

## Elemental Composition of Norwegian Rivers

**B. Salbu and A. C. Pappas**

University of Oslo, Oslo, Norway

**E. Steinnes**

Institutt for atomenergi, Kjeller, Norway

Instrumental neutron activation analysis has been applied for the determination of up to 40 elements in waters from eleven Norwegian rivers. In order to represent the composition of an *average* river in the region of Norway and possibly the greater part of the Scandinavian peninsula, weighted mean values are calculated on the basis of geometric mean values and discharge of the individual rivers. Factor analysis shows that Cambro-Silurian sedimentary and volcanic rocks influence the water composition considerably compared to Precambrian gneisses and granites. An influence of airborne supply is evident in coastal areas. In addition ore deposits are important for Zn and associated elements.

Comparison with literature data from Sweden shows good agreement for the elements concerned. The present values concerning alkalies, alkaline earths and halogens are, however, significantly lower than the estimated "world averages". This is probably due to a low abundance of marine deposits and sedimentary rocks in Scandinavia. Low values are also found for elements which are often associated with particulate matter (Fe, Al, V, Mo, As, Sb, Th, U), while the values obtained for rare earths (La, Ce, Sm) and some additional elements (Sc, Mn, Au) are significantly higher than the estimated "world averages".

### Introduction

Knowledge of the elemental composition of river water is often essential to understand quantitative relations in geochemical cycles. Variations between rivers may, however, be large, due to regional differences in climate, topography,

geology, and vegetation. Moreover the contribution from human activity to the chemistry of the river system is in many cases significant. Information about rivers draining different types of regions is therefore necessary in order to perform geochemical cycle calculations.

Recent developments in analytical chemistry have facilitated the determination of a great number of elements at very low concentration levels. This has led to an increased activity in studies of the elemental composition of natural water systems. The most extensive study of this kind so far seems to be that of Reeder, Hitchon and Levinson (1972), who carried out a geochemical investigation of the MacKenzie River drainage basin based on water analysis. In Scandinavia, the number of studies carried out is rather small and data collected has most often been restricted to a few parameters only. Concerning trace elements in Scandinavian rivers the knowledge is very limited.

Among modern analytical techniques the instrumental neutron activation analysis is appropriate to this kind of study because of its high sensitivity for simultaneous determination of a great number of elements. This technique has been applied for the determination of up to 40 elements in natural fresh water (Salbu, Steinnes and Pappas 1975). In the present paper data for the elemental composition of water from eleven Norwegian rivers are presented and discussed. The rivers (Fig. 1), were especially selected for study within the International Hydrological Decade programme in order to give mainly natural background information. The rivers are listed in Table 1, along with a brief indication of the main geology and petrology of the drainage basins. Data on mean discharge and drainage area are also given in the table.

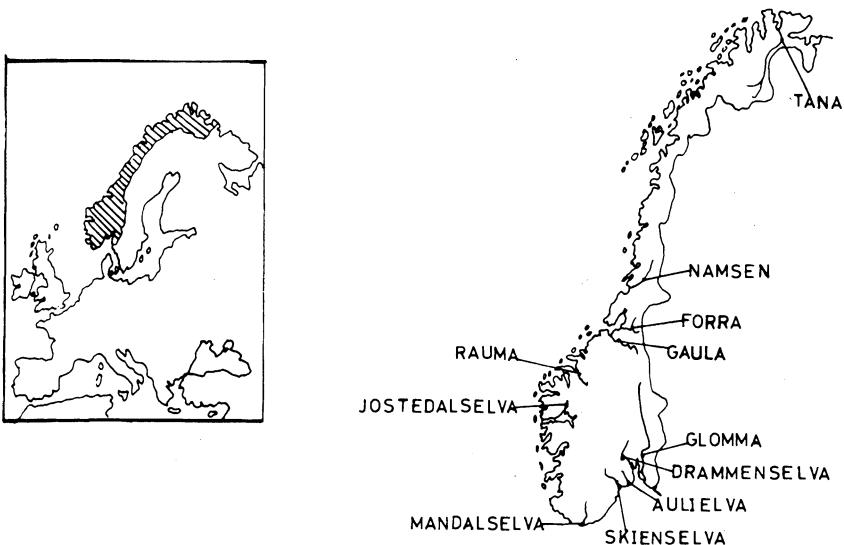


Fig. 1. Norwegian rivers selected for the present study.

