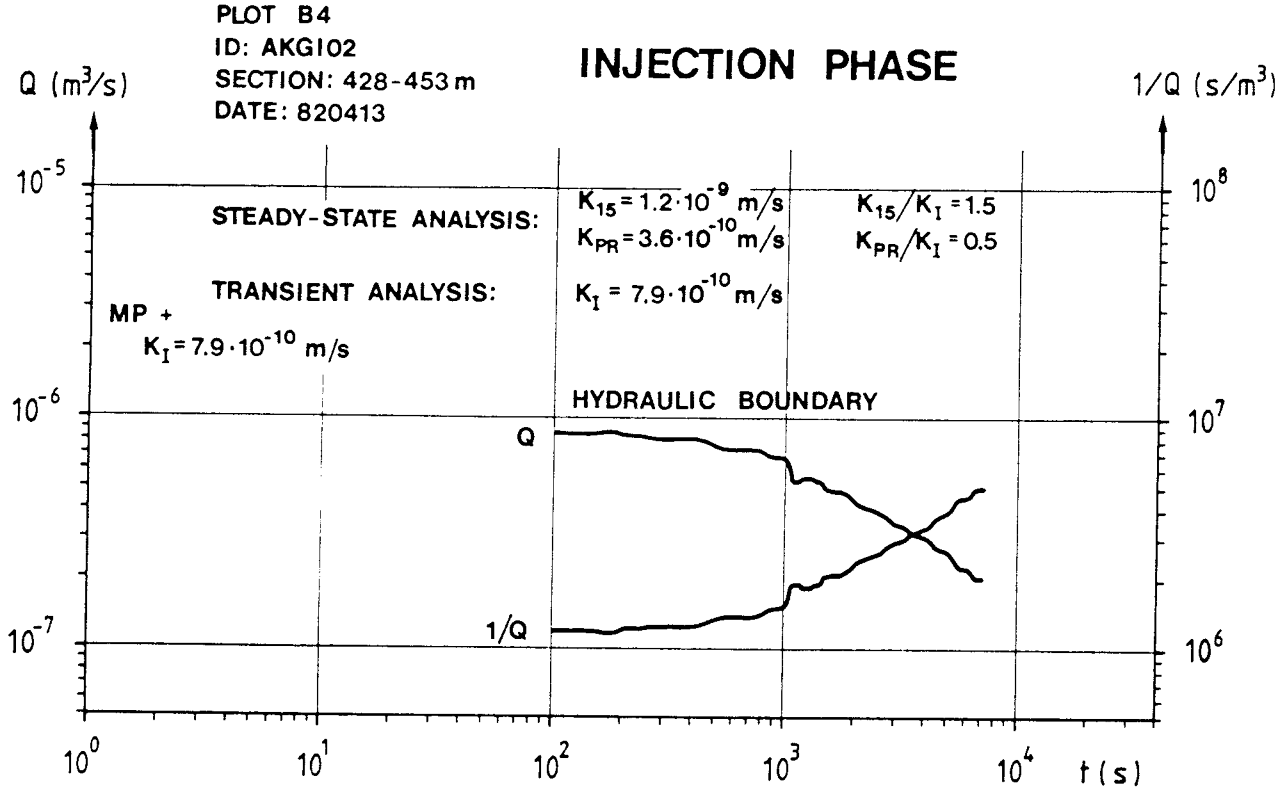
Appendix I:b A log-log plot of test data exhibiting a bilinear flow regime.



Appendix I:c A log-log plot of test data exhibiting a formation-linear flow regime.

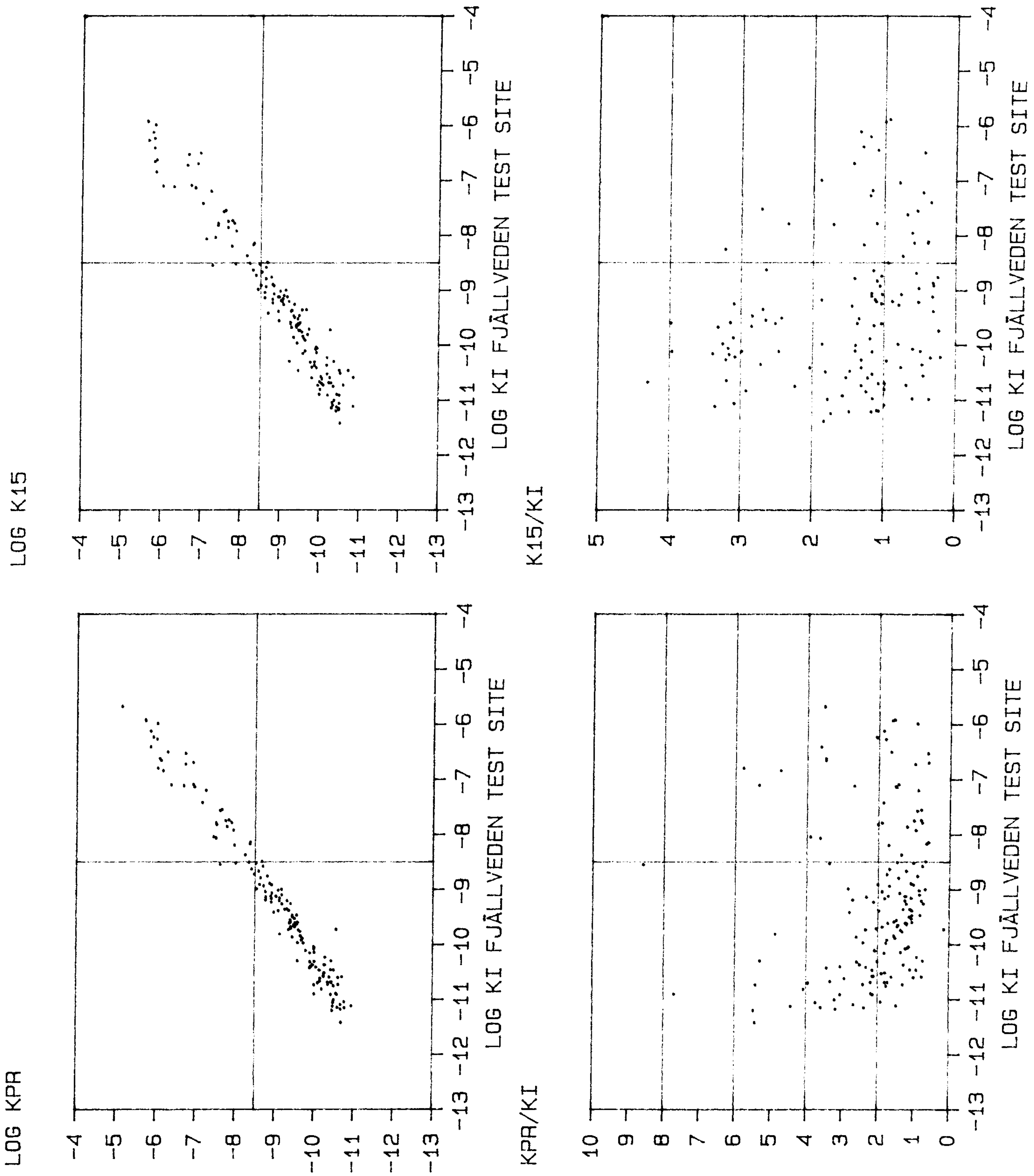


Appendix I:d A log-log plot of test data exhibiting a spherical flow regime.



