

# SKBF TECHNICAL KBS REPORT

**83-64**

## **Ion exchange capacities and surface areas of some major components and common fracture filling materials of igneous rocks**

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Göteborg, Sweden May 1983

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ION EXCHANGE CAPACITIES AND SURFACE AREAS  
OF SOME MAJOR COMPONENTS AND COMMON  
FRACTURE FILLING MATERIALS OF IGNEOUS ROCKS

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## SUMMARY

Surface/mass ratios have been determined by the ethylene glycol method and the BET-method, and an- and cation exchange capacities vs pH have been measured by an isotopic dilution technique for some 30-35 pure minerals. These minerals, which are representative of major components and common accessory minerals, including fracture minerals, of crystalline rocks, have also been used in radionuclide sorption studies within the Swedish waste program.

Generally, the anion exchange capacities are low ( $< 1$  meq/kg) for all the minerals. The cation exchange capacities, which increase with pH, are  $\leq 1$  meq/kg for the non-silicates with few exceptions, 1-10 meq/kg for most of the silicates except the phyllosilicates and ranging from 10 up to 800 meq/kg for clay minerals (e.g. montmorillonite) and some of the zeolites (e.g. stilbite).

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## 1. INTRODUCTION

High-level radioactive wastes and spent fuel will be placed in underground repositories in crystalline rock according to the present Swedish concept for waste disposal (1). The most important pathways from the repository to the biosphere for the radionuclides that eventually will be released from the waste canisters would be the open water-carrying fractures of the rock. The retention of these radionuclides, due to interactions with water-exposed mineral surfaces, would constitute a major geologic barrier for many of the elements in question.

The minerals in the fractures, both open water-carrying and healed, are usually quite different from the bulk of the rock. For igneous rocks like granite the major rock-forming minerals would be quartz, feldspars, micas and amphiboles, and also pyroxenes and olivine in basic rocks like basalt (2).

Essentially three categories of minerals are found in fractures:

- o weathering and alteration products of the major rock components (clay minerals etc.);
- o metamorphic and hydrothermal products;
- o precipitates from aqueous solutions at low temperatures.

In order to allow a quantitative description of the radionuclide retardation it is essential that the chemical properties of the pathways in the bedrock/groundwater system are characterized in detail.

The following projects, related in various ways to the mineralogy of water-carrying fractures and radionuclide migration in these pathways, are in progress within the Swedish waste program:

- o Characterization of fracture minerals (3,4);
- o Sorption of radionuclides on fracture minerals and rock-forming minerals (5-7);
- o Diffusion of radionuclides through fracture coatings into the underlying bulk rock (8-9);
- o Migration of radionuclides in natural fractures (10-13).

The surface/mass ratio and exchange capacities (cations and anions), for common fracture minerals as well as for some other accessory minerals and major components of igneous rocks, are given in this report. These data have been determined to serve as a basis for further discussions and

analyses of the observed radionuclide sorption and migration behaviour in fracture systems.

## 2. SELECTION OF MINERALS

Some minerals representative of crystalline rocks were selected for surface/mass ratios and capacity measurements, as well as for batch-wise sorption studies. These minerals include

- o major rock-forming minerals,
- o identified fracture minerals from drilling cores,
- o other common accessory minerals.

Included were also some common minerals

- o containing small amounts of actinides or lanthanides,
- o representative of all the six major silicate classes.

The selected minerals are listed in Table 1.

Pure well-characterized mineral fractions were crushed and sieved. The 0.044-0.063 mm fraction was washed and gently dried at 105°C (except for some of the clay minerals, see below) and used in the surface and capacity measurements.

## 3. EXPERIMENTAL

### 3.1. Surface areas

Surface/mass ratios were measured by the ethylene glycol method (E.G.) (14-16). A dried sample (200-1000 mg) was wetted by ethylene glycol followed by equilibration in an evacuated desiccator containing anhydrous calcium chloride-ethylene glycol solvate until the weight was constant. The remaining ethylene glycol layer on the mineral grains has a uniform thickness, and the total surface can be calculated from the weight difference between the untreated and the ethylene exposed sample. Relative errors are large; a minimum of 10-20% for values below 5 m<sup>2</sup>/g and possibly decreasing down to 5-10% at higher values.

Surface areas were also determined by the BET-method (17) for some of the minerals. The relative error is at least 10-15% in these measurements.

### 3.2. Exchange capacities

Anion and cation exchange capacities (AEC and CEC, meq/kg) were determined

Table 1 Minerals selected for studies of anion and cation exchanges capacitities (AEC and CEC) and determinations of surface areas.

Class	Name <sup>a</sup>	Remark
1. Sulfides	Galena	
	Sphalerite	
	Chalcopyrite	
	Pyrrhotite	
	Cinnabar	
2. Oxides	Pyrite	F
	Corundum	
Hydroxides	Hematite	
	Pyrolusite	
	Magnetite	
	Limonite/Goethite	
	Gibbsite	
3. Halides,	Fluorite	
	Carbonates	Calcite
Sulfates	Dolomite	F
Phosphates	Gypsum/Anhydrite	F
	Apatite	
4. Silicates		
a. nesosilicates	Olivine	M
	Garnet/Almandine	
	Zircon	
	Sphene	
b. sorosilicates	Epidote	F
c. cyclosilicates	Beryl	
c. inosilicates	Augite	
	Hornblende	M
d. phyllosilicates	Attapulgite	
	Serpentine	
	Kaolinite	F
	Halloysite	
	Montmorillonite	F
	Palygorskite	F
	Muscovite	M
	Biotite	M,F
	Chlorite	F
	Prehnite	F
	e. tectosilicates	Quartz
Microcline		M
Albite		M
Anorthite/Bytownite		M
Analcime		F
Stilbite		F
Laumontite	F	

<sup>a</sup> See description and composition e.g. in ref. 2. Detailed information concerning the particular mineral samples investigated in this study (origin, chemical composition, X-ray diffraction data etc.) are available but not included in this report.

<sup>b</sup> F = identified in fractures of crystalline rock (3,4).  
M = Major component in igneous rocks.



for the minerals as a function of pH. An isotopic dilution technique was employed (18), using  $^{82}\text{Br}$  (35h) and  $^{22}\text{Na}$  (2.6y) as tracers in the saturation of the mineral samples with  $\text{Br}^-$  and  $\text{Na}^+$ , respectively. A minimum of 3-4 samples were exposed to a spiked fairly concentrated NaBr-solution (0.5 M or higher) of known specific activity and of various pH (5-10). The minerals were saturated with respect to  $\text{Na}^+$  and  $\text{Br}^-$  (total contact time of 96h), and pH was measured. The aqueous phase was removed by centrifugation and the solid was thoroughly washed with methanol (5 times) to remove any remaining NaBr-solution. The total amount of  $^{22}\text{Na}$  and  $^{82}\text{Br}$  remaining on the solid was determined, and the amount of only  $^{22}\text{Na}$  after 6 weeks of storage, when the  $^{82}\text{Br}$  had decayed almost completely. The amounts of exchangeable  $\text{Na}^+$  and  $\text{Br}^-$  were calculated from the known specific activities.

#### 4. RESULTS AND DISCUSSION

Calculated surface/mass ratios are given in Table 2. The values obtained by the E.G.-method would possibly be representative of the surfaces available for interactions with species in aqueous phases in contact with the solids. The E.G.-surfaces are generally larger than the BET-surfaces for the same solid material, Fig. 1. The correlation between E.G.- and BET-surface data is, however, acceptable, considering the relative errors of these measurements.

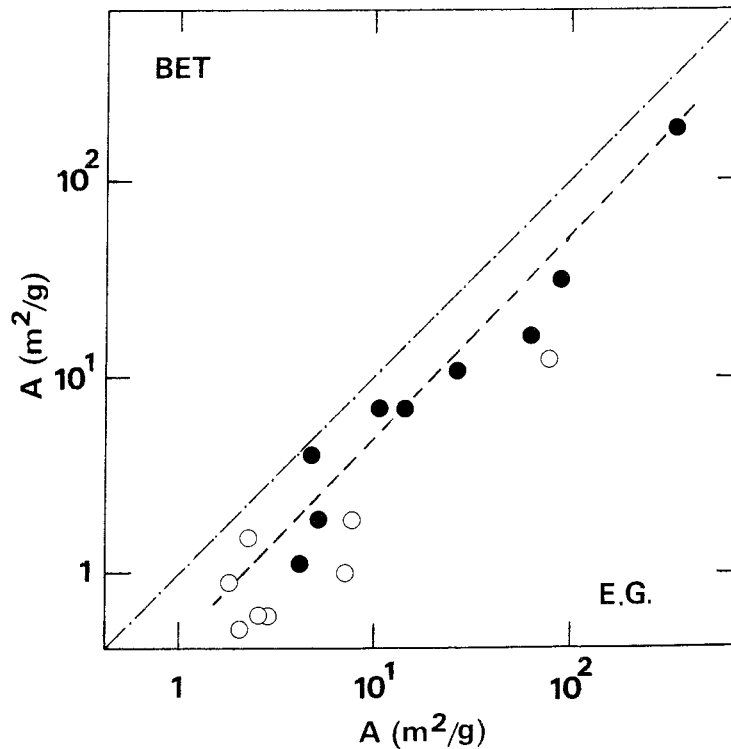
The measured exchange capacities (AEC and CEC) are given in Fig. 2-10 and summarized in Table 3. The anion exchange capacity is generally low both on non-silicates and silicates, rarely above 1 meq/kg. Exceptions are limonite and pyrolusite among the oxides/hydroxides (surface effects; small particles) and some of the silicates like olivine, zircon, attapulgite, muscovite, bytownite and laumontite which have values around or slightly above 1 meq/kg. High values (above 10 meq/kg) were found for some of the zeolites (analcime, and particularly stilbite) as well as for palygorskite, and occasionally for limonite (not given in Table 3). The AEC is slightly decreasing with increasing pH.

