

## **Groundwater Chemistry of Some Selected Areas in Southeastern Norway**

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Within three areas in Southeastern Norway, Lake Mjøsa district, Ås and Moss – Jeløy, groundwater samples for chemical analysis were collected during the years 1971-77 from 98 drilled wells in bedrocks. The water was taken at depths ranging from 15 m to 110 m below the land surface. The groundwater surface is usually present well below the overlying unconsolidated deposits of glacial, glacialfluvial or marine origin.

The movement of groundwater within the aquifers investigated is so slow that regional changes in water quality is not only dependent on weathering in the unsaturated zone, but also dependent on the solution of reservoir rocks below the groundwater surface. Variations in specific electrical conductance (20°C) largely reflects the different reservoir rock types. The highest values, around 550  $\mu\text{S}/\text{cm}$ , are typically found in dark calcareous shales, while sandstones and gneisses give values around 300  $\mu\text{S}/\text{cm}$ .

The areas Ås and Moss-Jeløy are situated below the Late-Postglacial marine limit. The groundwater is here more or less influenced by ancient sea salts, perhaps also by fossil sea water, left over in sediments or in rock fractures. Brackish groundwater was also found.

The composition of groundwater is largely governed by mineral-water equilibria. Most investigated water samples have not reached equilibrium with their surrounding minerals.

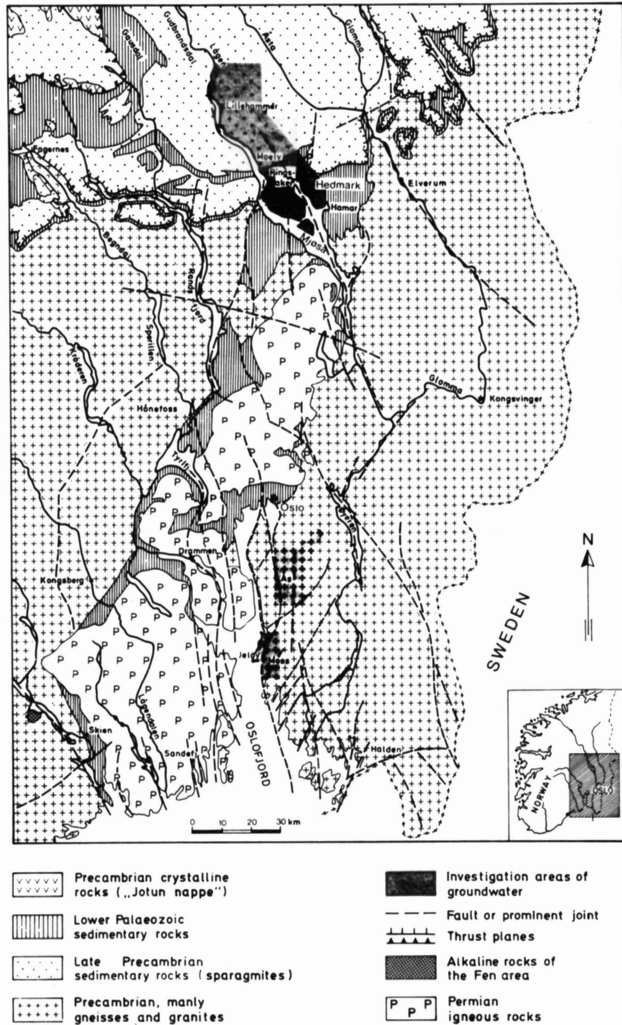


Fig. 1. Areas in which groundwater investigations were conducted. Geology mainly after Holtedahl and Dons (1960) and Ramberg and Larsen (1977).

## Introduction

In 1971 the Agricultural Research Council of Norway (NLVF) and the National Institute of Public Health (SIFF), Oslo, started a project whose aim was to gain information on the chemistry of groundwater in Norway. Three areas were selected for hydrochemical surveys: the Lake Mjøsa district, Ås and Moss – Jeløy (Figs. 1 and 2).

This paper deals with some results on the chemical composition of water circulating at depths down to 110 m in the fissures of bedrocks.

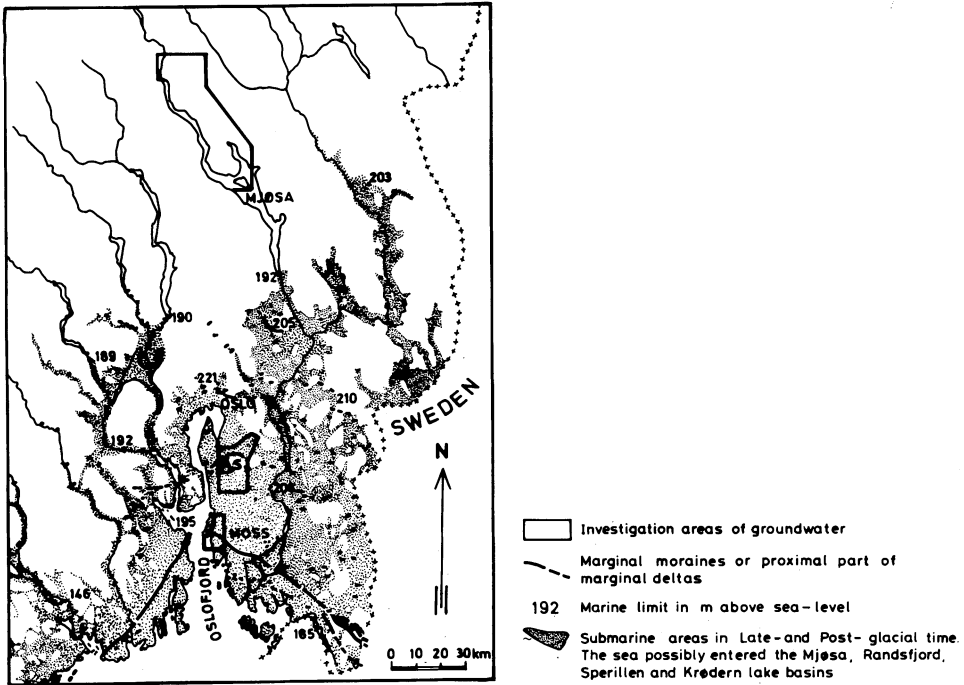


Fig. 2. Areas investigated in relation to the marine limit in Late-Post-glacial time. Geology after Holtedahl and Andersen (1960).

### Geology and Hydrogeology

The Lake Mjøsa district is situated in the marginal parts of the Caledonian mountain chain (Fig. 1), and most of it belongs to the Permian Oslo Graben. The Caledonide structures are dominantly folds and thrusts. A number of faults are of Permian age. The Late Precambrian-Silurian rocks of the district consist of conglomerates, sandstones, shales and calcareous units (Fig. 3). Steep-dipping joints, combined with joints following the bedding, are the most important secondary openings through which groundwater can flow.

Information derived from drilled wells (diameter 4 inches) show that groundwater occurs throughout the Lake Mjøsa district, and that usually enough water for domestic use can be found (Skjeseth 1953, 1956; Englund 1966). Competent rocks such as sandstones and conglomerates and massive limestones yield more water by drilling to depths of 50-100 m than do incompetent units such as shales and calcareous shales (Fig. 3).