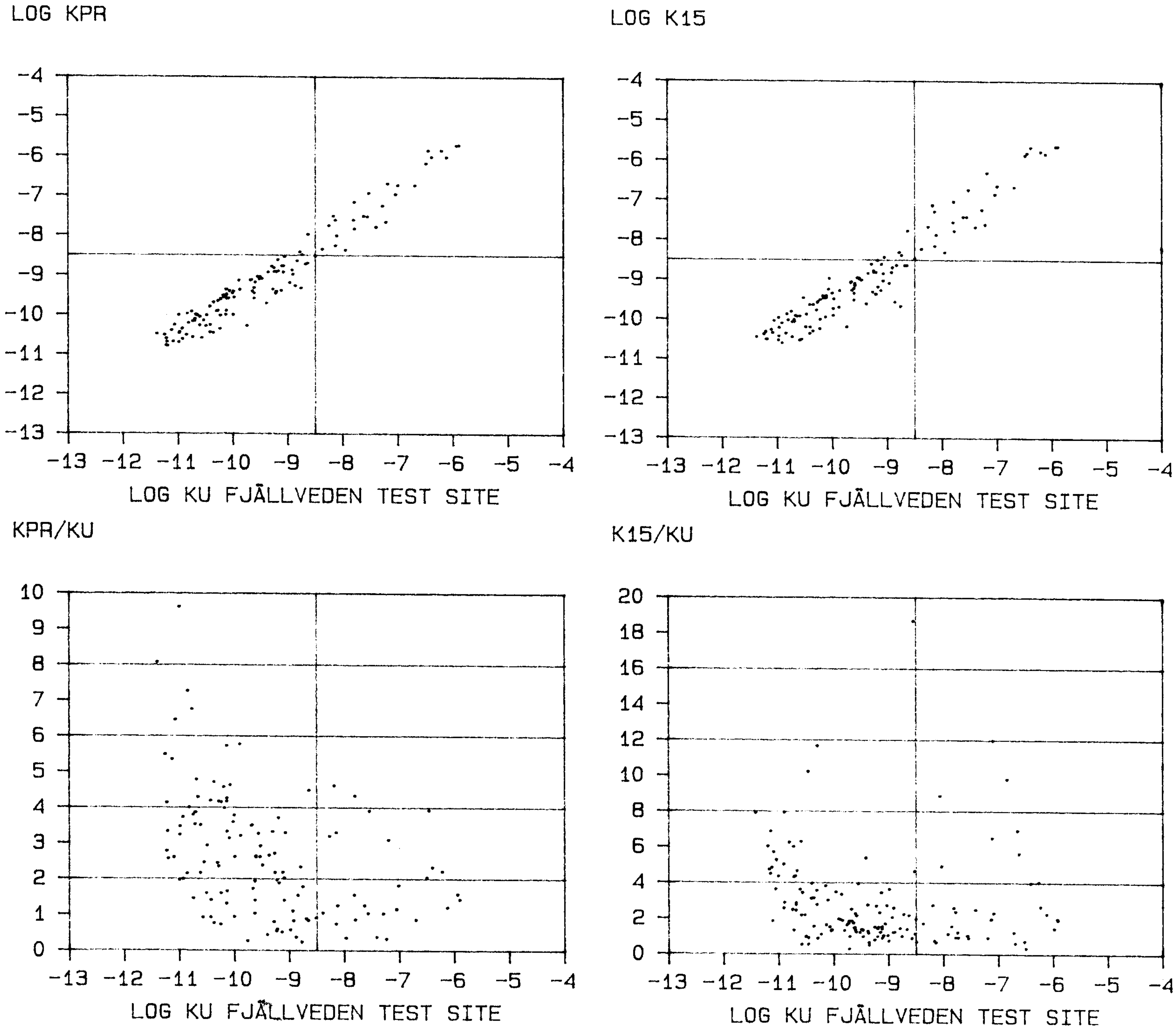
Appendix I:e A log-log plot of test data exhibiting effects of a closed outer hydraulic boundary.

APPENDIX II: CROSSPLOTS OF HYDRAULIC CONDUCTIVITY.