The cation exchange capacity is generally low for the halides, sulfates and phosphates among the non-silicates (< 1 meq/kg), and usually significantly higher, but still low (around 1 meq/kg) for the oxides. Exceptions are limonite and pyrolusite (surface effects).

Table 2 Surface/mass ratios.

Mineral	Surface/mass ratio, m <sup>2</sup> /g	
	Ethylene glycol (E.G.)	BET
Chalcopyrite	7.2	1.0
Cinnabar	7.7	1.9
Pyrite	7.0	
Hematite	1.8	0.9
Magnetite	2.1	1.5
Corundum	2.1	0.5
Limonite <sup>a</sup>	80	13
Gibbsite	13	
Fluorite	1.6	
Calcite	2.9	0.6
Dolomite	4.0	
Anhydrite	3.8	
Apatite	2.8	0.6
Olivine	5.0	2.0
Zircon	4.1	
Garnet/Almandine	2.1	
Sphene	3.3	
Epidote	4.2	
Augite	6.3	
Hornblende	4.6	4.3
Attapulgite <sup>a</sup>	340	190
Serpentine	61	15.7
Kaolinite <sup>a</sup>	27	11
Halloysite <sup>a</sup>	93	32.0
Montmorillonite <sup>a</sup>	800	
Muscovite	11	7.2
Biotite	14	7.0
Chlorite	24	
Quartz	2.8	0.3
Microcline	4.2	1.1
Albite	2.9	
Bytownite/Anorthite	3.1	

<sup>a</sup> Non-sieved material



**Figure 1** Correlation between surface/mass ratios ( $A$ ) as obtained by the BET-method and the ethylene glycol method (E.G.).

○ non-silicates, ● silicates.

Most silicates except the phyllosilicates and the zeolites among the tectosilicates have CEC-values in the range 1-10 meq/kg. For the phyllosilicates and zeolites values from 20-50 meq/kg (e.g. attapulgite, kaolinite, halloysite, muscovite, biotite, chlorite, laumontite) are usually observed, however, with the exceptions of some extreme high-capacity minerals with capacities of several hundred meq/kg (montmorillonite, analcime, stilbite).

The cation exchange capacity shows a pronounced pH-dependence (increasing CEC with pH) which is reasonable considering the charge vs pH of the mineral surfaces.

Thus, a degradation and weathering of e.g. feldspars into clay minerals can lead to an enhanced CEC by up to more than two orders of magnitude. It is obvious, that the composition of fracture minerals must have a large influence on the concentrations of cations in the water in contact with the clays ( $H^+$ ,  $Na^+$ ,  $K^+$ ,  $Mg^{2+}$ ,  $Ca^{2+}$ ) through ion exchange equilibria. This could be one reason for the close similarity in concentrations of these elements in deep groundwaters from a variety of geologic systems.

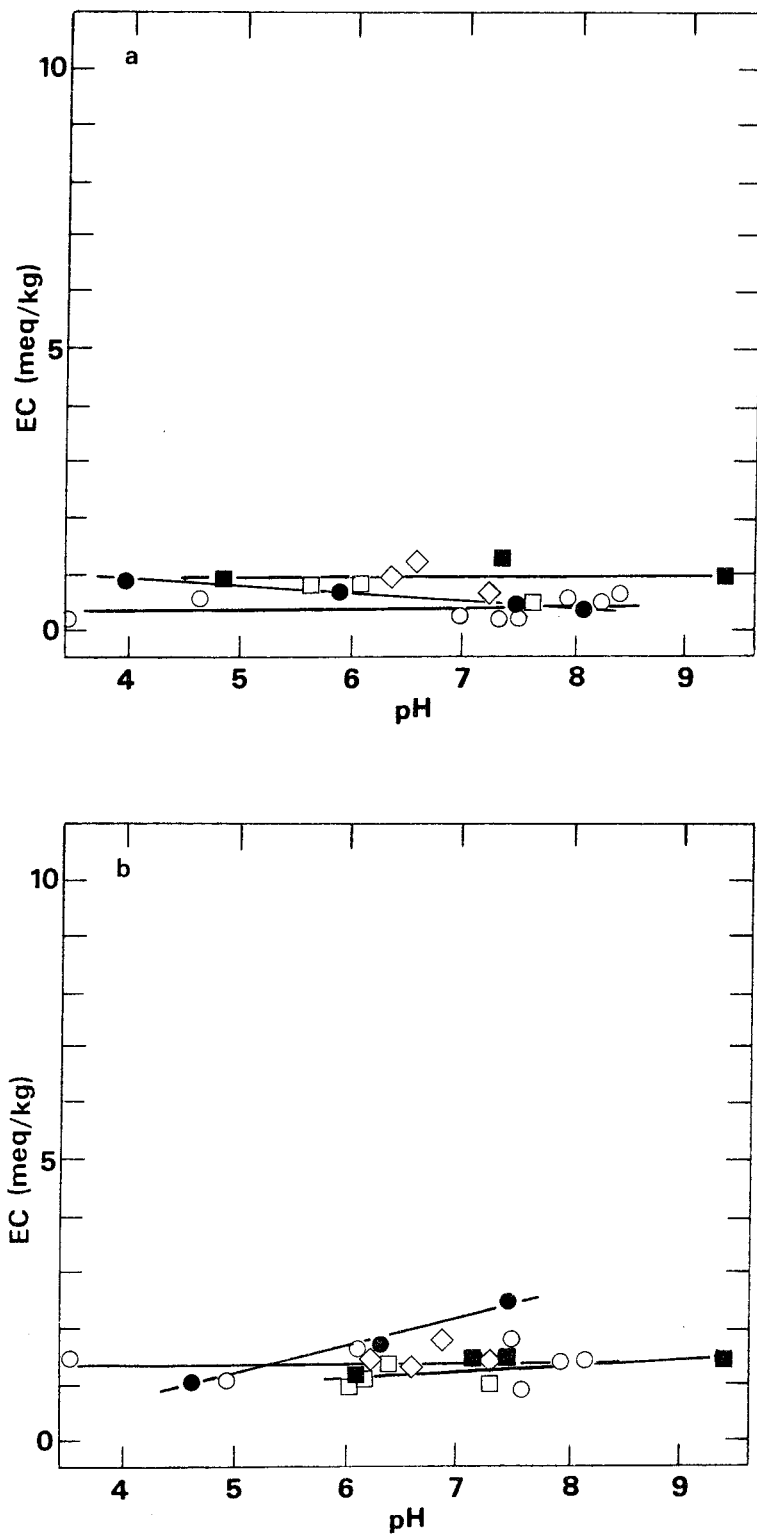


Figure 2 Exchange capacities for sulfides.

a. AEC; b. CEC.

■ galena, ◇ sphalerite, ● chalcopyrite,  
 □ pyrrhotite, ○ pyrite.