	Thick- ness in m	Stratigraphic unit	Tectonic style	Water quanti- ties obtained in drilled wells
Silurian	> 150	Brufvatn Formation		500 - 2000 l/h
		Ek Shale 7c - 8a		
	20-25	Pentam. L. st. 7a-7b Heigeysa Q. 6c		
Ordovician	~ 100	Mjøsa Limestone 4b 5 <sub>2</sub>		1000 - 5000 l/h
	~ 50	Furuberg Formation 4bβ - 4b 5 <sub>1</sub>		1000 - 2000 l/h
	~ 100	Hovinsholm Shale		500 - 2000 l/h
				~ 400 l/h
	~ 100	Ogygiocaris Shale 4aα Upper Didymogr. Shale 4aα		200 - 300 l/h
	~ 40	Orthoceras Limestone 3c		200 - 1500 l/h
	50-75	Lower Didymo- graptus Shale 2e - 3b Alum Shale 1c - 2d		50 - 200 l/h
Late Precambrian	25-50	L. Cambrian 1a-1b Shale and sandst.		500 - 1000 l/h
	> 150	Vangsås Formation		1000 - 3000 l/h
	40-60	Ekre Shale Moelv Tillite		
	> 150	Ring Formation		1000 - 2500 l/h
	> 100	Biri Shale and Limestone		300 - 1000 l/h
	100-150	Biskopås Conglomerate		1000 - 3000 l/h
	> 1100	Brettum Formation		300 - 1000 l/h

Fig. 3. Schematic representation of the stratigraphy of the Late Precambrian – Silurian rocks in the Lake Mjøsa District, showing water quantities usually obtained in drilled wells.

The Precambrian rocks in the areas of Ås and Moss belong to the Fennoscandian Precambrian Shield (Fig. 1). The dominate rock types are gneisses, often alternating with amphibolites. These areas are dissected by faults and prominent joints of mainly Precambrian and/or Permian age, some of which are now occupied by dikes.

On the basis of groundwater yields from 1,000 wells from the areas south, east and northeast of Oslo, Bryn (1961) showed that gneisses usually give about 400-500 l/h. Yields of up to 2,000-4,000 l/h can be obtained by drilling down to 80-100 m. Still higher water quantities, around 5,000-10,000 l/h, are often obtained by drilling along faults or prominent joints.

Little water circulates in the narrow fissures of amphibolites. Where such rocks alternate with gneisses, they represent impervious units, and the water therefore is mostly present in the neighbouring gneisses.

Gabbroes, as found at Vangen northeast of Ås, have few and generally narrow fissures which give little water by drilling. Near the rock boundaries, however, adequate water quantities for domestic use (around 500 l/h) can usually be found.

The Silurian Ringerike Sandstone and the Permian volcanic rocks on the island Jeløy were downfaulted approximately 2,000 m in Permian time, and they are thus strongly fractured. They usually yield much water by drilling down to 40-60 m – the sandstone about 800-900 l/h and the volcanic rocks about 2,000-3,000 l/h.

The Lake Mjøsa district is situated above, and the other investigated areas mainly below the marine limit from Late- and Postglacial time (Fig. 2).

The groundwater surface is usually present well below the overlying unconsolidated deposits of glacial, glacialfluvial or marine origin.

## **Methods of Investigation**

### **Groundwater Samples**

Water samples for chemical analysis were collected from 98 selected wells in the areas of Lake Mjøsa, Ås, Moss and Jeløy (Fig. 4). Sampling was mainly carried out in producing wells, and the water was taken from taps mounted on pumps of the type Grundfos, CPE (centrifugal pump ejector). Only wells with hoses of plastic and with water extracted 15 to 110 m below the land surface were investigated.

A number of wells situated in the same aquifers were investigated in an attempt to draw some conclusions regarding the chemistry of the groundwater in specific aquifers.

Before collecting water samples from the wells, stagnant water was flushed out of the tap in a volume equivalent to about 2 times the volume of the water in the well. Stagnant water in wells may have a composition different from that of groundwater in situ (Brown et al. 1975).

The water samples were collected during the years 1971-1975 in the Lake Mjøsa district, and during the years 1974-1977 in the areas of Ås, Moss and Jeløy.

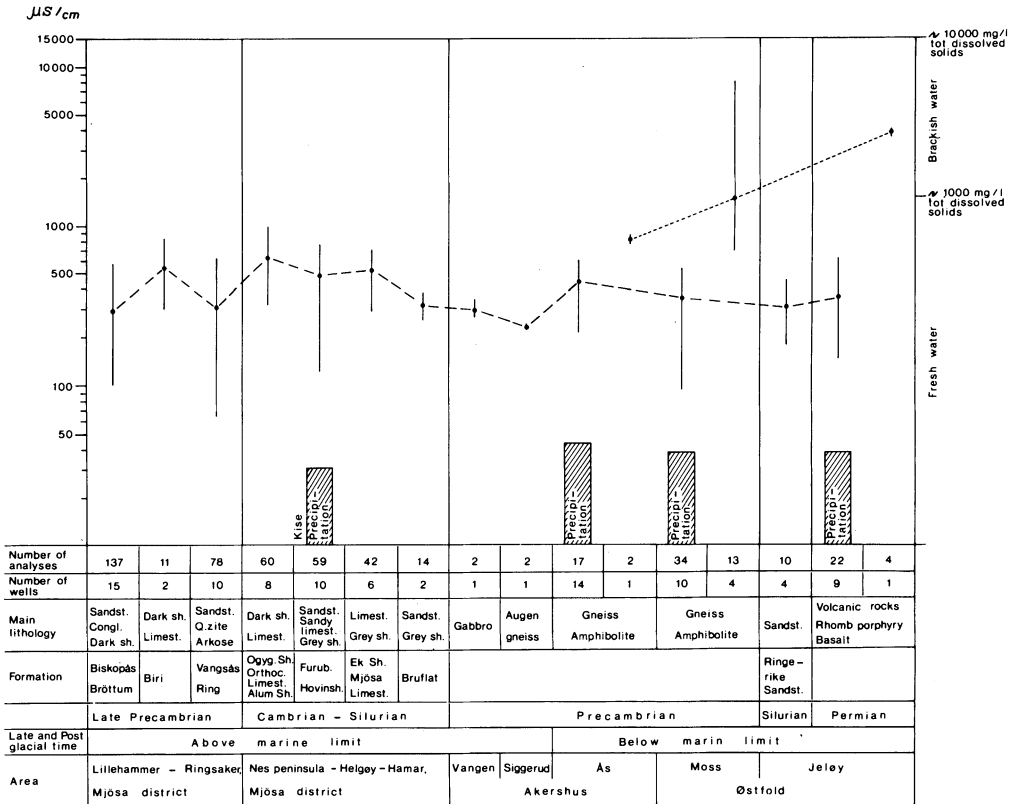


Fig. 4. Conductivity ( $\mu\text{S}/\text{cm}$  at  $20^\circ\text{C}$ ) in precipitation and groundwater from southeastern Norway. Arithmetic mean and range of the groundwater data are given.