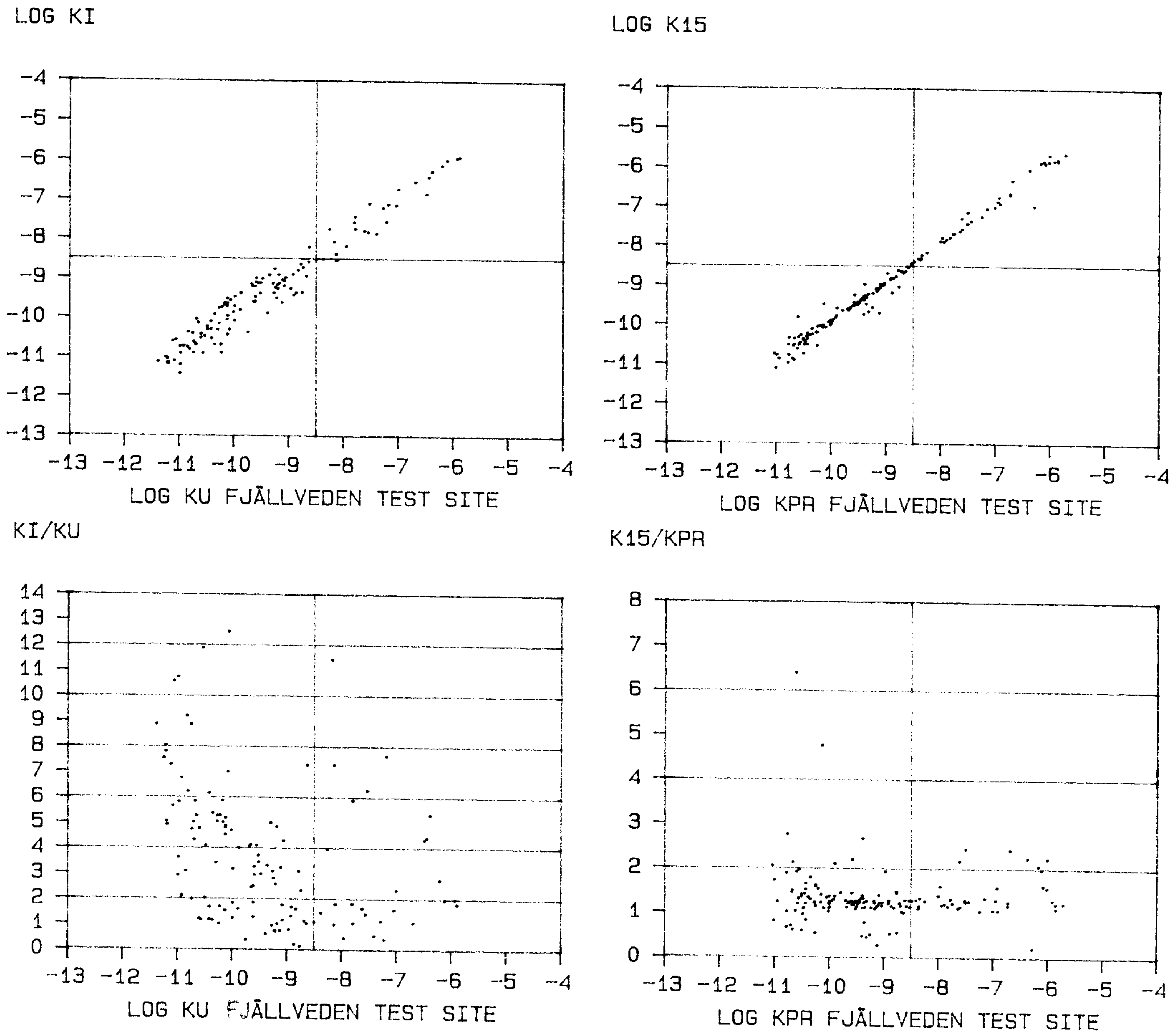


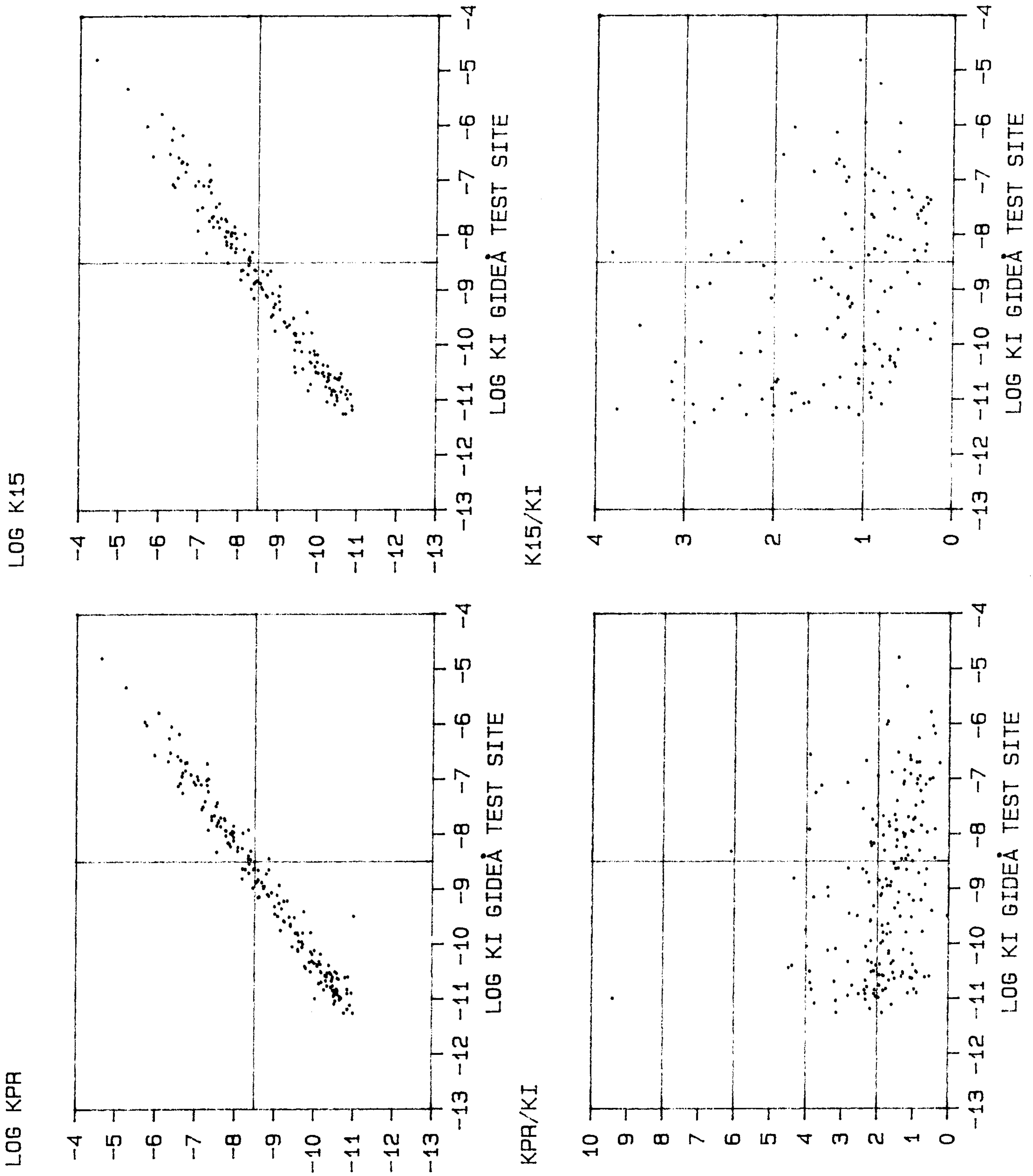
Appendix II:a Correlation between hydraulic conductivity from steady state and transient analysis and distribution of different conductivity ratios as a function of actual hydraulic conductivity.

Appendix II:b Correlation between hydraulic conductivity from steady state and transient analysis and distribution of different conductivity ratios as a function of actual hydraulic conductivity.