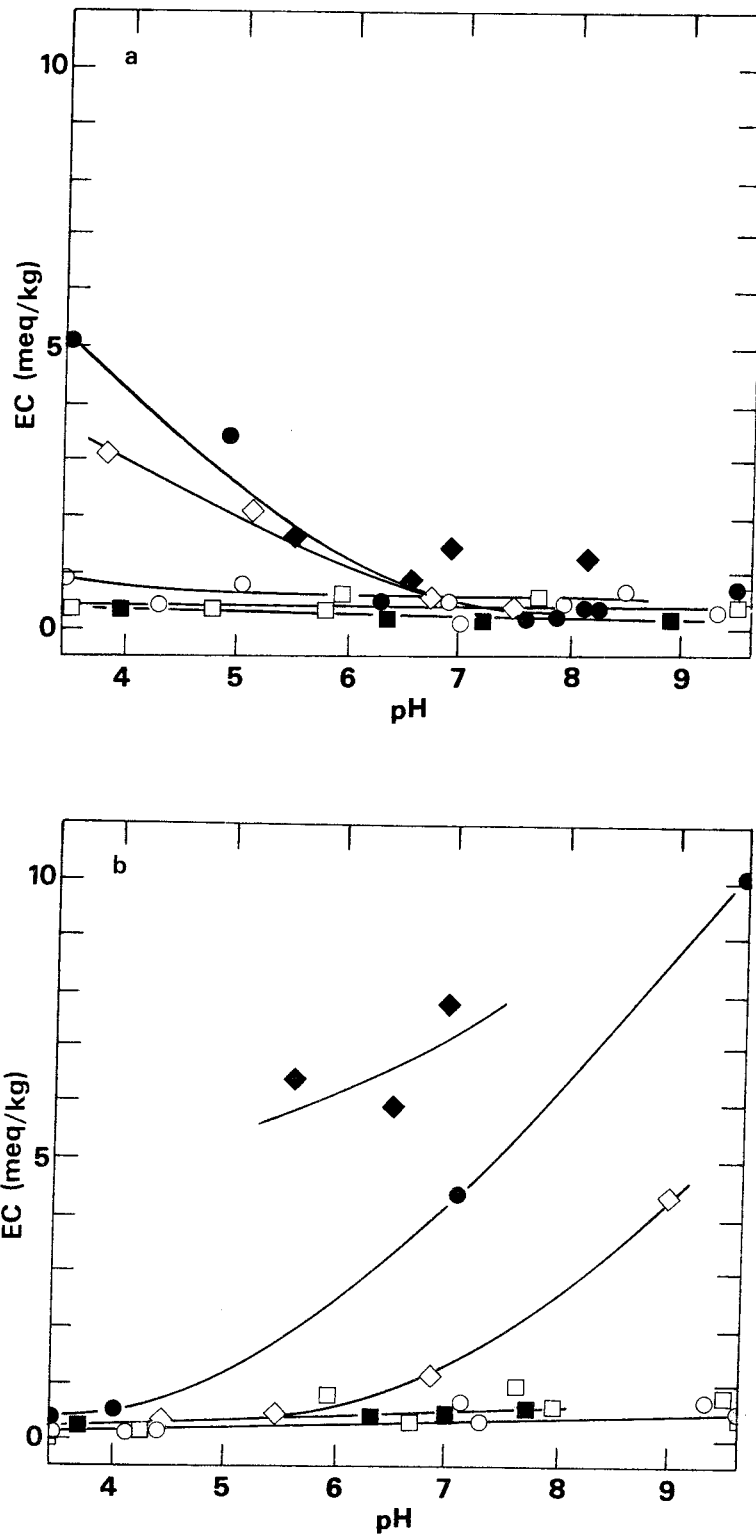


Figure 3 Exchange capacities for oxides and hydroxides.

a. AEC; b. CEC.

■ corundum, □ hematite, ◆ pyrolusite,  
○ magnetite, ● limonite, ◇ gibbsite.

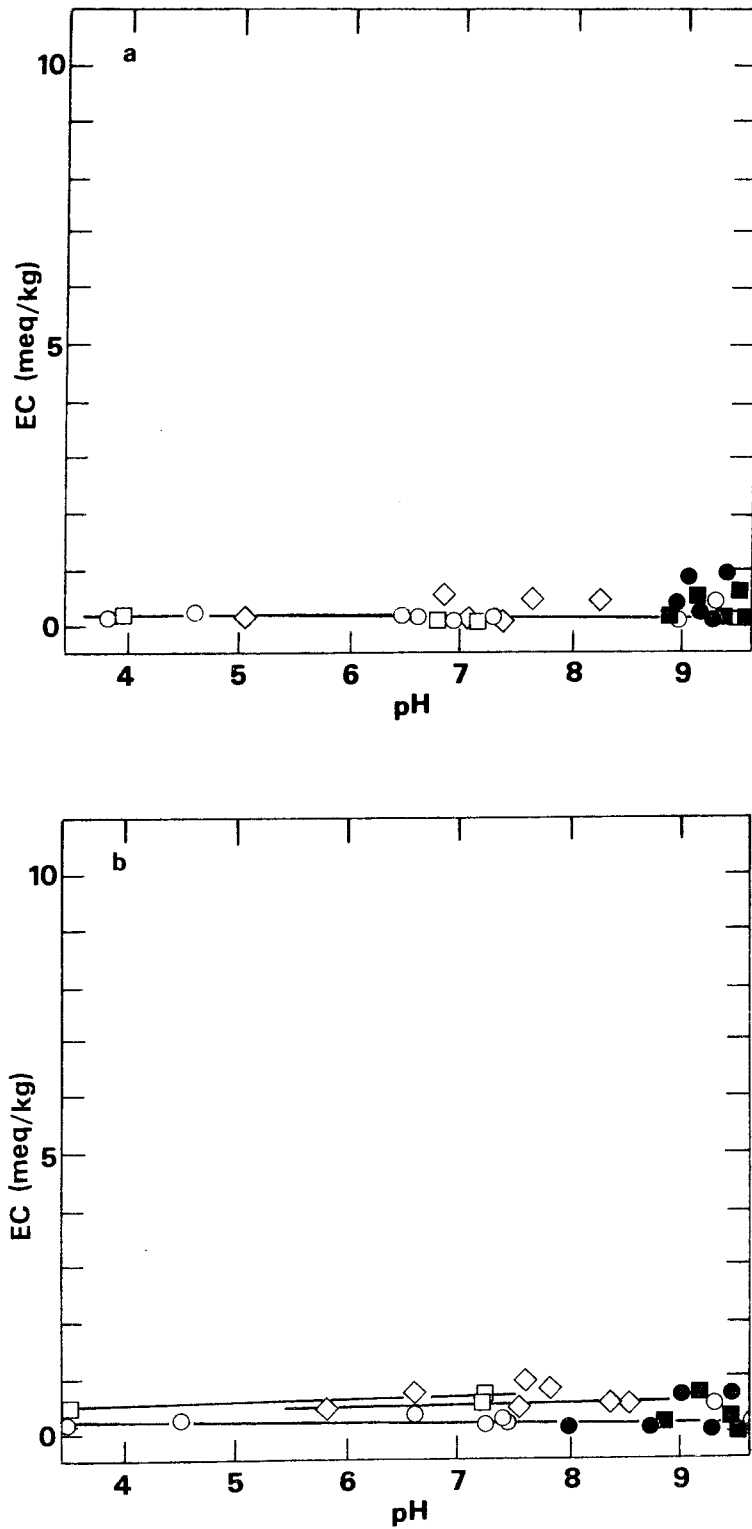


Figure 4 Exchange capacities for halides, carbonates, sulfates and phosphates.

a. AEC; b. CEC.

○ fluorite,    ■ calcite,    ● dolomite,  
 □ anhydrite,    ◇ apatite.

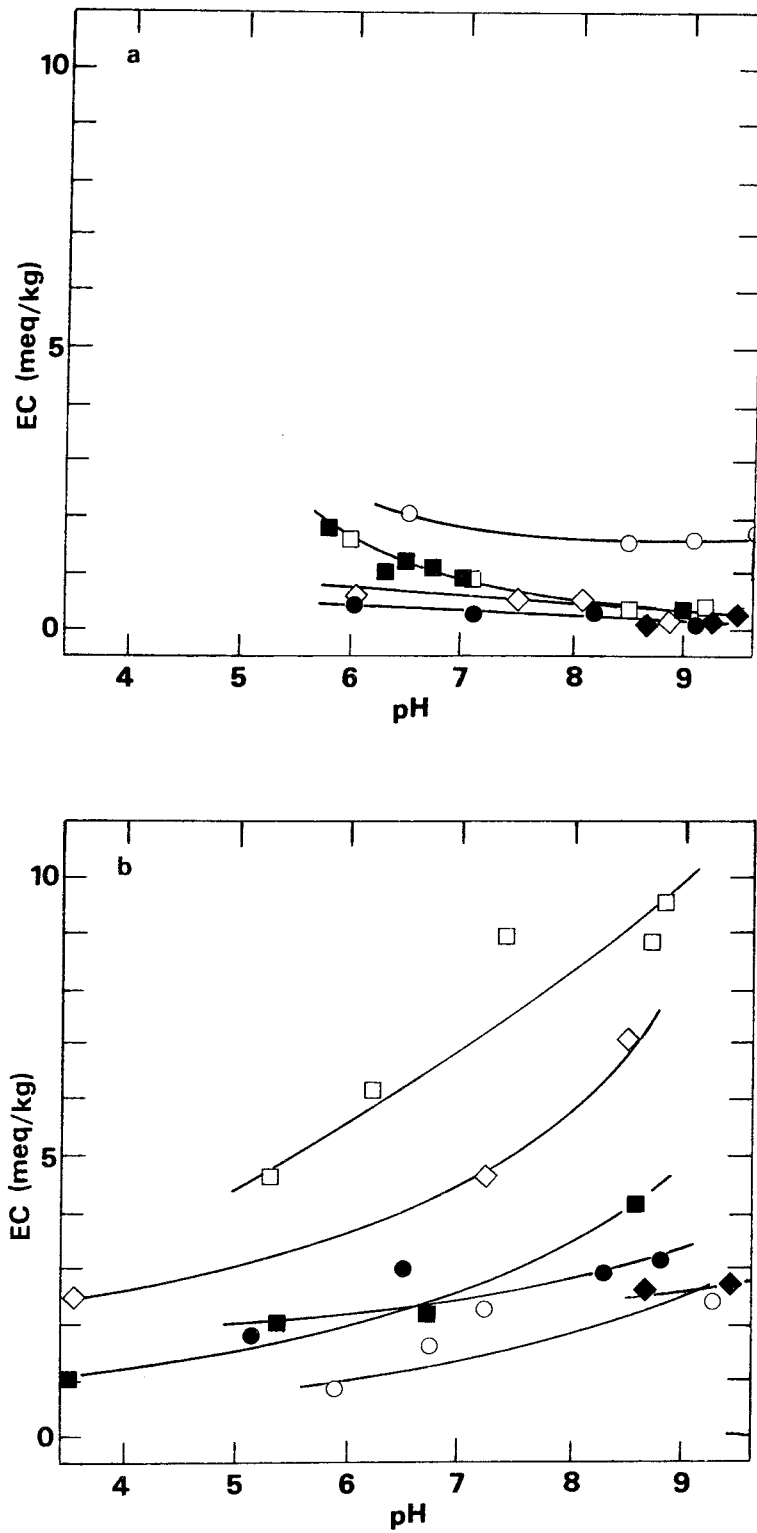


Figure 5 Exchange capacities for neso- and sorosilicates.

a. AEC; b. CEC.