### Analysis of Water Samples

pH-values and temperature were measured in the field. Water samples were filled into suitable plastic and air-tight glass (for  $\text{HCO}_3^-$  determination) containers. The samples were then brought to the laboratory at the National Institute of Public Health (SIFF), Oslo, where a large number of parameters were determined on unfiltered samples. In this paper only the following parameters are discussed: specific electrical conductance at  $20^\circ\text{C}$ ,  $\text{K}^+$ ,  $\text{Na}^+$ ,  $\text{Mg}^{2+}$ ,  $\text{Ca}^{2+}$ ,  $\text{HCO}_3^-$ ,  $\text{SO}_4^-$ ,  $\text{Cl}^-$  and  $\text{F}^-$ . The content of  $\text{Si}^{4+}$  ( $\text{SiO}_2$ ) was analysed at the Norwegian Institute for Water Research (NIVA), Oslo. All analyses were carried out by conventional methods.

### **Presentation of Data**

This paper is based on the analytical results from 507 water samples. The data are presented in tables and graphs showing the average concentration (arithmetic mean) of a given element (Tables 1 and 2), supplemented with the range of the values (Figs. 4 and 7-9).

The chemical data have also been reduced to a form suitable for plotting in the trilinear diagrams of Piper (1944). These diagrams are based on the percent of the sum of cations or anions (on an equivalent basis). The distribution, or spread of points, of the data is shown in the diagrams by the contour at 3% per 0.25% area. This means that approximately 85-90% of the data fall within the contour lines.

For the equilibrium calculations activities were used. Nearly all the water data fall within the contour lines of the diagrams in Figs. 11 and 12.

### **Specific Electrical Conductance**

It is believed that the movement of groundwater within the investigated aquifers is so slow that regional changes in quality is not only dependent on weathering in the unsaturated zone, but also dependent on the solution of reservoir rocks below the groundwater surface. The observed variations in specific conductance (Tables 1, 2 and Fig. 4) largely reflect the different reservoir rock types.

Late Precambrian sandstones, conglomerates and quartzites of the Lake Mjøsa district, give water with specific conductance at about 300  $\mu\text{S}/\text{cm}$ . Higher values, about 550  $\mu\text{S}/\text{cm}$  are typically found in the dark grey to black shales of the Biri Formation, where limestone beds are rather common. A similar trend is found within Cambro-Silurian rocks. The highest values, about 650  $\mu\text{S}/\text{cm}$ , occur in water from dark grey to black shales interbedded with limestone. Somewhat lower values, about 500  $\mu\text{S}/\text{cm}$ , are found in massive limestones and sandy limestones and sandstones, while low values, about 300  $\mu\text{S}/\text{cm}$ , are typical for sandstones and grey shales.

Infiltration conditions, rock petrography, as well as density (frequency) and type of water-conducting joints largely determine the specific conductance of the groundwater in the Lake Mjøsa district. Shales and calcareous shales developed narrow joints during the tectonic deformation of the rocks. Relatively fewer, but more open joints occur in competent units such as sandstones, conglomerates and limestones. This implies a larger contact between water and rock in incompetent rocks than in competent units. The water movement is slow in narrow joints, which probably gives a longer time of contact between water and rock than in more open fractures.

If infiltration is rapid, as in sandstones, sandy shales and massive limestones, the weathering takes place partly at or below the groundwater surface. In the case

Table 1 - Average chemical composition of some waters from southeastern Norway. Observation period 1971 - 1977.

Type of water	Area	Formation	Rock type	pH	$\mu\text{S/cm}$ at 20°C	mg/l								Number of analyses			
						Ca	Mg	Na	K	SiO <sub>2</sub>	Cl	SO <sub>4</sub>	HCO <sub>3</sub>		F		
Precipitation	Lake Mjøsa district			4.6	31	0.48	0.07	0.18	0.25	0.20	0.40	6.50	0.09	8			
	Ås			4.8	44	0.75	0.10	0.35	0.55	0.17	0.66	5.50	0.10	3			
	Moss-Jeløy			4.6	42	0.67	0.18	0.95	0.93	0.21	1.30	5.15	0.10	6			
Groundwater	Lake Mjøsa - district	Cambrian-Silurian	Bruflat	Sandst. Grey sh.	7.6	315	52.0	10.5	3.0	0.9	7.5	3.2	6.0	165.0	0.06	14	
			Ek Sh. Mjøsa L.st.	Limest. Grey sh.	7.4	520	66.0	18.0	18.5	5.0	11.0	8.6	44.5	250.0	0.13	42	
			Furu-berg Hovinsholm	Sandst. Sandy L.st. Grey sh.	7.4	480	55.0	15.5	30.0	6.6	12.4	16.3	41.5	250.0	0.20	59	
			Ogyg.Sh Orthoc.L.st. Alum Sh.	Dark sh. Limest.	7.7	625	105.0	19.5	46.0	5.7	15.6	30.0	52.5	300.0	0.33	60	
		Late Precambrian	Vangsås Ring	Sandst. Q.zite Arkose	7.0	304	40.0	4.9	13.5	3.4	12.0	10.6	28.0	133.0	0.20	78	
			Biri	Dark sh. Limest.	7.5	545	05.0	8.3	5.2	1.0	13.5	17.8	45.0	125.0	0.10	11	
			Biskopås Brøttum	Sandst. Congl. Dark sh.	7.4	295	43.0	5.6	8.5	1.3	14.0	6.1	38.0	115.0	0.15	137	
	Akershus	Vangen	Precambrian	Gabbro		7.0	292	46.0	3.3	3.3	1.6	12.0	3.8	26.5	85.0	0.06	2
				Augen gneiss		7.0	230	32.0	3.1	6.2	1.4	15.0	3.6	5.7	67.0	0.15	2
		Ås		Gneiss Amphib.	7.7	440	36.5	6.5	40.0	4.9	11.0	20.0	29.5	88.0	0.54	17	
		Moss		Gneiss Amphib	7.5	365	25.5	5.4	38.5	4.6	16.0	29.5	25.0	132.0	0.75	34	
	Jeløy	Silurian	Ringerike Sandst.	Sandst.	7.3	309	38.7	5.3	16.3	3.8	6.8	15.0	22.5	130.0	0.11	10	
		Permian		Rhomb. porphyry Basalt		7.4	362	36.3	6.8	34.0	1.9	14.4	22.8	20.5	160.0	0.22	22

- A. The areas of lake Mjøsa, Siggerud and Vangen are above the marine limit from Late-Postglacial time. The other areas are situated below this limit. Groundwater ranging from fresh to brackish do occur (Table 2).
- B. The chemical composition of the water from each rock type may vary considerably from the average composition shown, depending on hydraulic conditions, sampling depth, or absence of soil, etc. (Figs. 4, 7-9).
- C. Abbreviations: Congl. = conglomerate, sandst. = sandstone, Q.zite = quartzite, sh. = shale, limest. or 1.st. = limestone, amphib. = amphibolite.



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Table 2 - Average chemical composition of some fresh-to-brackish groundwaters from areas below the marine limit in Late-Postglacial time.  
Observation period 1971-1977.