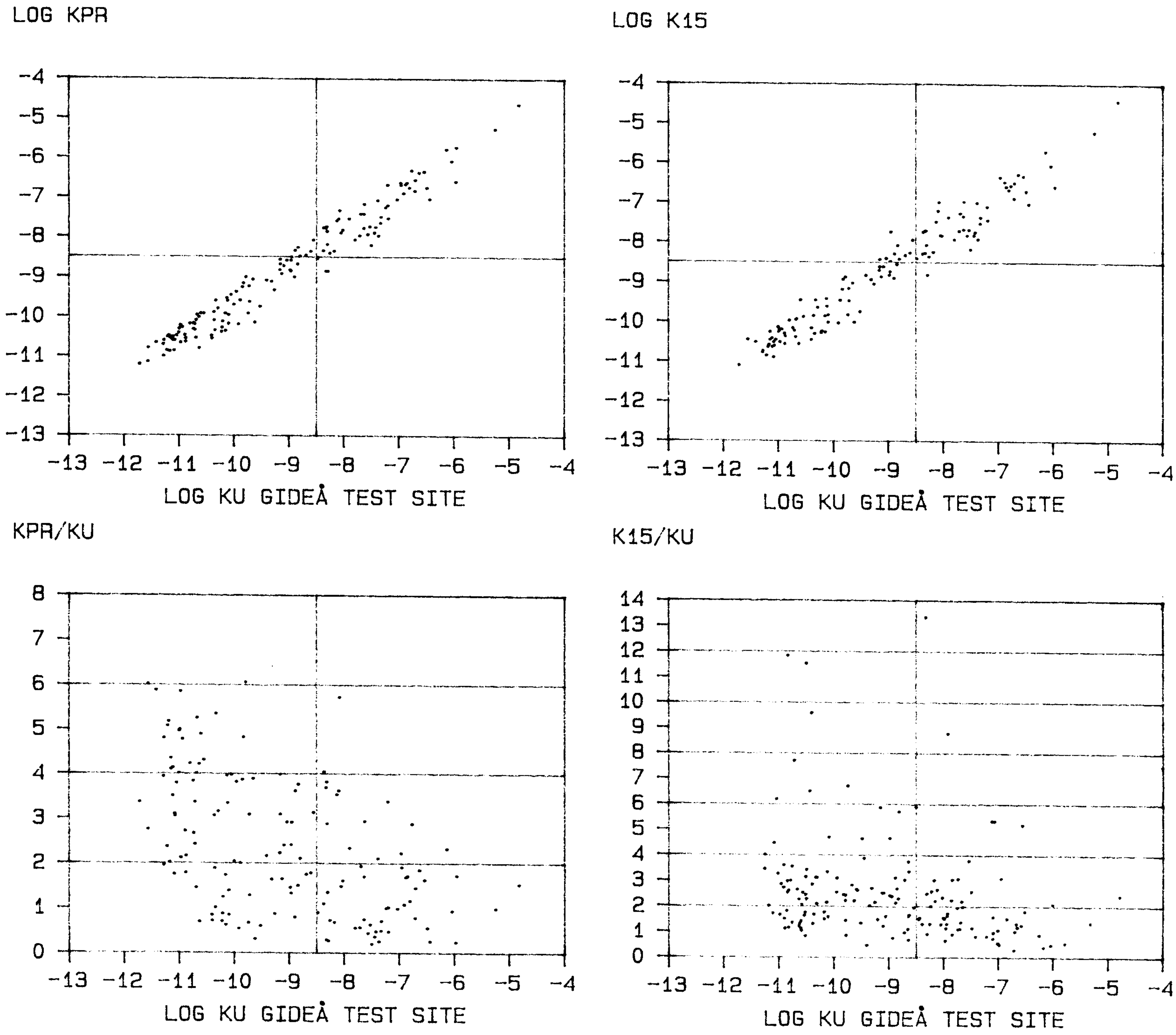
Appendix II:c Correlation between hydraulic conductivity from steady state and transient analysis and distribution of different conductivity ratios as a function of actual hydraulic conductivity.

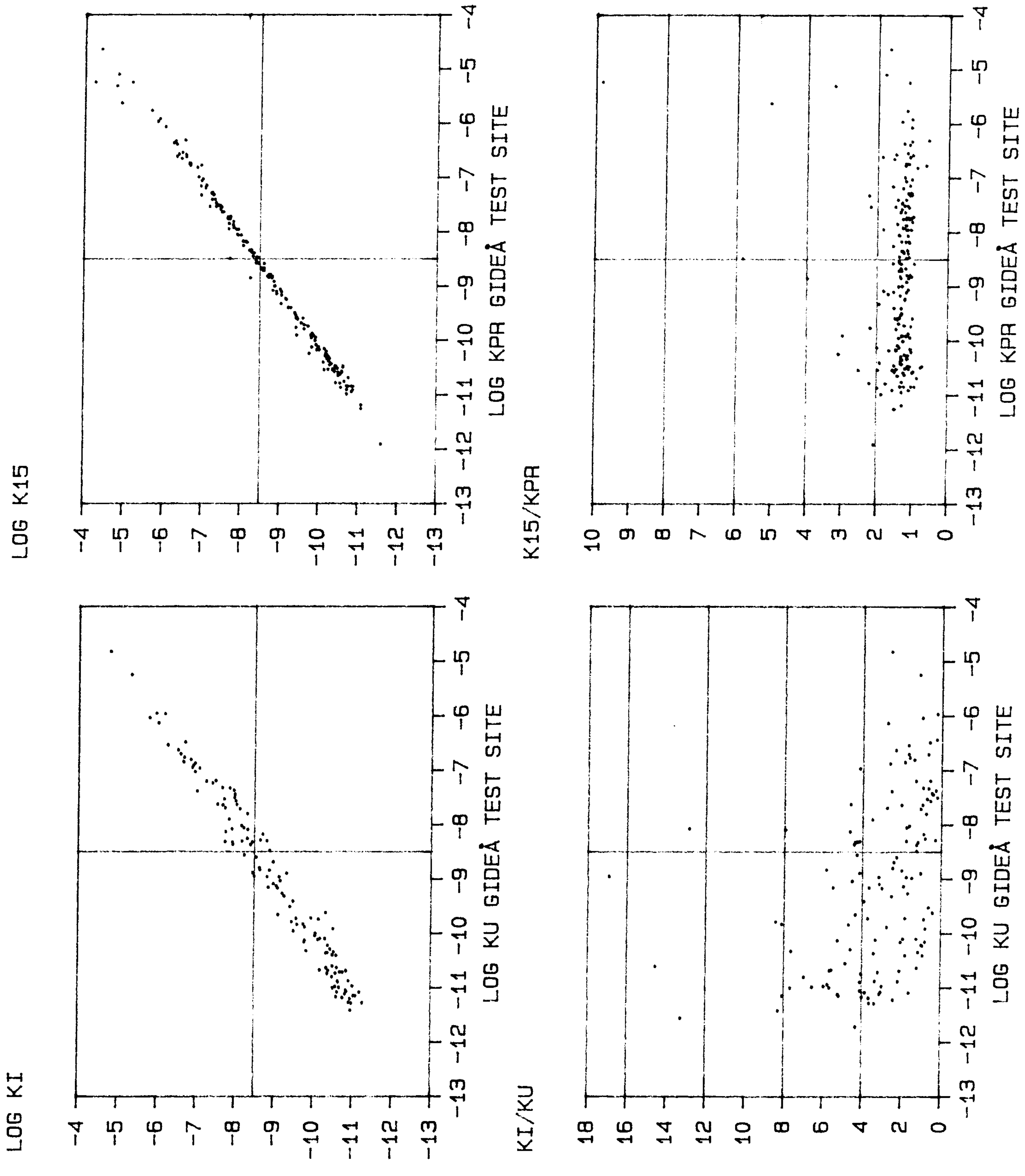




Appendix II:d Correlation between hydraulic conductivity from stady state and transient analysis and distribution of different conductivity ratios as a function of actaul hydraulic conductivity.

Appendix II:e Correlation between hydraulic conductivity from steady state and transient analysis and distribution of different conductivity ratios as a function of actual hydraulic conductivity.