○ olivine, ● almandine, ■ zircon, □ sphene,  
◇ epidote, ◆ prehnite (phyllosilicate).

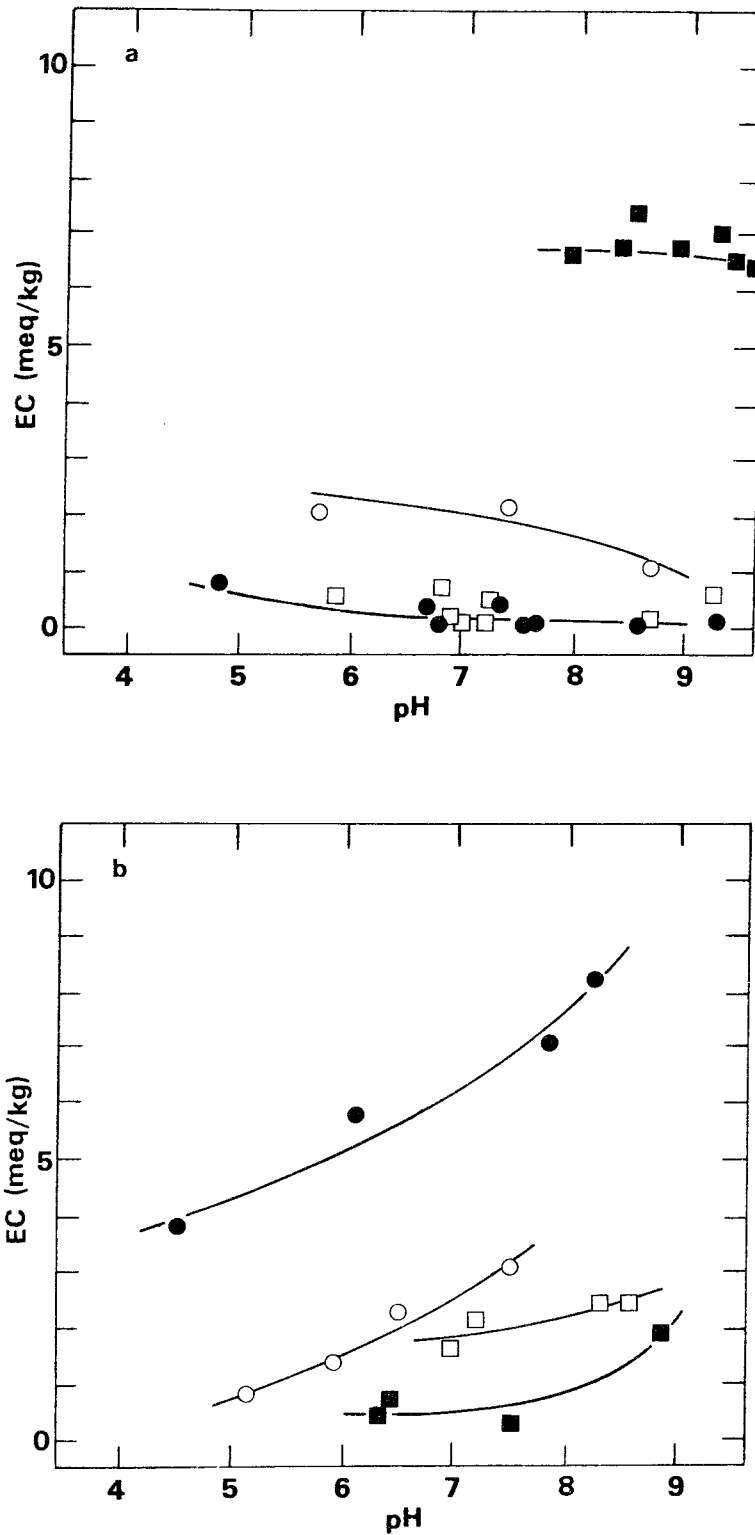


Figure 6 Exchange capacities for cyclo- and inosilicates.  
a. AEC; b. CEC.

○ beryl, ● augite, □ hornblende,  
■ serpentine (phyllosilicate).



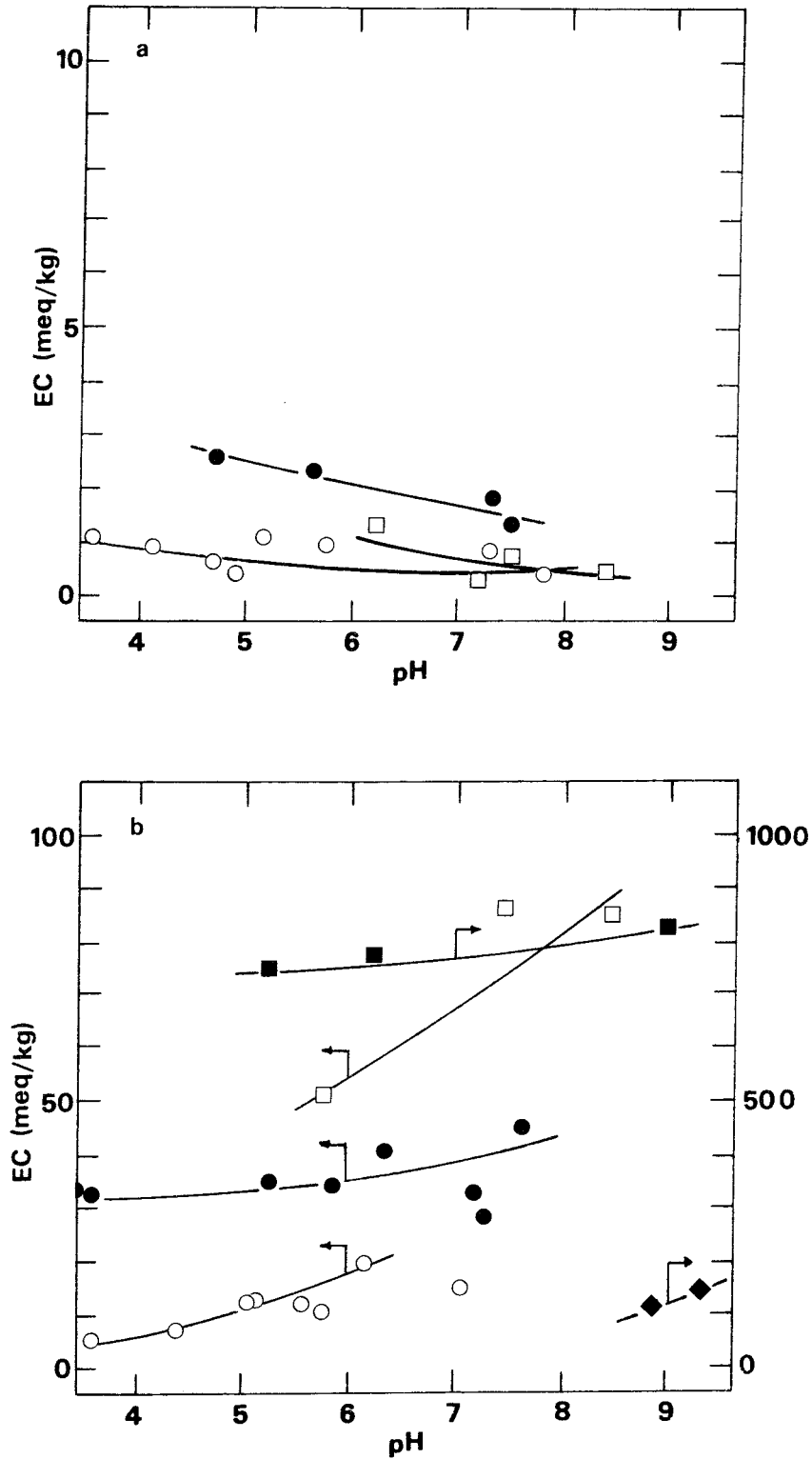


Figure 7 Exchange capacities for phyllosilicates.

a. AEC; b. CEC.

○ kaolinite, ● halloysite, ■ montmorillonite,  
◇ palygorskite, □ attapulgite (inosilicate).