Area	Rock/ sediment type	pH	$\mu\text{S/cm}$ at 20°C	mg/l									Number of analyses
				Ca	Mg	Na	K	SiO <sub>2</sub>	Cl	SO <sub>4</sub>	HCO <sub>3</sub>	F	
Ås	Gneiss Amphibolite	7.5	800	50.6	11.5	115.0	13.5	10.0	105.0	32.0	155.0	0.74	2
Moss	Gneiss Amphibolite	7.9	1490	24.0	7.5	160.0	8.5	14.0	430.0	52.0	260.0	1.33	13
Jeløy	Marine Quaternary deposits	7.8	3750	85.5	34.3	755.0	7.9	23.6	1358.0	61.5	215.0	0.48	4

Water with conductivity higher than 1,500  $\mu\text{S/cm}$  at 20°C  
( $\sim$  1000 mg/l total dissolved solids) is here referred to as brackish water.

of slow infiltration, as in thick soil zones or in pelitic units, weathering may take place to a large degree in the soil zone or in the uppermost unsaturated part of the rock.

Within massive limestones, as the Mjøsa Limestone, many joints have been secondarily enlarged due to solution, and the groundwater today can therefore move rather easily. This may partly explain the higher concentration of ions in the groundwater from calcareous shales than in the water from limestones.

Because the joints are open and the dominant minerals are quartz, feldspar and illite, it is not surprising that sandstones and conglomerates yield groundwater with relatively low specific conductance.

The yield of water in drilled wells (Fig. 3) is also largely dependent on rock type and consequently on the nature of the joints, in which water flows.

There are several ways by which groundwater acquires dissolved salts. The first is by atmospheric deposition (Fig. 4). This source is rather unimportant, however, as shown by investigations carried out in Sweden (Jacks 1973 a, p. 209). A second source is the weathering of minerals in soils and rocks. This is by far the most important process. The thirdly source is incorporation of old sea salts, perhaps also fossil sea water, left over from glacial times, in sediments or in rock fractures within areas below the Late-Postglacial marine limit. Finally, anthropogenic sources and biological processes may be of importance.

Joints and fractures in the Precambrian rocks of the Ås and Moss areas are mostly open and permit easy flow of water. The specific conductance of 300  $\mu\text{S/cm}$  in the gabbro at Vangen, and that of 250  $\mu\text{S/cm}$  in the augen gneiss at Siggerud, are probably mainly a function of weathering in the unsaturated zone.

Somewhat higher values are generally found in the gneiss and amphibolites at Ås (around 450  $\mu\text{S/cm}$ ) and Moss (around 380  $\mu\text{S/cm}$ ). This is due to the fact that

these areas were below the marine limit from Late-Postglacial time. One of the wells investigated at Ås and four at Moss have extremely high values of specific conductance, around 800 and 1,500  $\mu\text{S}/\text{cm}$ . These wells are clearly influenced by the leaching of ancient sea salts (Table 2).

The volcanic rocks on the island Jeløy have mostly open joints and are sufficiently permeable to permit rapid and extensive circulation of water. The specific conductance is about 350  $\mu\text{S}/\text{cm}$  for most wells. One artesian well has a specific conductance of about 3,800  $\mu\text{S}/\text{cm}$ . This value is caused by leaching of marine clays (Table 2).

The Ringerike Sandstone gives groundwater with a specific conductance at about 300  $\mu\text{S}/\text{cm}$ . This value is also typical for the groundwater of Late Precambrian and Silurian sandstones of the lake Mjøsa district.

### **Classification of Water**

A classification of water based on the total concentration of the dissolved solids is shown in Fig. 4. It follows that most investigated groundwaters are fresh according to the scheme of classification given by Davis and De Wiest (1966, p. 118). Six wells from the areas of Ås, Moss and Jeløy have been grouped together, because the waters range from fresh to brackish.

To indicate similarities and differences in the composition of groundwater from the geological units, the trilinear diagram of Piper (1944) is useful (Figs. 5 and 6).

Groundwater from Late Precambrian rocks of the Lake Mjøsa district is mainly calcium bicarbonate and calcium sulfate water (Fig. 5), while the groundwater from Cambro-Ordovician rocks has a relatively higher concentration of magnesium, sodium, potassium and bicarbonate. The Silurian Bruflat Formation gives calcium bicarbonate water. These relationships can be explained by variations in the bedrock lithology.

Dolomite, and to a lesser degree chlorite, are probably the main source minerals for magnesium. These minerals occur most frequently in Ordovician shales, calcareous shales and limestones (Bjørlykke and Englund 1979), where the groundwater has a rather high concentration of magnesium.

Calcite is the main source for calcium, and in carbonate rocks the groundwater is dominated by calcium and bicarbonate.

Albite weathering is the most important source of sodium. The large concentration of this element in the groundwater from the Alum Shale – Ogygiocariss Shale (Figs. 5 and 8) reflects, probably, the fact that these units were deposited in a marine environment. Sodium ions were then either sorbed on exchangeable sites on clay minerals, incorporated into authigenic albites, or deposited in marine salts. Traces of such salts could, perhaps, have survived in some smaller, isolated

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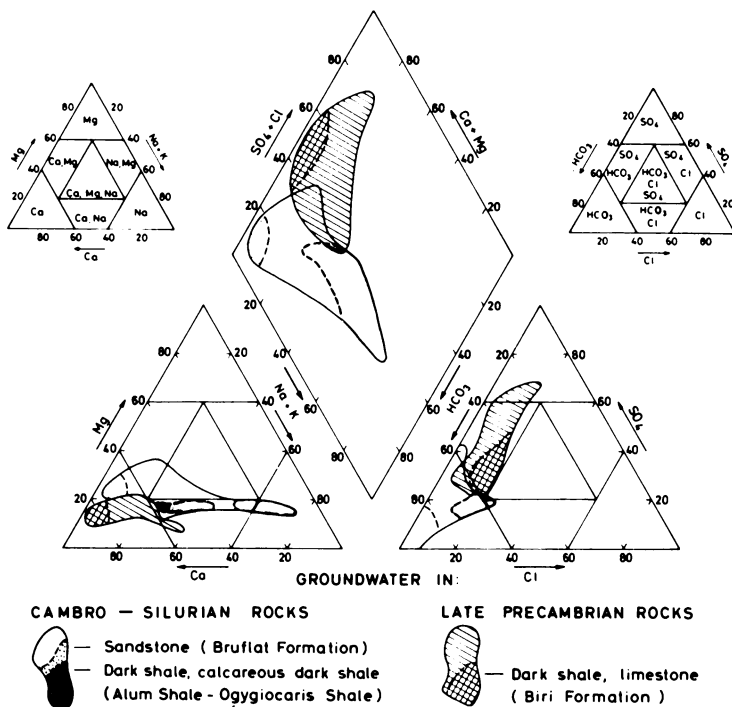


Fig. 5. Groundwater data from the Lake Mjøsa district plotted in a trilinear Piper (1944) diagram. Contoured at 3% per 0.25% area. The scheme of water classification is after Davis and DeWiest (1966 p. 119).

rock joints(?).

The groundwater of the Alum Shale-Ogygiocaris Shale is also rich in chloride (Figs. 5 and 9). This ion enters the mineral apatite, which is known as a common accessory mineral in Late Precambrian rocks (Englund 1972, 1973). Traces of marine salts in some rock joints would also yield chloride to groundwater(?).