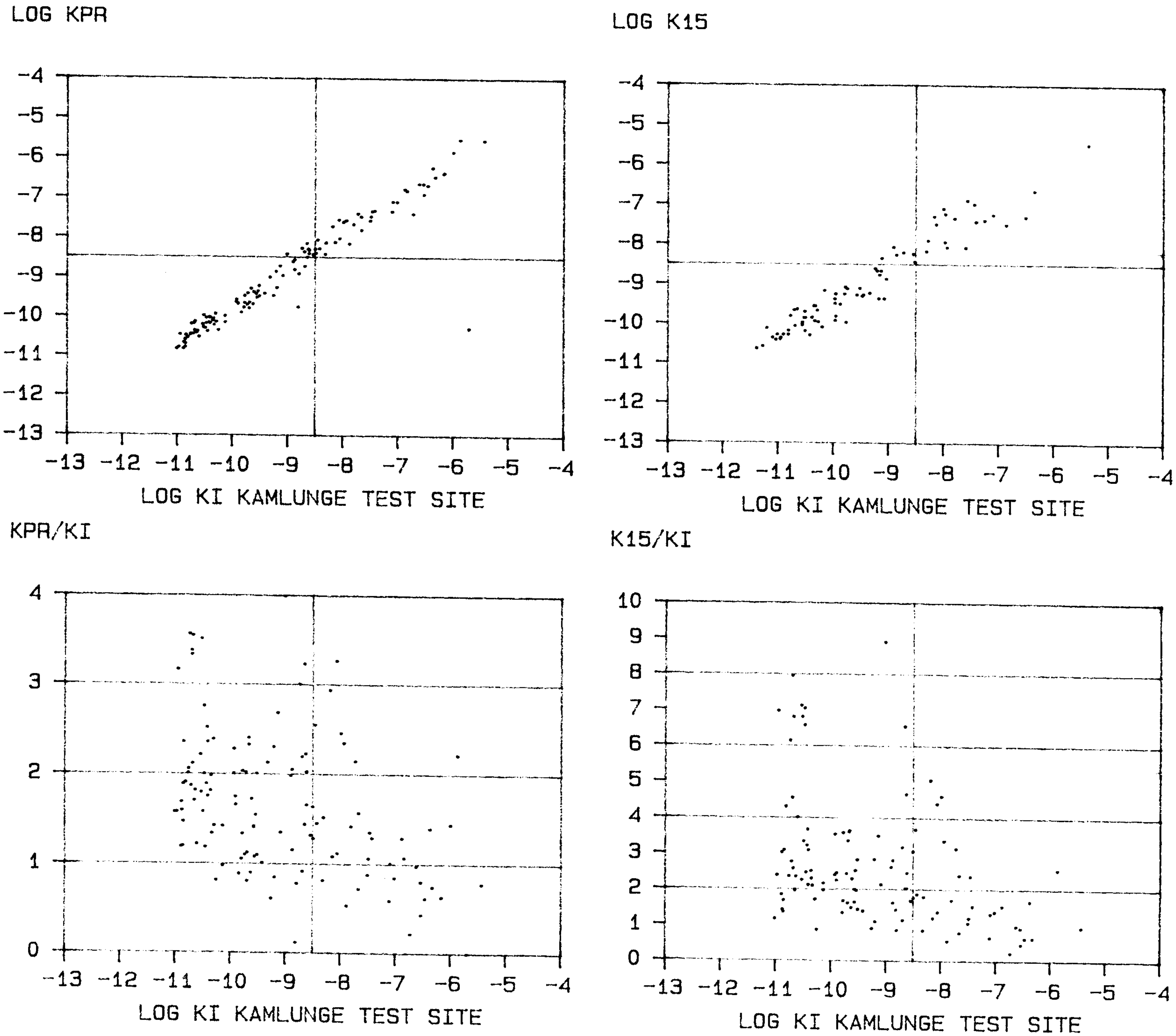




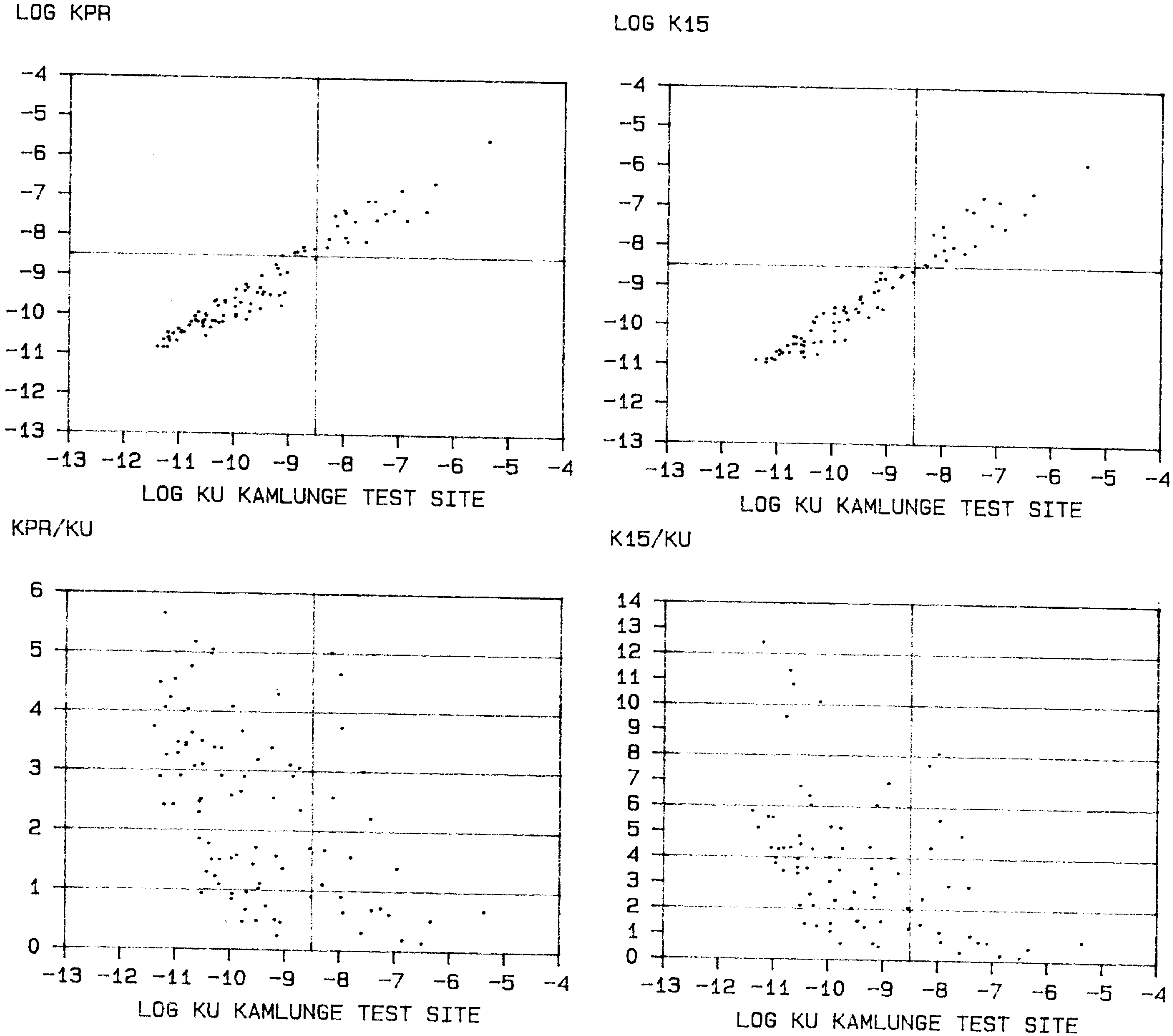
Appendix II:f Correlation between hydraulic conductivity from steady state and transient analysis and distribution of different conductivity ratios as a function of actual hydraulic conductivity.