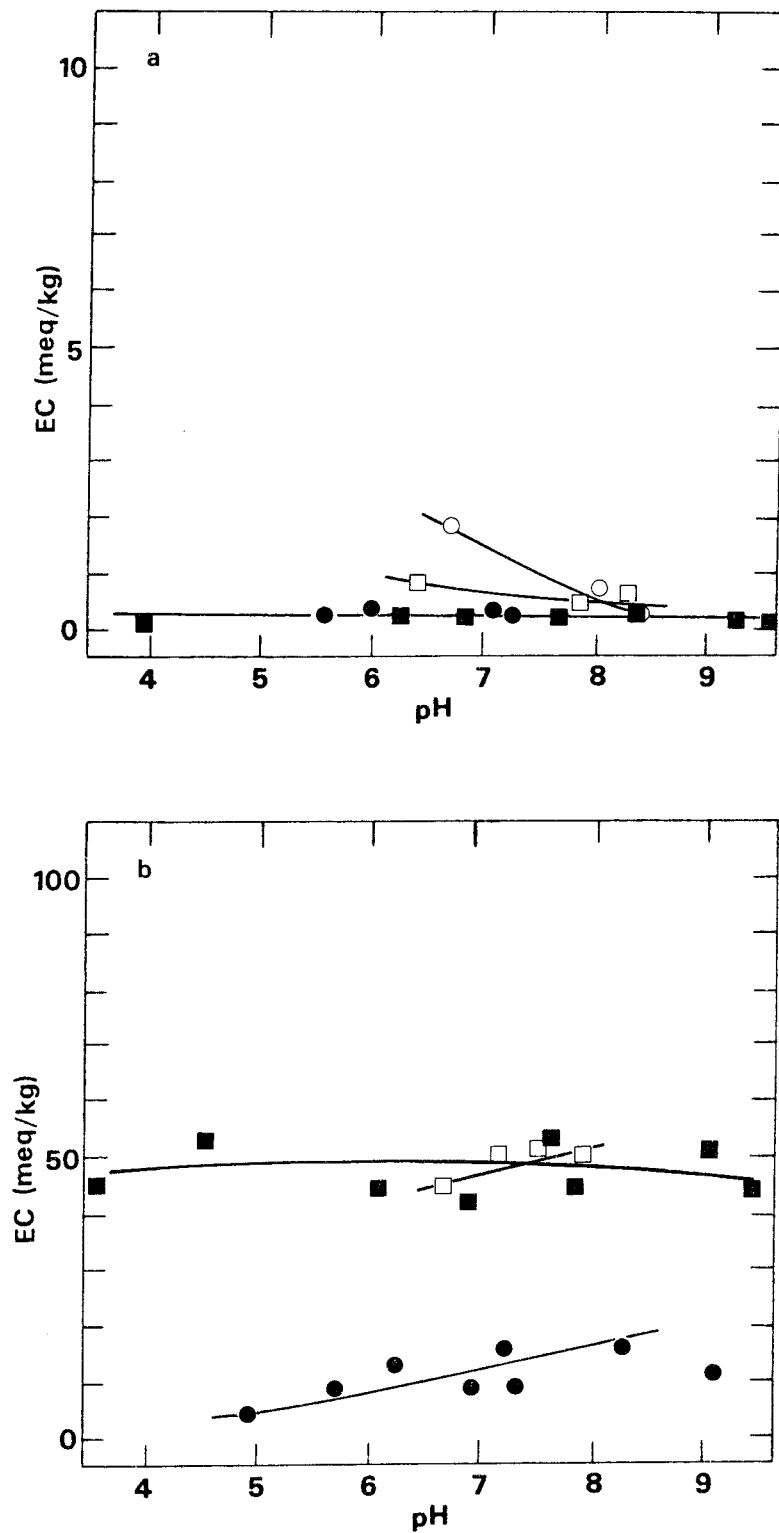


Figure 8 Exchange capacities for phyllosilicates.

a. AEC; b. CEC.

○ montmorillonite, □ muscovite, ● biotite, ■ chlorite.

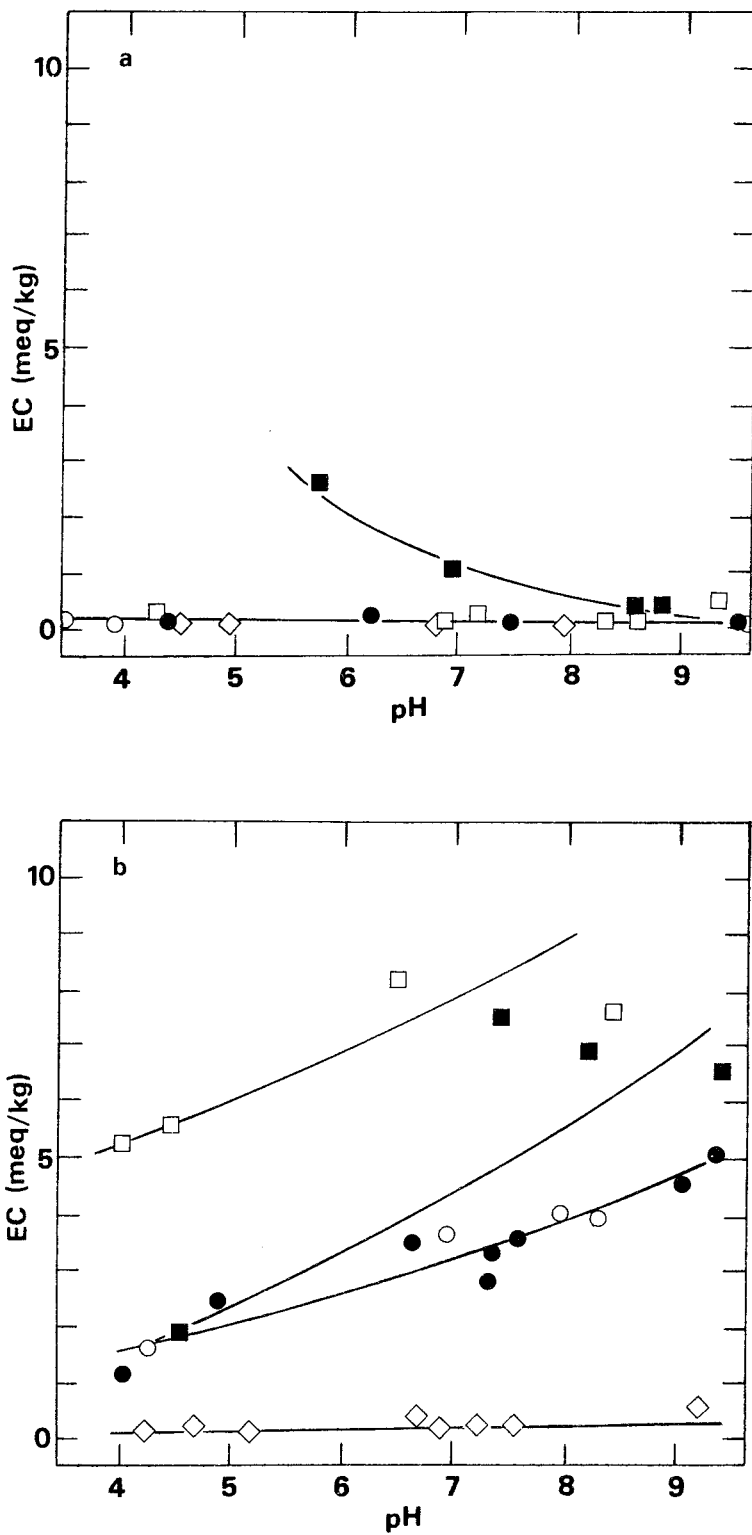


Figure 9 Exchange capacities for tectosilicates.

a. AEC; b. CEC.

◇ quartz, ● microcline, ○ albite,  
 ■ anorthite, □ bytownite.