Groundwater from Precambrian areas above the Late- Postglacial marine limit is dominated by calcium and bicarbonate, to a lesser degree by sulfate and chloride (Fig. 6). Weathering of plagioclase, amphibole, pyroxene, micas and chlorites is responsible for much of the sodium, calcium, potassium and magnesium in the groundwater of these areas, as well as in other areas with gneisses or sandstones. Dolomite and calcite are either very subordinate constituents in such rocks, or are lacking.

Analyses of two or more waters that are of similar chemical composition except for the exchange of calcium for sodium, will plot on a straight line parallel to the base of the lower left triangle in Fig. 6. These data thus indicate that Ca-Na

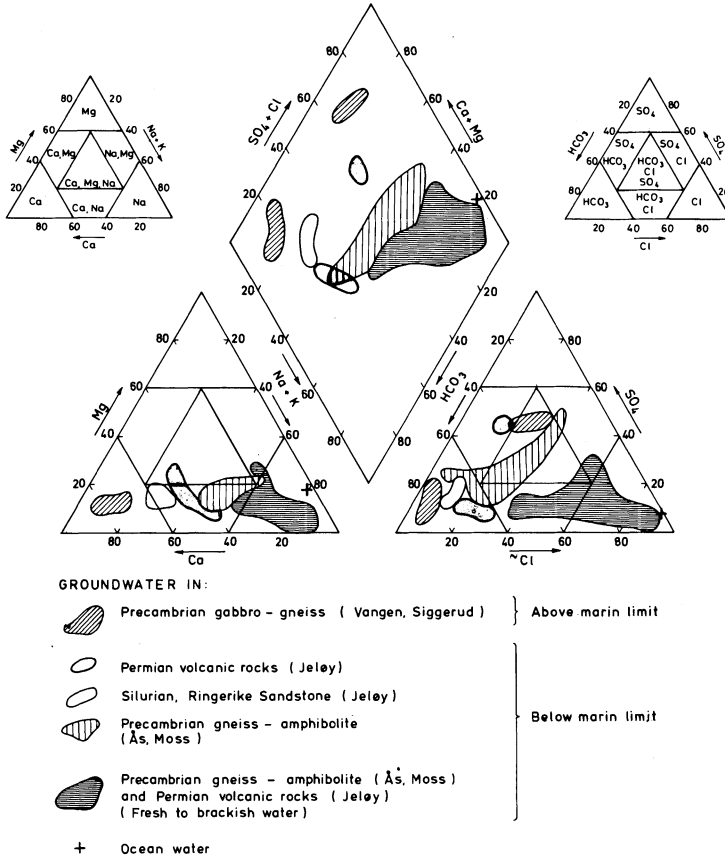


Fig. 6. Groundwater data from the areas of Ås, Moss and Jeløy plotted in a trilinear Piper (1944) diagram. Contoured at 3% per 0.25% area. The scheme of water classification is after Davis and DeWiest (1966 p. 119).

exchange must have occurred. There is an increasing influence of old sea salts, perhaps also traces of old sea water, from the areas of Vangen – Siggerud to the surrounding of Ås and Moss. Due to thin and discontinuous Quaternary marine deposits on the island Jeløy, the groundwater here is not usually influenced by marine salts.

High contents of chloride is also typical for much groundwater from the areas of Ås and Moss (Fig. 6).

Oxidation of pyrites adds sulfate to the groundwater. This mineral occurs frequently in the Cambro-Ordovician dark shales of the Lake Mjøsa district, and is also common in most Late Precambrian units. It is, however, a subordinate constituent of Precambrian and Permian rocks of the Ås, Moss and Jeløy areas.

## **Analytical Data**

### **pH-values**

The pH of infiltrating water increases from about 4.6 in the precipitation to about 6.0-7.0 near, or just below, the groundwater surface. Within this zone most of the weathering takes place. Deeper groundwater is usually buffered within the pH range of 7.0 to 7.7 (Table 1).

Groundwater in limestones, shales and calcareous shales have pH-values in the range 7.4-7.7, while values around 7.0 prevail in arkoses and quartzites. In relation to proton consuming weathering processes this is reasonable, as carbonate minerals weather more easily than the feldspars and quartz of the sandstones.

In Precambrian gneisses most groundwaters have pH-values in the range 7.0-7.3, while 7.5-7.7 is commonly found in amphibolites. This is in harmony with the fact that amphibolites weather more easily than most gneisses.

Somewhat lower values often occur in the volcanic rocks at Jeløy, with pH-values around 7.4. The highest values, 7.5-7.9, are usually found in the fresh to brackish groundwaters at Ås, Moss and Jeløy (Table 2).

The acidity of the groundwaters is partly due to the presence of dissolved CO<sub>2</sub>. This constituent is, however, mainly produced in the soil zone, and within the pH-range of 7.0-8.0 in the groundwater, bicarbonate is the dominant dissolved carbon species. Weathering below the groundwater surface is therefore largely due to additional hydronium ions. These can be supplied by processes as oxidation of pyrites and ammonia. Another potential source of H<sup>+</sup> is from the production of organic acids.

### **Cations**

Calcium is the principal cation in most groundwaters from areas above the Late-Postglacial marine limit, while sodium dominates in areas below this limit (Figs. 7 and 8).

The concentration of magnesium in groundwater is much lower than the calcium concentration (Fig. 7). This is also generally the case for fresh groundwaters throughout the world, where values below 40 mg Mg<sup>2+</sup>/l and below 100 mg Ca<sup>2+</sup>/l are common (Matthess 1973, pp. 185-188).

The distribution pattern of potassium resembles that of sodium (Fig. 8), but the concentrations are much lower, mostly below 10 mg K<sup>+</sup>/l. Values above some few tens of mg K<sup>+</sup>/l are rather unusual in groundwaters (Matthess 1973, p. 184), while very high concentrations of sodium must be reached before any precipitate is formed.

Potassium-bearing minerals such as microcline and illites – sericites are very resistant to solution, and potassium is apparently preferentially incorporated into clay minerals. These mechanisms can not, however, satisfactorily explain the