Appendix II:g

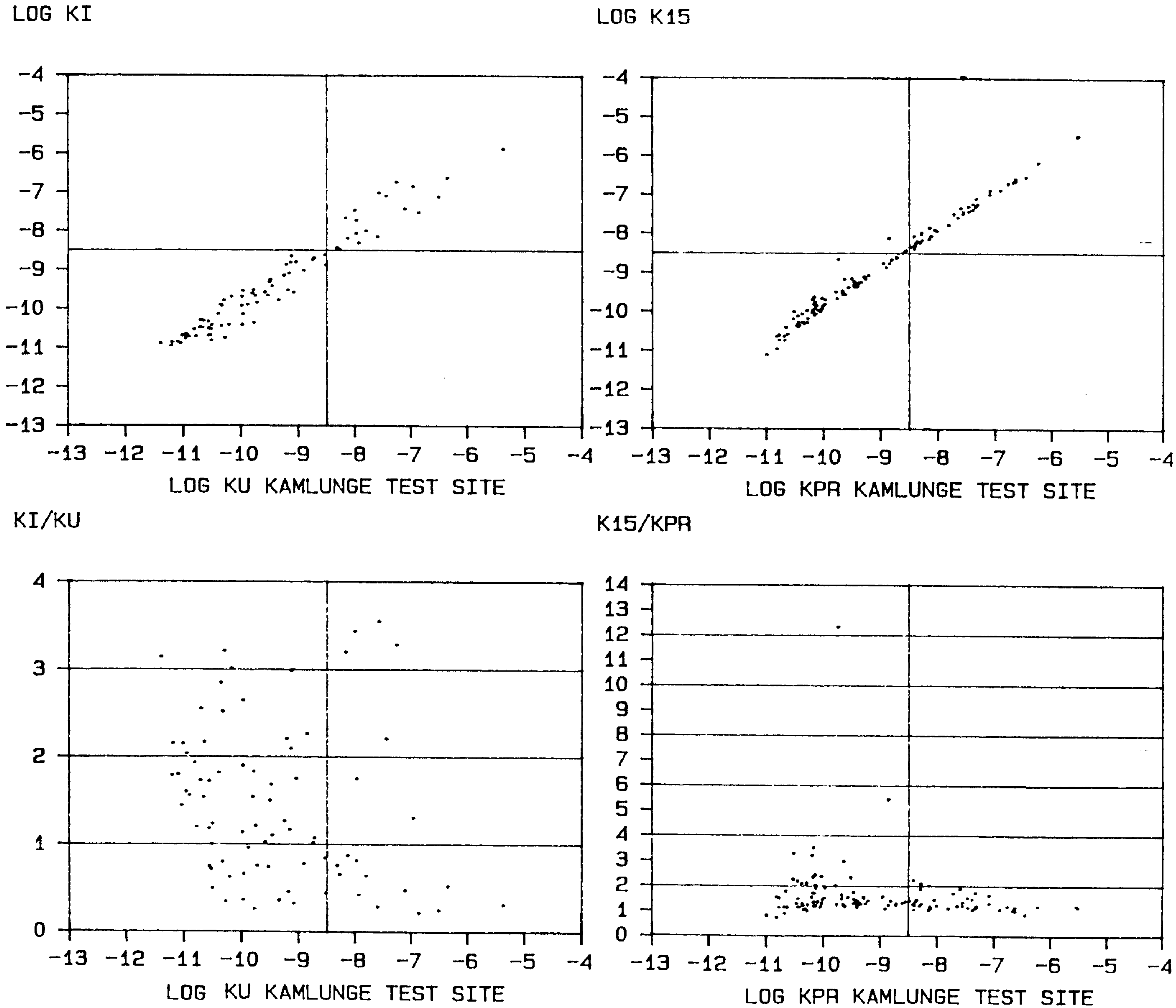
Correlation between hydraulic conductivity from steady state and transeint analysis and distribution of different conductivity ratios as a function of actual hydraulic conductivity.