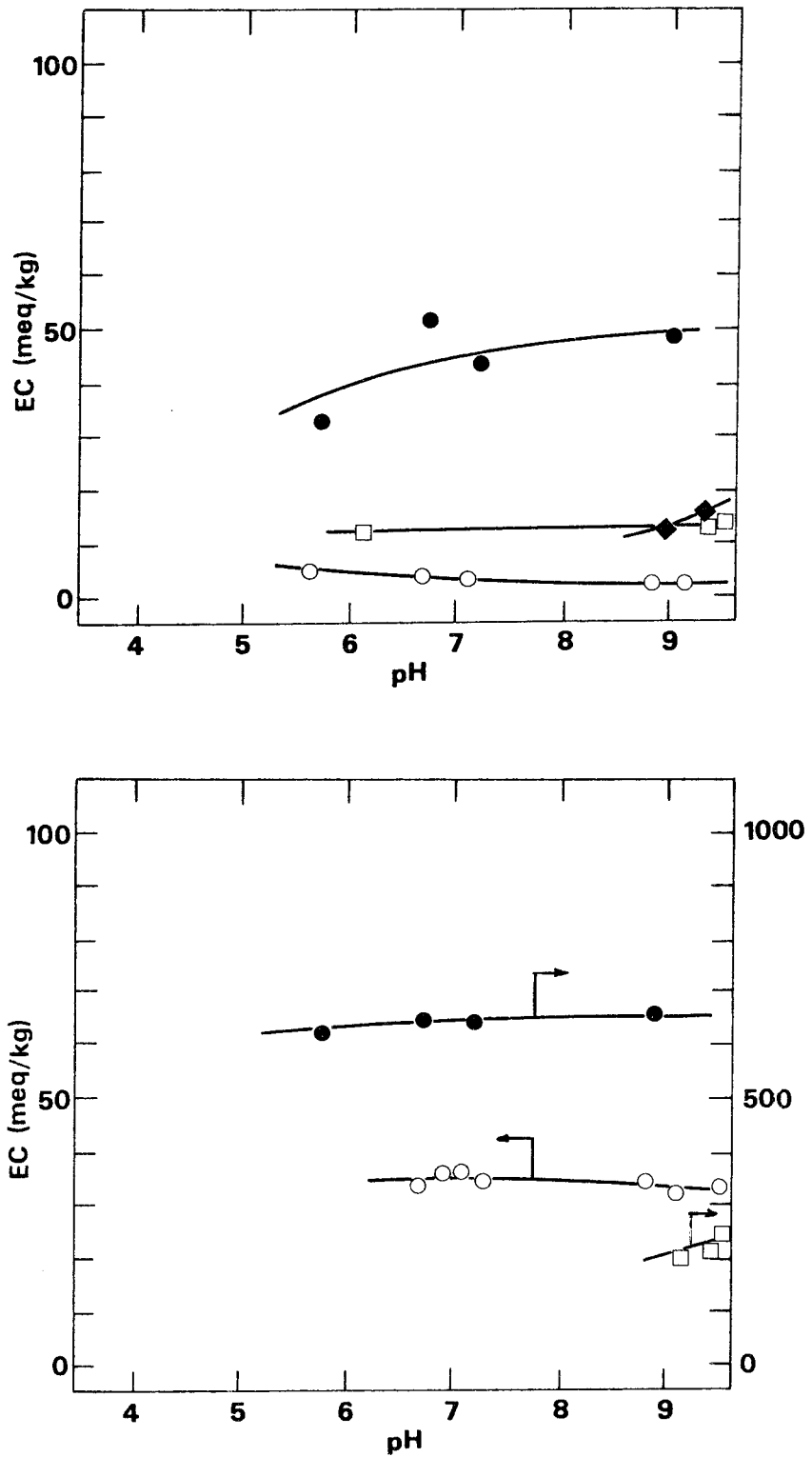


Figure 10 Exchange capacities for tectosilicates.

a. AEC; b. CEC.

□ analcime, ● stilbite, ○ laumontite,  
◆ palygorskite (phyllosilicate)

Table 3 Exchange capacities at pH5 and pH8  
(Extrapolations from Fig. 2-10)

	AEC, meq/kg		CEC, meq/kg	
	pH 5	pH 8	pH 5	pH 8
Galena	1.0	1.0	0.9	1.1
Sphalerite		0.5	1.3	1.4
Chalcopyrite	0.7	0.3	1.0	2.6
Pyrrhotite	0.9	0.4	0.8	1.5
Pyrite	0.2	0.2	1.3	1.5
Corundum	0.4	0.3	0.2	0.4
Hematite	0.3	0.4	0.2	0.5
Pyrolusite	2.0	1.5	5	8
Magnetite	0.8	0.5	0.2	0.4
Limonite	3.5	0.7	1.0	6.3
Fluorite	0.1	0.1	0.2	0.2
Calcite		0.1		0.2
Dolomite		0.1		0.2
Anhydrite	0.1	0.1	0.5	0.8
Apatite	0.1	0.1	0.4	0.5
Olivine	2.3	1.7	0.8	1.8
Zircon	2.3	0.6	1.5	3.5
Epidote	0.7	0.4	2.8	6.0
Beryl	2.5	1.8	0.8	4.5
Augite	0.2	0.2	4.0	8.0
Hornblende	0.2	0.1	1.8	2.5
Attapulgite	1.5	0.5	45	85
Serpentine		6.8	0.4	1.0
Kaolinite	0.8	0.6	9.0	28
Halloysite	2.5	1.5	32	45
Montmorillonite		0.7	700	800
Palygorskite		10		80
Muscovite	1.0	0.6		52
Biotite	0.4	0.3	6	17
Chlorite	0.3	0.3	50	50
Prehnite		0.3		25
Quartz	0.1	0.1	0.1	0.2
Microcline	0.2	0.1	1.8	3.7
Albite	0.2	0.1	1.8	3.7
Anorthite	3	0.5	2.2	5
Bytownite	0.3	0.2	6	9
Analcime	12	12		180
Stilbite	30	45	630	640
Laumontite	5	3	35	35

For many of the silicates there is a significant correlation between CEC and the surface/mass ratio, Fig. 11, and also to some extent for the non-silicates. Also there are significant correlations between radionuclid sorption behaviour and surface/mass ratio and/or exchange capacities, as discussed in detail elsewhere (5-7). This relations can briefly be summarized as follows:

- o The sorption is generally increasing with increasing available cation exchange capacity for non-hydrolyzed spherical cations like  $\text{Cs}^+$  and  $\text{Sr}^{2+}$ ; to some extent also for  $\text{Am}^{3+}$  (at low pH), but to a less extent for species like  $\text{NpO}_2^+$ .
- o There is only a qualitative correlation (or no correlation at all) between sorption and exchange capacity for hydrolysed or complexed ions (e.g.  $\text{Am(III)}$  at intermediate pH;  $\text{U(VI)}$  at intermediate pH in the presence of carbonate).
- o There is usually some minor correlation between sorption and surface/mass ratio for hydrolysed cations and a more significant correlation for anionic species (e.g.  $\text{I}^-$ , ref. 19).

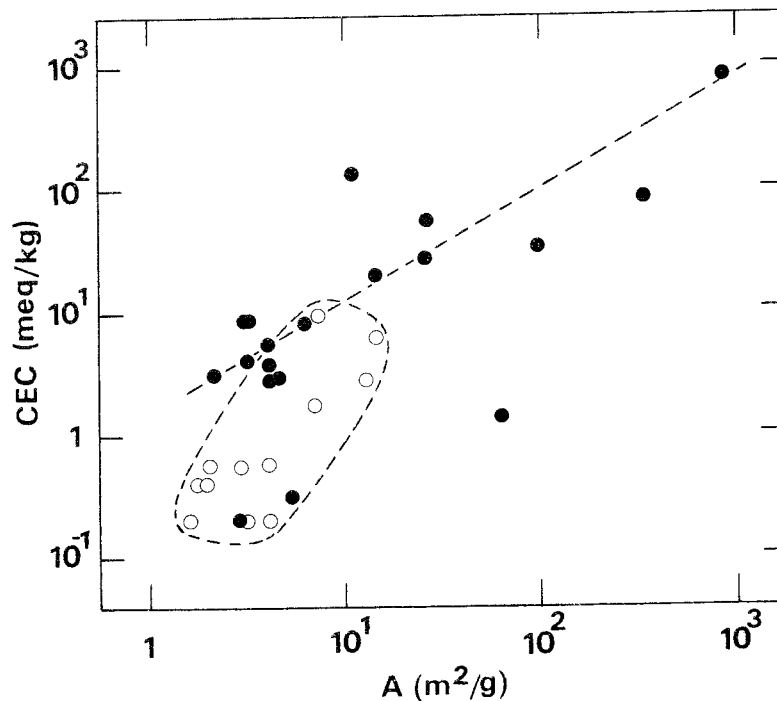


Figure 11 Correlation between cation exchange capacity (CEC) and surface/mass ratio (A).

○ non-silicates, ● silicates.

The presence of weathering products with high CEC in water-filled fractures will have a large impact on the Na-K-Mg-Ca-relations as well as on pH in deep groundwaters (20). Cation exchange reactions would be expected to be much faster than the release of cations due to the progressing weathering processes. These reactions would be rate-controlled by the diffusion of reacting species ( $H^+$ ) and reaction products through a solid layer, although porous and water saturated.

The degree of weathering, crystallinity, particle size distribution, porosity etc. of minerals from various sources vary considerably. The values in Table 2 and 3 are representative of the particular minerals selected in this study and for further sorption measurements reported elsewhere (5-7). Substantially different surface/mass ratios could be obtained for minerals from other sources or by the use of other experimental procedures or size fractions. The presence of small amounts of weathering products of high CEC (e.g. clay minerals) in minerals of low CEC (e.g. feldspars) could give apparent CEC-values that could be more than one order of magnitude higher than the values given in Table 3 in certain systems (micas, feldspars).

## 5. CONCLUSIONS

Some general conclusions are:

- o The anion exchange capacity is low for most of the studied mineral systems and decreasing with pH. Values above 1 meq/kg were only obtained for limonite (surface effect) and for some of the zeolites.
- o The cation is low for all non-silicates and only occasionally above 1 meq/kg, e.g. for the oxides and sulfides. Slightly higher values are obtained for most of the silicates, and extremely high values are obtained for clayish minerals as well as zeolites (e.g. up to 800 meq/kg) for montmorillonite).
- o The weathering and decomposition of rock-forming minerals generally gives products with a strongly increased CEC.
- o Exchange capacities, AEC (for anions like  $I^-$ ) and CEC (for cations) have a large and significant influence on the sorption of particularly non-hydrolyzed.