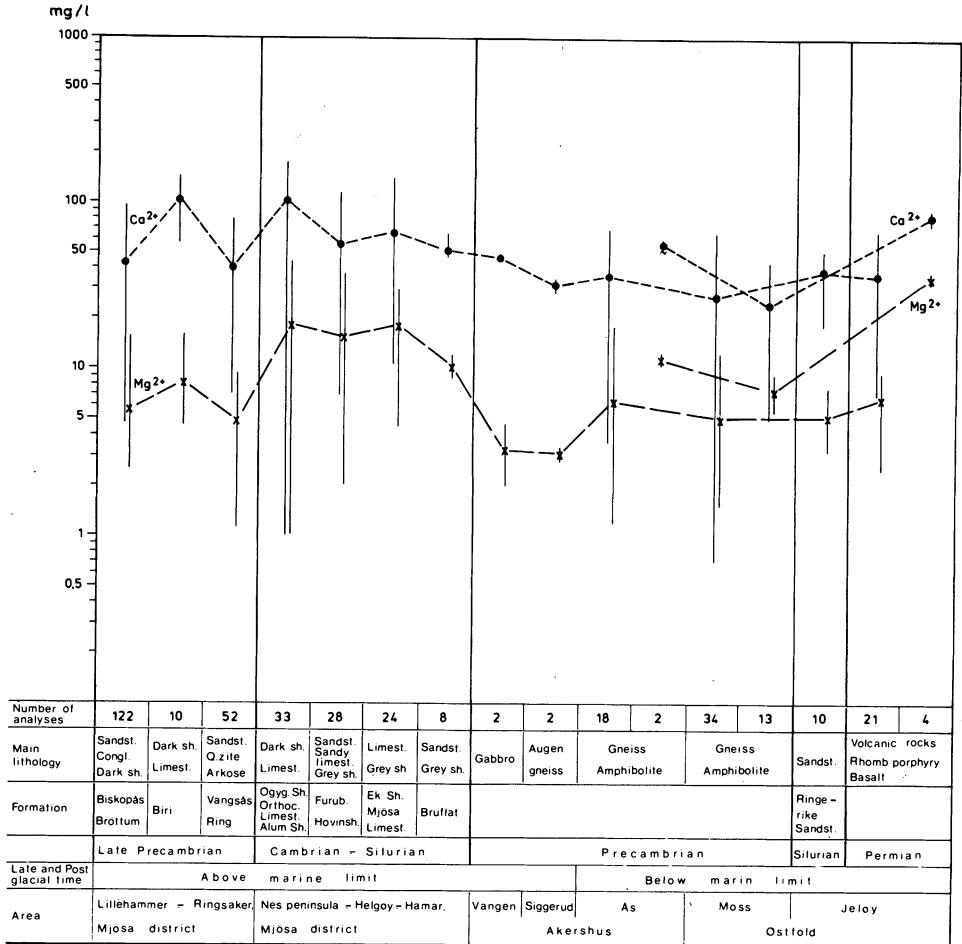


Fig. 7. Concentrations of calcium and magnesium in groundwater from southeastern Norway. Range and arithmetic means of the groundwater data are shown.

observed distribution pattern, though weathering of microcline, trioctahedral micas and illites-sericites must be of importance.

The potassium concentration in groundwater is higher in agricultural areas, such as the Cambro-Ordovician rocks of the Lake Mjøsa district and in the Precambrian rocks at Ås (Table 1). This is in accordance with Harth (1965), who has shown that the use of fertilizers in areas of intense agriculture increases the concentration of potassium in groundwater.

An obvious source for silica in groundwater are the silica minerals. The concentrations of silica show little regional variation (Fig. 8), in accordance with observa-

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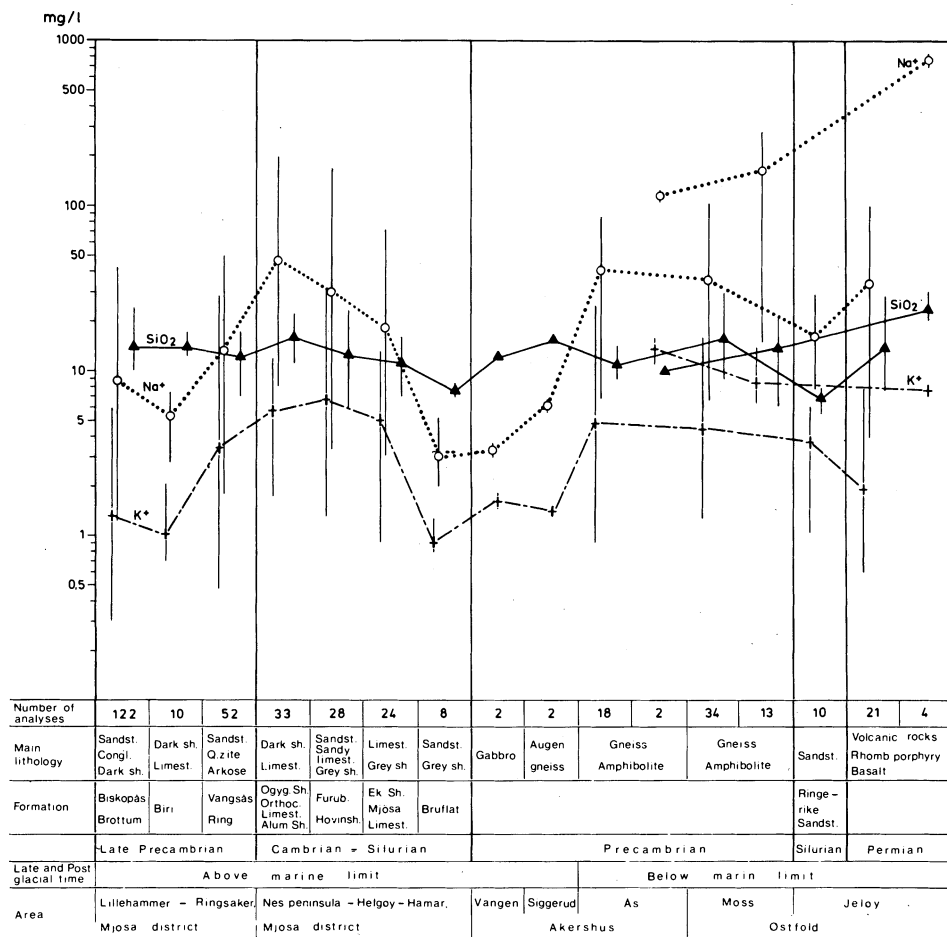


Fig. 8. Concentrations of sodium, potassium and silica (SiO<sub>2</sub>) in groundwater from southeastern Norway. See Fig. 7.

tions made in groundwaters from many different parts of the world (Bricker and Garrels 1967). This is explained by clay-mineral reactions, which control silica concentrations and the ultimate pH-value in many groundwaters.

### Anions

The concentration of bicarbonate (Fig. 9) is within the range found in other parts of the world. Values between 50-400 mg HCO<sub>3</sub><sup>-</sup>/l are often reported (Matthess 1973, p. 195).

In Precambrian rocks at Ås and Moss the bicarbonate of the water comes from the atmosphere, or from carbon dioxide in the soil (plant respiration and decay of