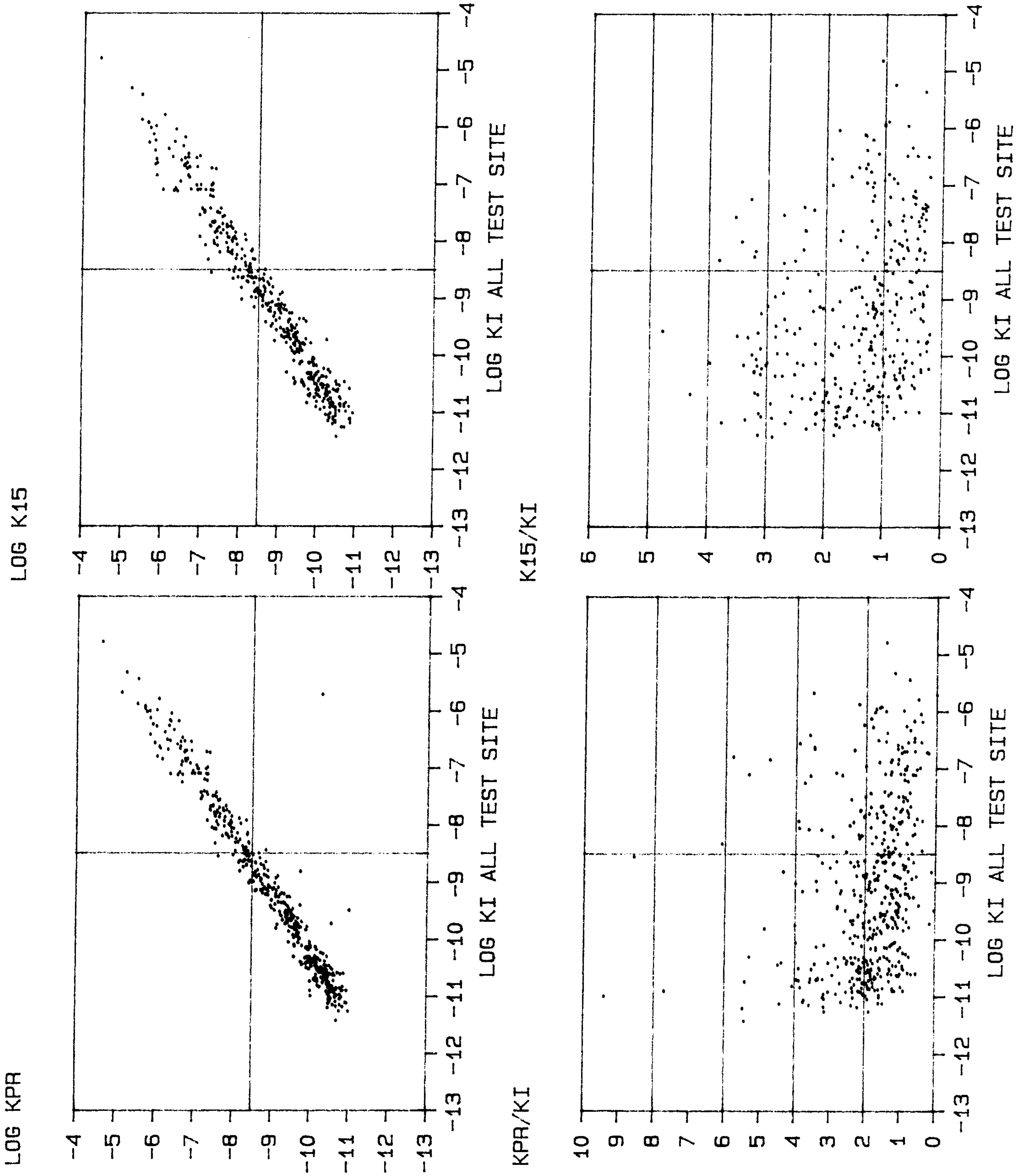


Appendix II:h Correlation between hydraulic conductivity from steady state and transient analysis and distribution of different conductivity ratios as a function of actual hydraulic conductivity.

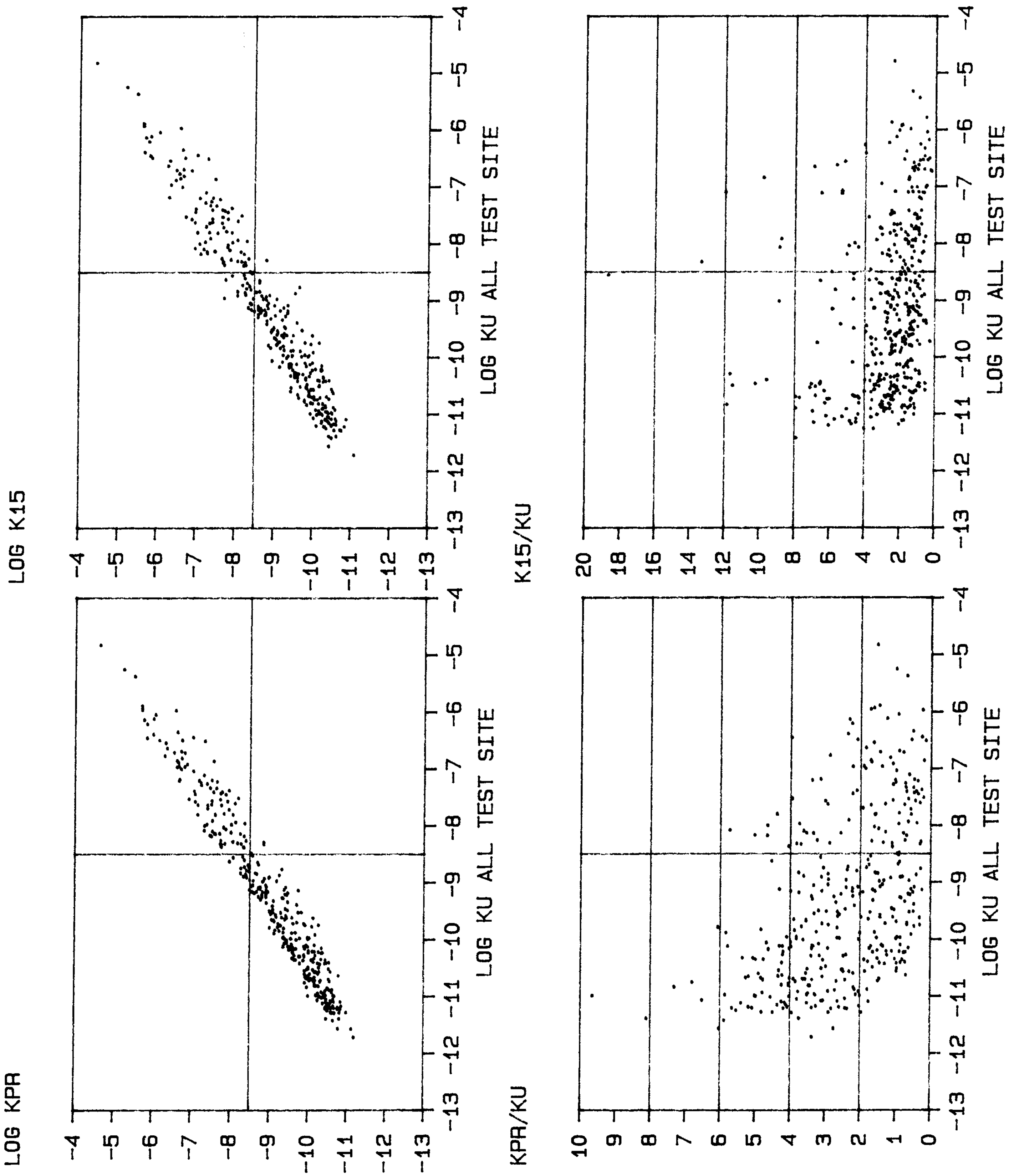


Appendix II:i Correlation between hydraulic conductivity from steady state and transient analysis and distribution of different conductivity ratios as a function of actual hydraulic conductivity.