## 6. ACKNOWLEDGEMENT

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## 7. REFERENCES

1. As described in the reports issued by SKBF/KBS, Box 5864, S-102 48 Stockholm, Sweden (KBS-I: 1977, KBS-II: 1978, KBS-III: 1983, in press)
2. C.S. Hurlbut, Dana's Manual of Mineralogy, John Wiley and Sons Inc., New York 1966.
3. S.Å. Larson, E.-L. Tullborg and S. Lindblom, "Sprickmineralogiska undersökningar", Report Prav 4.20, Programrådet för radioaktivt avfall, Stockholm 1980.
4. E.-L. Tullborg and S.Å. Larson, "Fissure Fillings from Finnsjön and Studsvik Sweden. Identification, Chemistry and Dating", KBS TR 82-20, Svensk Kärnbränslesäkerhet AB, Stockholm 1982.
5. B. Allard, S.Å. Larson, Y. Albinsson, E.-L. Tullborg, M. Karlsson, K. Andersson and B. Torstenfelt, "Minerals and Precipitates in Fractures and Their Effects on the Retention of Radionuclides in Crystalline Rocks", Proc. Workshop on Near-Field Phenomena in Geologic Repositories for Radioactive Waste, Seattle 1981, OECD/NEA, Paris 1982, p. 93.
6. B. Allard, "Sorption of Actinides in Granitic Rock", KBS TR 82-21, Svensk Kärnbränsleförsörjning AB, Stockholm 1982.
7. K. Andersson, B. Torstenfelt and B. Allard, "Sorption of Radionuclides in Geologic Systems", KBS TR 83-63, Svensk Kärnbränsleförsörjning AB, Stockholm 1983.
8. L. Birgersson and I. Neretnieks, "Diffusion in the Matrix of Granitic Rock. Field Tests in the Stripa Mine", KBS TR 82-08, Svensk Kärnbränsleförsörjning AB, Stockholm 1982.



9. B. Torstenfelt, T. Ittner, B. Allard, K. Andersson and U. Olofsson, "Mobilities of Radionuclides in Fresh and Fractured Crystalline Rock", KBS TR 82-26, Svensk Kärnbränsleförsörjning AB, Stockholm 1982.
10. T. Eriksen, "Radionuclide Transport in a Single Fissure. A Laboratory Study", KBS TR 83-01, Svensk Kärnbränsleförsörjning AB, Stockholm 1983.
11. I. Neretnieks, T. Eriksen and P. Tähtinen, "Tracer Movement in a Single Fissure in Granitic Rock: Some Experimental Results and Their Interpretation", Water Resources Res. 18 (1982) 849.
12. O. Landström, C.-E. Klockars, O. Persson, K. Andersson, B. Torstenfelt, B. Allard, E.-L. Tullborg and S.Å. Larson, "Migration Experiments in Studsvik", KBS TR 83-18, Svensk Kärnbränsleförsörjning AB, Stockholm 1983.
13. L. Moreno, I. Neretnieks and C.-E. Klockars, "Evaluation of Some Tracer Tests in the Granitic Rock at Finnsjön", KBS TR 83-38, Svensk Kärnbränsleförsörjning AB, Stockholm 1983.
14. R.S. Dyal and S.B. Hendricks, "Total Surface of Clays in Polar Liquids as a Characteristic Index", Soil Sci. 69 (1950) 421.
15. C.A. Bower and J.O. Goertzen, "Surface Area of Soils and Clays by an Equilibrium Ethylene Glycol Method", Soil Sci. 87 (1959) 289.
16. B.L. McNeal, "Effect of Exchangeable Cations on Glycol Retention by Clay Minerals", Soil Sci. 97 (1964) 96.
17. S. Brunauer, P.H. Emmett and R. Teller, "Adsorption of Gases in Multi-molecular Layers", J. Am. Chem. Soc. 60 (1938) 309.
18. C.W. Francis and D.F. Grigal, "A Rapid and Simple Procedure Using Sr<sup>85</sup> for Determining Cation Exchange Capacities of Soils and Clays", Soil Sci. 112 (1971) 17.

19. B. Allard, B. Torstenfelt, K. Andersson and J. Rydberg, "Possible Retention of Iodine in the Ground", in C.J. Northrup (Ed.), Scientific Basis for Nuclear Waste Management. Vol. 2, Plenum Publ. Corp., New York 1981, p. 673.
  
20. B. Allard, S.Å. Larson, E.-L. Tullborg and P. Wikberg, "Chemistry of Deep Groundwaters from Granitic Bedrock", KBS TR 83-59, Svensk Kärnbränsleförsörjning AB, Stockholm 1983.

LIST OF KBS's TECHNICAL REPORTS

1977-78

TR 121 KBS Technical Reports 1 - 120.  
Summaries. Stockholm, May 1979.

1979

TR 79-28 The KBS Annual Report 1979.  
KBS Technical Reports 79-01--79-27.  
Summaries. Stockholm, March 1980.

1980

TR 80-26 The KBS Annual Report 1980.  
KBS Technical Reports 80-01--80-25.  
Summaries. Stockholm, March 1981.

1981

TR 81-17 The KBS Annual Report 1981.  
KBS Technical Reports 81-01--81-16  
Summaries. Stockholm, April 1982.

1983

TR 83-01 Radionuclide transport in a single fissure  
A laboratory study  
Trygve E Eriksen  
Department of Nuclear Chemistry  
The Royal Institute of Technology  
Stockholm, Sweden 1983-01-19

TR 83-02 The possible effects of alfa and beta radiolysis  
on the matrix dissolution of spent nuclear fuel  
I Grenthe  
I Puigdomènech  
J Bruno  
Department of Inorganic Chemistry  
Royal Institute of Technology  
Stockholm, Sweden January 1983

- TR 83-03 Smectite alteration  
Proceedings of a colloquium at State University of  
New York at Buffalo, May 26-27, 1982  
Compiled by Duwayne M Anderson  
State University of New York at Buffalo  
February 15, 1983
- TR 83-04 Stability of bentonite gels in crystalline rock -  
Physical aspects  
Roland Pusch  
Division Soil Mechanics, University of Luleå  
Luleå, Sweden, 1983-02-20
- TR 83-05 Studies in pitting corrosion on archeological  
bronzes - Copper  
Åke Bresle  
Jozef Saers  
Birgit Arrhenius  
Archaeological Research Laboratory  
University of Stockholm  
Stockholm, Sweden 1983-01-02
- TR 83-06 Investigation of the stress corrosion cracking of  
pure copper  
L A Benjamin  
D Hardie  
R N Parkins  
University of Newcastle upon Tyne  
Department of Metallurgy and Engineering Materials  
Newcastle upon Tyne, Great Britain, April 1983
- TR 83-07 Sorption of radionuclides on geologic media -  
A literature survey. I: Fission Products  
K Andersson  
B Allard  
Department of Nuclear Chemistry  
Chalmers University of Technology  
Göteborg, Sweden 1983-01-31
- TR 83-08 Formation and properties of actinide colloids  
U Olofsson  
B Allard  
M Bengtsson  
B Torstenfelt  
K Andersson  
Department of Nuclear Chemistry  
Chalmers University of Technology  
Göteborg, Sweden 1983-01-30
- TR 83-09 Complexes of actinides with naturally occurring  
organic substances - Literature survey  
U Olofsson  
B Allard  
Department of Nuclear Chemistry  
Chalmers University of Technology  
Göteborg, Sweden 1983-02-15
- TR 83-10 Radiolysis in nature:  
Evidence from the Oklo natural reactors  
David B Curtis  
Alexander J Gancarz  
New Mexico, USA February 1983

- TR 83-11 Description of recipient areas related to final storage of unprocessed spent nuclear fuel  
Björn Sundblad  
Ulla Bergström  
Studsvik Energiteknik AB  
Nyköping, Sweden 1983-02-07
- TR 83-12 Calculation of activity content and related properties in PWR and BWR fuel using ORIGEN 2  
Ove Edlund  
Studsvik Energiteknik AB  
Nyköping, Sweden 1983-03-07
- TR 83-13 Sorption and diffusion studies of Cs and I in concrete  
K Andersson  
B Torstenfelt  
B Allard  
Department of Nuclear Chemistry  
Chalmers University of Technology  
Göteborg, Sweden 1983-01-15
- TR 83-14 The complexation of Eu(III) by fulvic acid  
J A Marinsky  
State University of New York at Buffalo, Buffalo, NY  
1983-03-31
- TR 83-15 Diffusion measurements in crystalline rocks  
Kristina Skagius  
Ivars Neretnieks  
Royal Institute of Technology  
Stockholm, Sweden 1983-03-11
- TR 83-16 Stability of deep-sited smectite minerals in crystalline rock - chemical aspects  
Roland Pusch  
Division of Soil Mechanics, University of Luleå  
1983-03-30
- TR 83-17 Analysis of groundwater from deep boreholes in Gideå Sif Laurent  
Swedish Environmental Research Institute  
Stockholm, Sweden 1983-03-09
- TR 83-18 Migration experiments in Studsvik  
O Landström  
Studsvik Energiteknik AB  
C-E Klockars  
O Persson  
E-L Tullborg  
S Å Larson  
Swedish Geological  
K Andersson  
B Allard  
B Torstenfelt  
Chalmers University of Technology  
1983-01-31