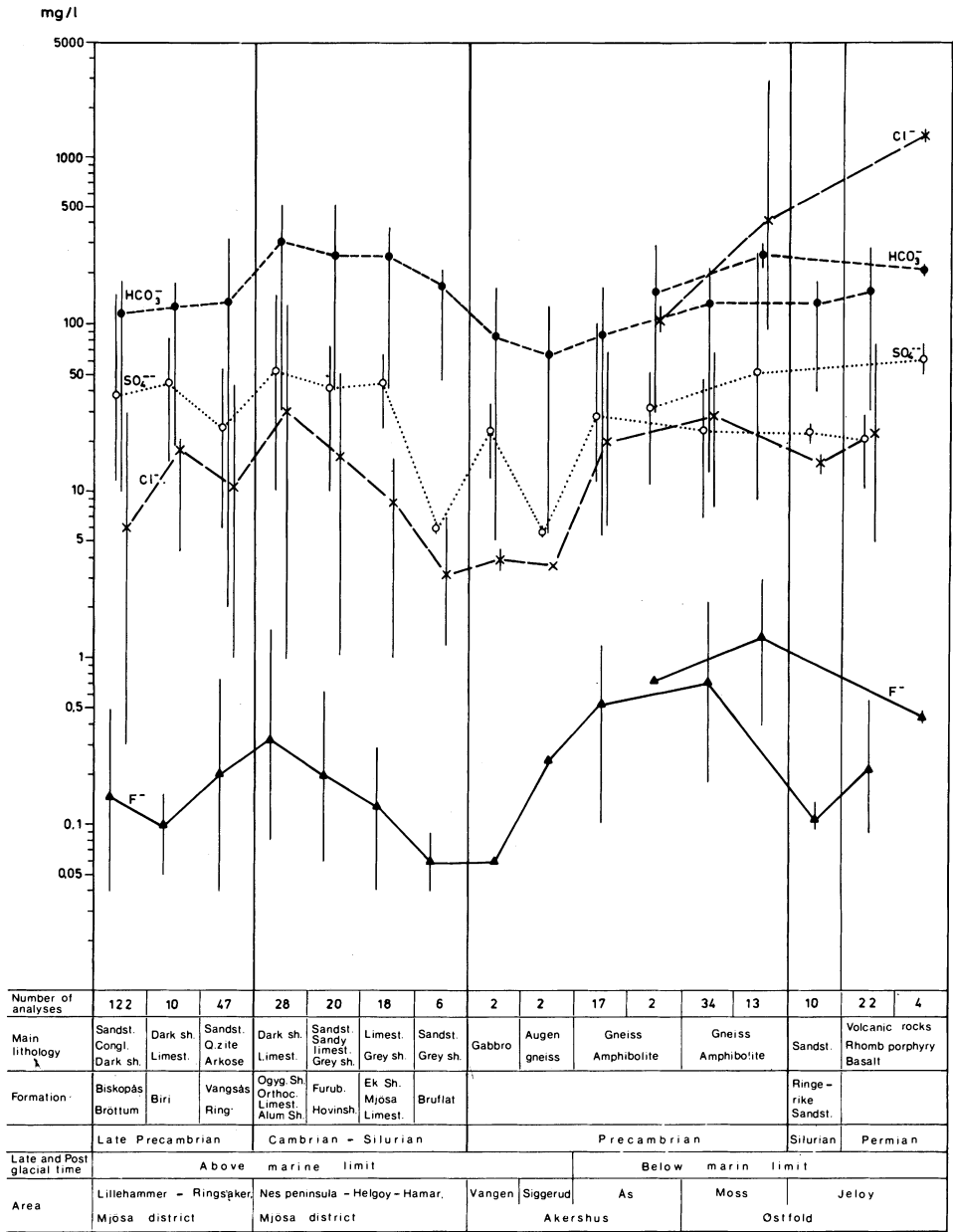


Fig. 9. Concentrations of bicarbonate, sulfate, chloride and fluoride in groundwater from southeastern Norway. See Fig. 7.



organic material). In carbonate rocks near Lake Mjøsa a great part of the bicarbonate comes from the rocks. Theoretically, about one half of the bicarbonate present in water could have originated from carbonate minerals (Hem 1970, p. 288).

The high content of bicarbonate in the fresh to brackish water at Ås, Moss and Jeløy may partly be due to leaching of marine carbonate shell fragments.

Groundwaters from sandstones and conglomerates and many metamorphic rocks throughout the world have sulfate concentrations mostly below 30 mg/l (Matthess 1973, p. 201). Within the areas investigated higher values are often found (Fig. 9), especially in rocks with much abundant pyrites.

Antropogenic sources usually have a small effect on groundwater composition. Locally, however, salt used for deicing roads could have supplied both calcium and chloride, and fertilizers could have influenced the concentration of potassium.

It is well known that in regions close to the sea, rain brings chloride and cations, especially sodium, to the soil surface. Marine influence of this kind seems, however, to have a minor influence on the chemistry of deep circulating groundwaters.

The above data are in accordance with groundwaters throughout the world. In rocks poor in chloride, values below 30 mg Cl/l are common, and higher values indicate mineralized water or antropogenic sources (Matthess 1973, p. 203). Within the areas investigated such high values are characteristically found below the Late-Postglacial marine limit.

In natural fresh waters with a content of total dissolved solids less than 1000 mg/l, the concentration of fluoride is usually less than 1 mg/l (Hem 1970, p. 178).

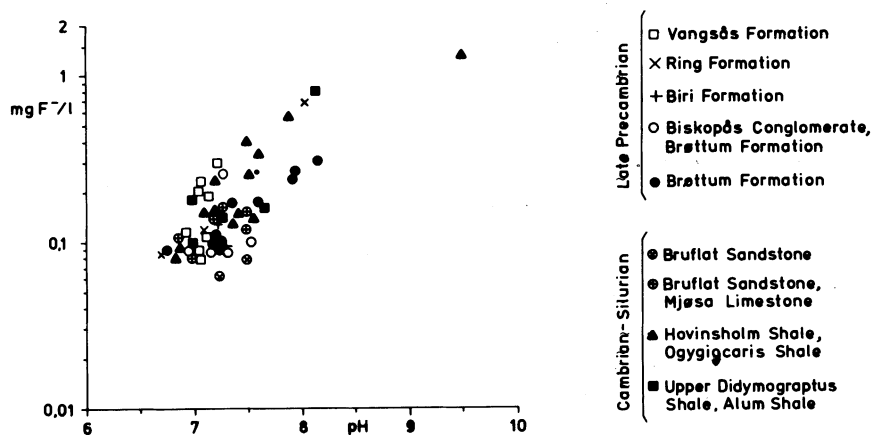


Fig. 10. The concentration of fluoride as a function of the pH in groundwater from the Lake Mjøsa district.

Data from the areas investigated (Fig. 9) are mainly in accordance with this.

Release of fluoride by weathering is probably significant. The main source must be minerals containing hydroxyls, such as illites – sericites, chlorites and amphiboles where fluoride partly replaces the hydroxyl-groups.

It has been found in the Lake Mjøsa district (Fig. 10), and in groundwaters from Precambrian rocks of the Stockholm area in Sweden (Jacks 1973 b, p. 214), that waters with high pH-values have high amounts of fluoride. Such waters more effectively exchange hydroxyl ions for fluoride.

Fluorite ( $\text{CaF}_2$ ) is observed on fractures of Permian age, especially from the areas of Ås, Moss and Jeløy. This probably explains the high fluoride content in groundwater from these areas.

### **Water Chemistry and Mineral Stability**

Primary minerals, secondary minerals and solutions tend to reach equilibrium. Departure from equilibrium is, however, usually observed at low temperatures, because natural water systems are rather complex (Barnes and Hem 1973). By studying relatively simple cases, one can approach the phenomena. This can be done by using theoretically calculated stability diagrams (Helgeson et al. 1973) of the type shown in Figs. 11 and 12.

The chemistry of groundwaters from bedrocks in Scandinavia has been plotted in such diagrams by e.g. Jacks (1973 a), Englund and Jørgensen (1975) and Englund et al. (1977). These investigations have shown that albite, plagioclase, microcline, Fe/Mg-chlorites, and largely also calcite, are unstable in contact with groundwaters down to about 100 m below the land surface.