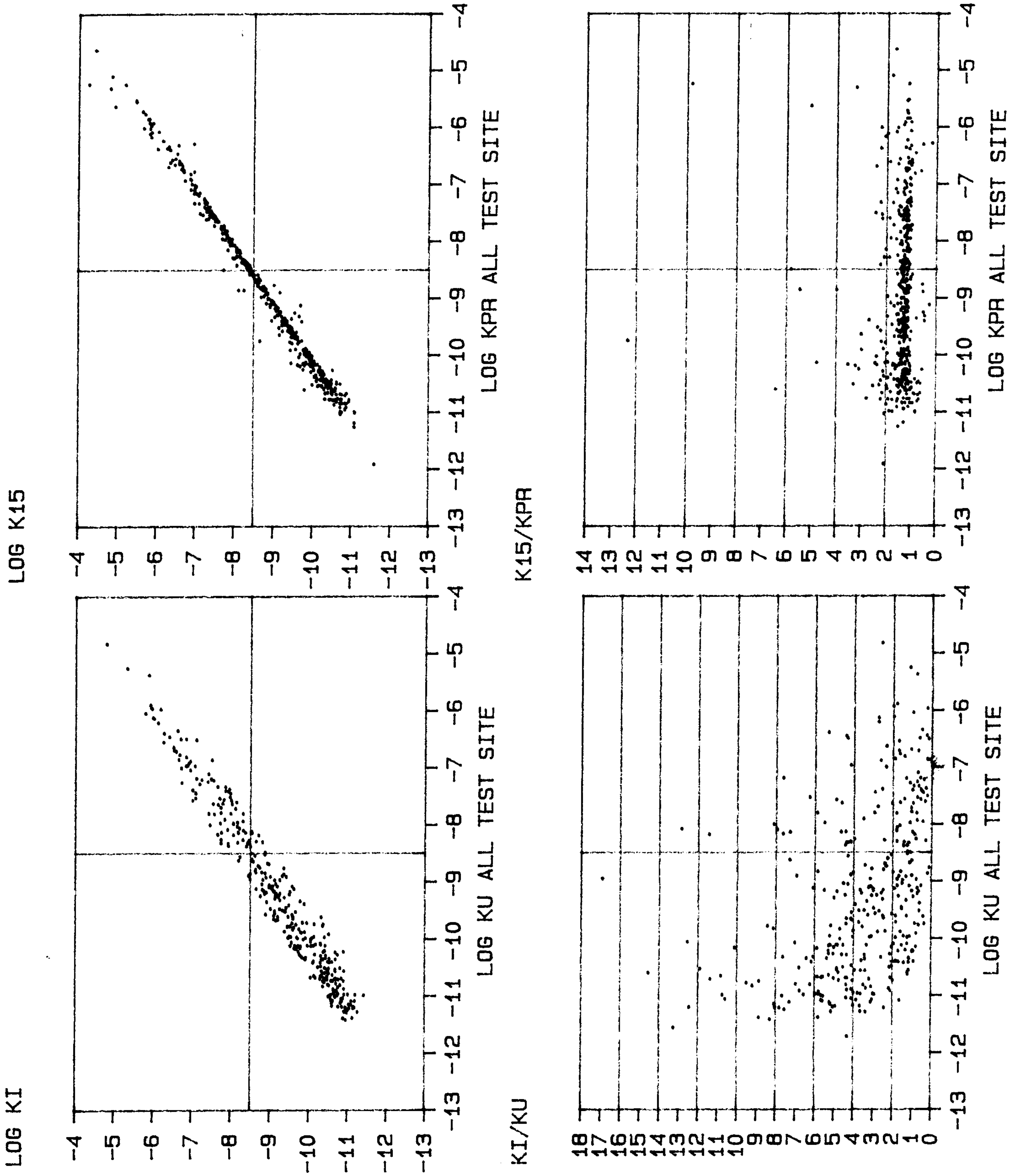




Appendix II:j Correlation between hydraulic conductivity from steady state and transient analysis and distribution of different conductivity ratios as a function of actual hydraulic conductivity.



Appendix II:k Correlation between hydraulic conductivity from steady state and transient analysis and distribution of different conductivity ratios as a function of actual hydraulic conductivity.



Appendix II:1 Correlation between hydraulic conductivity from steady state and transient analysis and distribution of different conductivity ratios as a function of actual hydraulic conductivity.

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The Taavinunnanen gabbro massif. A compilation of results from geological, geophysical and hydrogeological investigations.
Bengt Gentzschein
Sven-Åke Larson
Eva-Lena Tullborg
Swedish Geological Company
Uppsala, January 1985

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Porosities and diffusivities of some non-sorbing species in crystalline rocks.
Kristina Skagius
Ivars Neretnieks
The Royal Institute of Technology
Department of Chemical Engineering
Stockholm, 1985-02-07

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The chemical coherence of natural spent fuel at the Oklo nuclear reactors.
David B. Curtis
New Mexico, USA, March 1985

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Diffusivity measurements and electrical resistivity measurements in rock samples under mechanical stress.
Kristina Skagius
Ivars Neretnieks
The Royal Institute of Technology
Department of Chemical Engineering
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Christer Ljunggren
Ove Stephansson
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Ulf Mattila
Div of Rock Mechanics
University of Luleå
Luleå, Sweden, October 1985

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Complex forming properties of natural occurring fulvic acids
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Jacob A. Marinsky,
A. Mathuthu,
M. Bicking and
J. Ephraim
State University of New York at Buffalo
Buffalo, New York 14214,
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In situ one-year burial experiments with simulated nuclear waste glasses
Larry L Hench, Derek Spilman and T Buonaquisti
College of Engineering, Univ. of Florida, Gainesville, USA
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Chalmers Univ. of Technology, Gothenburg, Sweden
Lars Werme
SKB, Stockholm, Sweden

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Studsvik Energiteknik AB, Nyköping, Sweden

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Chemical interactions between the bentonite and the natural solutions from the granite near a repository for spent nuclear fuel
Bertrand Fritz and Marie Kam
Université Louis Pasteur de Strasbourg, Institut de Géologie, France
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John Smellie, Nils-Åke Larsson
Swedish Geological Company, Uppsala, Sweden
Peter Wikberg
Royal Institute of Technology, Stockholm Sweden
Leif Carlsson
Swedish Geological Company, Göteborg, Sweden
November 1985

TR 85-12
Hydrogeological investigations and tracer tests in a well-defined rock mass in the Stripa mine
Peter Andersson
Carl-Erik Klockars
Swedish Geological Company
Division of Engineering Geology
Uppsala 1985-11-29

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Analysis of hydrodynamic dispersion in discrete fracture networks using the method of moments
Anders Rasmuson
Dep of Chemical Engineering, Royal Inst of Technology Stockholm
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Radionuclide migration in strongly fissured zones—The sensitivity to some assumptions and parameters
Anders Rasmuson, Ivars Neretnieks
Dep of Chemical Engineering, Royal Inst of Technology Stockholm
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Diffusion measurements of cesium and strontium in biotite gneiss
Kristina Skagius, Ivars Neretnieks
Dep of Chemical Engineering, Royal Inst of Technology Stockholm
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R S Forsyth
Studsvik Energiteknik AB, Nyköping, Sweden
L O Werme
The Swedish Nuclear Fuel and Waste Management Co (SKB), Stockholm, Sweden
J Bruno
Royal Institute of Technology, Dept of Inorganic Chemistry, Stockholm, Sweden
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Roland Pusch*, Mikael Erlström, Lennart Börgesson
Swedish Geological Co, Lund
* also Lund University of Technology and Natural Sciences, Lund
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Kurt Pörn, Ove Åkerlund
Studsvik Energiteknik AB, Nyköping, Sweden
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