- TR 83-19 Analysis of groundwater from deep boreholes in Fjällveden  
Sif Laurent  
Swedish Environmental Research Institute  
Stockholm, Sweden 1983-03-29
- TR 83-20 Encapsulation and handling of spent nuclear fuel for final disposal  
1 Welded copper canisters  
2 Pressed copper canisters (HIPOW)  
3 BWR Channels in Concrete  
B Lönnerberg, ASEA-ATOM  
H Larker, ASEA  
L Ageskog, VBB  
May 1983
- TR 83-21 An analysis of the conditions of gas migration from a low-level radioactive waste repository  
C Braester  
Israel Institute of Technology, Haifa, Israel  
R Thunvik  
Royal Institute of Technology  
November 1982
- TR 83-22 Calculated temperature field in and around a repository for spent nuclear fuel  
Taivo Tarandi, VBB  
Stockholm, Sweden April 1983
- TR 83-23 Preparation of titanates and zeolites and their uses in radioactive waste management, particularly in the treatment of spent resins  
Å Hultgren, editor  
C Airola  
Studsvik Energiteknik AB  
S Forberg, Royal Institute of Technology  
L Fälth, University of Lund  
May 1983
- TR 83-24 Corrosion resistance of a copper canister for spent nuclear fuel  
The Swedish Corrosion Research Institute and its reference group  
Stockholm, Sweden April 1983
- TR 83-25 Feasibility study of EB welding of spent nuclear fuel canisters  
A Sanderson, T F Szluha, J Turner  
Welding Institute  
Cambridge, United Kingdom April 1983
- TR 83-26 The KBS UO<sub>2</sub> leaching program  
Summary Report 1983-02-01  
Ronald Forsyth, Studsvik Energiteknik AB  
Nyköping, Sweden February 1983
- TR 83-27 Radiation effects on the chemical environment in a radioactive waste repository  
Trygve Eriksen  
Royal Institute of Technology, Stockholm  
Arvid Jacobsson  
University of Luleå, Luleå  
Sweden 1983-07-01

- TR 83-28 An analysis of selected parameters for the  
BIOPATH-program  
U Bergström  
A-B Wilkens  
Studsvik Energiteknik AB  
Nyköping, Sweden 1983-06-08
- TR 83-29 On the environmental impact of a repository for  
spent nuclear fuel  
Otto Brotzen  
Stockholm, Sweden April 1983
- TR 83-30 Encapsulation of spent nuclear fuel -  
Safety Analysis  
ES-konsult AB  
Stockholm, Sweden April 1983
- TR 83-31 Final disposal of spent nuclear fuel -  
Standard programme for site investigations  
Compiled by  
Ulf Thoregren  
Swedish Geological  
April 1983
- TR 83-32 Feasibility study of detection of defects in thick  
welded copper  
Tekniska Röntgencentralen AB  
Stockholm, Sweden April 1983
- TR 83-33 The interaction of bentonite and glass with  
aqueous media  
M Mosslehi  
A Lambrosa  
J A Marinsky  
State University of New York  
Buffalo, NY, USA April 1983
- TR 83-34 Radionuclide diffusion and mobilities in compacted  
bentonite  
B Torstenfelt  
B Allard  
K Andersson  
H Kipatsi  
L Eliasson  
U Olofsson  
H Persson  
Chalmers University of Technology  
Göteborg, Sweden April 1983
- TR 83-35 Actinide solution equilibria and solubilities in  
geologic systems  
B Allard  
Chalmers University of Technology  
Göteborg, Sweden 1983-04-10
- TR 83-36 Iron content and reducing capacity of granites and  
bentonite  
B Torstenfelt  
B Allard  
W Johansson  
T Ittner  
Chalmers University of Technology  
Göteborg, Sweden April 1983

- TR 83-37 Surface migration in sorption processes  
A Rasmuson  
I Neretnieks  
Royal Institute of Technology  
Stockholm, Sweden March 1983
- TR 83-38 Evaluation of some tracer tests in the granitic  
rock at Finnsjön  
L Moreno  
I Neretnieks  
Royal Institute of Technology, Stockholm  
C-E Klockars  
Swedish Geological, Uppsala  
April 1983
- TR 83-39 Diffusion in the matrix of granitic rock  
Field test in the Stripa mine. Part 2  
L Birgersson  
I Neretnieks  
Royal Institute of Technology  
Stockholm, Sweden March 1983
- TR 83-40 Redox conditions in groundwaters from  
Svartboberget, Gideå, Fjällveden and Kamlunge  
P Wikberg  
I Grenthe  
K Axelsen  
Royal Institute of Technology  
Stockholm, Sweden 1983-05-10
- TR 83-41 Analysis of groundwater from deep boreholes in  
Svartboberget  
Sif Laurent  
Swedish Environmental Research Institute  
Stockholm, Sweden 1983-06-10
- TR 83-42 Final disposal of high-level waste and spent  
nuclear fuel - foreign activities  
R Gelin  
Studsvik Energiteknik AB  
Nyköping, Sweden May 1983
- TR 83-43 Final disposal of spent nuclear fuel - geological,  
hydrological and geophysical methods for site  
characterization  
K Ahlbom  
L Carlsson  
O Olsson  
Swedish Geological  
Sweden May 1983
- TR 83-44 Final disposal of spent nuclear fuel - equipment  
for site characterization  
K Almén, K Hansson, B-E Johansson, G Nilsson  
Swedish Geological  
O Andersson, IPA-Konsult  
P Wikberg, Royal Institute of Technology  
H Åhagen, SKBF/KBS  
May 1983



- TR 83-45 Model calculations of the groundwater flow at Finnsjön, Fjällveden, Gideå and Kamlunge  
L Carlsson  
A Winberg  
Swedish Geological, Göteborg  
B Grundfelt  
Kemakta Consultant Company, Stockholm  
May 1983
- TR 83-46 Use of clays as buffers in radioactive repositories  
Roland Pusch  
University of Luleå  
Luleå May 25 1983
- TR 83-47 Stress/strain/time properties of highly compacted bentonite  
Roland Pusch  
University of Luleå  
Luleå May 1983
- TR 83-48 Model calculations of the migration of radionuclides from a repository for spent nuclear fuel  
A Bengtsson  
Kemakta Consultant Company, Stockholm  
M Magnusson  
I Neretnieks  
A Rasmuson  
Royal Institute of Technology, Stockholm  
May 1983
- TR 83-49 Dose and dose commitment calculations from ground-waterborne radioactive elements released from a repository for spent nuclear fuel  
U Bergström  
Studsvik Energiteknik AB  
Nyköping, Sweden May 1983
- TR 83-50 Calculation of fluxes through a repository caused by a local well  
R Thunvik  
Royal Institute of Technology  
Stockholm, Sweden May 1983
- TR 83-51 GWHRT - A finite element solution to the coupled ground water flow and heat transport problem in three dimensions  
B Grundfelt  
Kemakta Consultant Company  
Stockholm, Sweden May 1983
- TR 83-52 Evaluation of the geological, geophysical and hydrogeological conditions at Fjällveden  
K Ahlbom  
L Carlsson  
L-E Carlsten  
O Duran  
N-Å Larsson  
O Olsson  
Swedish Geological  
May 1983

- TR 83-53 Evaluation of the geological, geophysical and hydrogeological conditions at Gideå  
K Ahlbom  
B Albino  
L Carlsson  
G Nilsson  
O Olsson  
L Stenberg  
H Timje  
Swedish Geological  
May 1983
- TR 83-54 Evaluation of the geological, geophysical and hydrogeological conditions at Kamlunge  
K Ahlbom  
B Albino  
L Carlsson  
J Danielsson  
G Nilsson  
O Olsson  
S Sehlstedt  
V Stejskal  
L Stenberg  
Swedish Geological  
May 1983
- TR 83-55 Evaluation of the geological, geophysical and hydrogeological conditions at Svartboberget  
K Ahlbom  
L Carlsson  
B Gentzschein  
A Jämtlid  
O Olsson  
S Tirén  
Swedish Geological  
May 1983
- TR 83-56 I: Evaluation of the hydrogeological conditions at Finnsjön  
II: Supplementary geophysical investigations of the Sternö peninsula  
B Hesselström  
L Carlsson  
G Gidlund  
Swedish Geological  
May 1983
- TR 83-57 Neotectonics in northern Sweden - geophysical investigations  
H Henkel  
K Hult  
L Eriksson  
Geological Survey of Sweden  
L Johansson  
Swedish Geological  
May 1983

- TR 83-58 Neotectonics in northern Sweden - geological investigations  
R Lagerbäck  
F Witschard  
Geological Survey of Sweden  
May 1983
- TR 83-59 Chemistry of deep groundwaters from granitic bedrock  
B Allard  
Chalmers University of Technology  
S Å Larson  
E-L Tullborg  
Swedish Geological  
P Wikberg  
Royal Institute of Technology  
May 1983
- TR 83-60 On the solubility of technetium in geochemical systems  
B Allard  
B Torstenfelt  
Chalmers University of Technology  
Göteborg, Sweden 1983-05-05
- TR 83-61 Sorption behaviour of well-defined oxidation states  
B Allard  
U Olofsson  
B Torstenfelt  
H Kipatsi  
Chalmers University of Technology  
Göteborg, Sweden 1983-05-15
- TR 83-62 The distribution coefficient concept and aspects on experimental distribution studies  
B Allard  
K Andersson  
B Torstenfelt  
Chalmers University of Technology  
Göteborg, Sweden May 1983
- TR 83-63 Sorption of radionuclides in geologic systems  
K Andersson  
B Torstenfelt  
B Allard  
Chalmers University of Technology  
Göteborg, Sweden 1983-06-15
- TR 83-64 Ion exchange capacities and surface areas of some major components and common fracture filling materials of igneous rocks  
B Allard  
M Karlsson  
Chalmers University of Technology  
E-L Tullborg  
S Å Larson  
Swedish Geological  
Göteborg, Sweden May 1983