The change in water chemistry from precipitation to groundwater within the areas investigated is illustrated by the diagrams in Figs. 11 and 12. The concentrations of silica and calcium increase as precipitation percolates down to the groundwater in Quaternary deposits and bedrocks. Similar trends are found from diagrams in which calcium is replaced with either sodium, potassium or magnesium.

Within the Lake Mjøsa district, groundwater in Ordovician calcareous shales is often saturated with respect to calcite. Conditions not far from saturation are obtained in the fresh to brackish groundwaters at Ås, Moss and Jeløy.

Groundwater data from the areas studied indicate the existence of leonhardite and kaolinite. This can be seen from Figs. 11 and 12, and diagrams in which calcium is replaced with either sodium, potassium or magnesium (Englund et al. 1977). Leonhardite has so far not been identified within the areas investigated.

Reactions between minerals and water consume  $\text{H}^+$ , and silica and cations are released to solution (e.g. Bricker 1967, Likens et al. 1977, Rosenqvist 1977).

## Groundwater Chemistry in Southern Norway

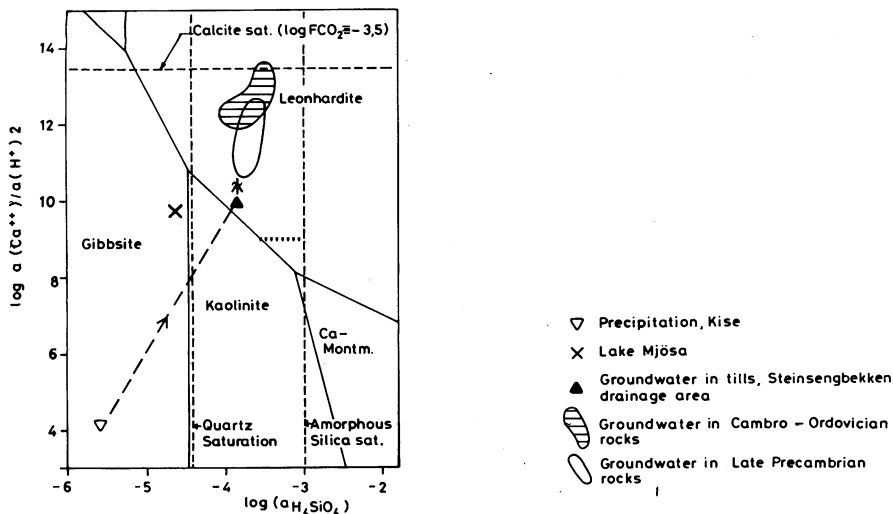


Fig. 11. Stability fields of some minerals in the system  $\text{HCl-H}_2\text{O-Al}_2\text{O}_3\text{-CaO-CO}_2\text{-SiO}_2$  at  $0^\circ\text{C}$  and 1 atm. (Helgeson et al. 1973). The compositions of different types of water from the Lake Mjøsa district are shown.

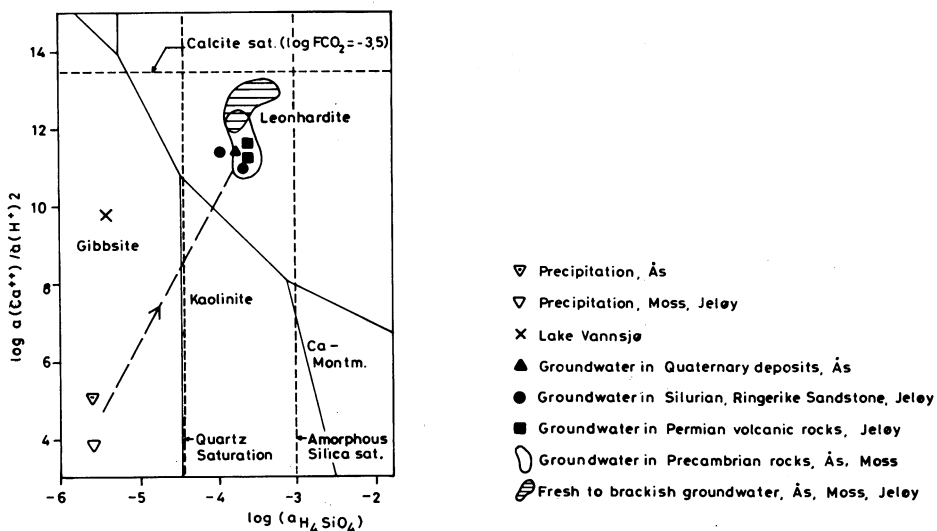


Fig. 12. Stability fields of some minerals in the system  $\text{HCl-H}_2\text{O-Al}_2\text{O}_3\text{-CaO-CO}_2\text{-SiO}_2$  at  $0^\circ\text{C}$  and 1 atm. (Helgeson et al. 1973). The compositions of different types of water from the areas of Ås, Moss and Jeløy are shown.

Neof ormation of minerals and the transformation of one mineral to another are very time-consuming processes in nature. The short time-span involved in the contact between groundwater and primary minerals has probably not allowed much neof ormation of minerals to occur within the aquifers investigated.

## **Conclusions**

1) Data derived from drilled wells show that groundwater occurs in joints and other fractures throughout the areas investigated. Open tension fractures give more water than narrow shear joints.

Within the Lake Mjøsa district there is a clear connection between stratigraphic development, tectonic structures and the yield of water by drilling (Fig. 3). In Precambrian rocks, regional feather joints arranged »en echelon« between larger faults, are important water-bearing fractures.

2) The groundwater surface in bedrock is usually present well below the overlying morainic or glacialfluvial material, and consequently the water must to a large extent penetrate this material. Weathering of minerals in the unsaturated zone is therefore of great importance for the chemical composition of groundwater.

3) The movement of groundwater is so slow that regional changes in water quality are also dependent on the solution of reservoir rocks below the groundwater surface.

4) Variations in the specific electrical conductivity of groundwater largely reflect the various reservoir rock types. The highest values, around 550  $\mu\text{S}/\text{cm}$ , are typically found in dark calcareous shales, while sandstones and gneisses give values around 300  $\mu\text{S}/\text{cm}$ .

5) Below the Late-Postglacial marine limit, the groundwater is influenced by ancient sea salts and perhaps also by old sea water. Brackish groundwaters has been detected. Due to ion exchange, old sea water contains more  $\text{Ca}^{++}$  than normal sea water.

6) Groundwater from Late Precambrian rocks contains mainly calcium, bicarbonate and sulfate, while the groundwater from Cambro-Ordovician rocks are relatively richer in magnesium, sodium, potassium and bicarbonate.

In Precambrian gneisses and gabbros above the Late-Postglacial marine limit the groundwater is dominated by calcium and bicarbonate and to a lesser degree by sulfate and chloride. Fresh-to-brackish groundwater below this limit is dominated by sodium, chloride and bicarbonate.

7) The chemical composition of groundwater in bedrocks is largely governed by mineral-water equilibria. Reactions between minerals and water consumes  $\text{H}^+$ , and releases silica and other cations to solution.

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