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**Table 1 – Rivers studied in the present work.**

River	Discharge m <sup>3</sup> /s	Mean discharge m <sup>3</sup> /s (NVE 1976)	Drainage area Km <sup>2</sup> (NVE 1976)	Main geology of drainage basin (Holteidahl and Dons 1960)	Main petrology of drainage basin (Holteidahl and Dons 1960)
Tana	June 303 Aug. 152 Oct. 118	161	14005	Pre- and Eocambrian rocks	Gneisses, granites amphibolites
Namsen	June 303 Aug. 104 Oct. 252	154	3302	Cambro-Silurian sediments and meta volcanics	Limestones, calcareous schists, schists, greenstones
Forra	June 35.1 Aug. 31.9 Oct. 35.1	21	488	Cambro-Silurian sediments and meta volcanics	Limestones, calcareous schists, schists, greenstones
Gaula	June 418 Aug. 14.7 Oct. 72.7	76	3055	Cambro-Silurian sediments and meta volcanics	Limestones, calcareous schists, schists, greenstones
Rauma	May 53.5 June 47.1 Sept. 21.7	37	1098	Caledonian rocks	Gneisses, gneiss-granites
Jostedals- elva	May 39.7 Aug. 52.6 Oct. 17.4	58	832	Caledonia rocks	Gneisses, gneiss-granites
Glomma	June 1100 Aug. 543 Oct. 375	679	40013	Pre-Eocambrian and Cambro-Silurian rocks	Gneisses, arkoses, greenstones
Drammens- elva	June 205 Aug. 122 Oct. 72	313	16020	Pre- and Eocambrian rocks	Gneisses, quartzites
Auli- elva	June 1.3 Aug. 1.3 Oct. 1.5	7	362	Permian volcanic rocks, recent marine deposits.	Alkali syngenetic rocks
Skjens- elva	June 145 Aug. 164 Oct. 81	285	9975	Pre- and Eocambrian rocks	Gneisses, granites, quartzites
Mandals- elva	June 35.4 Aug. 48.8 Oct. 17.5	87	1746	Pre- and Eocambrian rocks, recent marine deposits	Gneisses, granites

## **Experimental**

### **Sampling**

Cleaned polyethylene bottles of 1-litre were used for water collection, after rinsing with river water at the site. Immediately after sampling, the water was transferred to another 1-litre polyethylene bottle containing 5 ml of high-purity nitric acid in order to prevent loss of trace elements due to sorption effects between sampling and analysis.

### **Activation Analysis**

Prior to the analysis the bottles were shaken and after a time lapse of 6 hours to allow settling of particles greater than 1  $\mu\text{m}$ , about 5 ml were decanted into quartz or polyethylene ampoules for irradiation. The sample amount taken for analysis was determined by weighing, whereafter the ampoules were immediately heat-sealed. The samples were then assayed by neutron activation analysis according to the procedure described by Salbu et al. (1975). The main factor affecting the reproducibility was in most cases counting statistics. Blank contributions from the polyethylene bottles, nitric acid, and irradiation containers were studied systematically and corrections were applied to the obtained results when necessary. In the case of antimony and gold a relatively high and somewhat variable blank made the determination of these elements uncertain and the given values might be somewhat underestimated.

In the case of iodine corrections had to be applied for loss during storage and irradiation. In all other cases the blank contribution was of minor importance.

### **Qualitative Mineral Analysis**

After the water analysis had been carried out the 1 litre water samples were filtered through 0.22  $\mu\text{m}$  Millipore filters. The suspended material ( $>0.22 \mu\text{m}$ ) was analyzed with respect to mineral composition using X-ray diffraction analysis. The minerals were identified according to the criteria given by Brown (1961). In general, the content of suspended material was low. In some cases it was too low to be determined.

## **Results**

From each of the eleven rivers covered by the present work, three samples taken in May - October 1971 (Table 1), were analyzed. In addition to the minerals identified in the suspended fractions, geometric mean values of the three water samples from each river for the concentration of 5 major elements (Na, K, Mg, Ca and Cl) and 34 trace elements are given in Table 2. Of these trace elements 17 (Cs, Sr, Sc, La, Sm, Eu, V, Cr, Mn, Fe, Co, Au, Zn, Al, Sb, Br, I) could be

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determined in all, or nearly all, samples. Another 7 elements (Rb, Ba, Ce, Yb, Ag, Ti, Hf) were detected in a more limited number of samples, while the remaining 10 (Dy, Th, U, Mo, W, Cu, Cd, Ga, As, Se) were present below the detection limit of the analytical procedure in most cases.

Cumulative frequency distribution plots of one element present almost entirely in solution (Cl) and one assumed to be transported mainly in association with colloidal or suspended material (Al), based on all individual observations in all rivers, are shown in Fig. 2. It is clearly indicated that the lognormal distribution gives a better fit to the experimental data than does the Gaussian. Similar plots were obtained for other elements tested. Geometric mean values rather than arithmetic means are therefore used in Table 2. The applicability of the lognormal distribution to geochemical trace element data has previously been demonstrated in the case of granites and diabases (Ahrens 1954) and stream sediments (Lepeltier 1969), and are through the present study extended to include trace elements in water systems.

Because of the temporal variability of the composition of river water, the question may be raised whether the limited number of samples taken from each river can be considered representative. In connection with the IHD-programme the Norwegian Institute of Water Research (NIVA 1973) has obtained data concerning parameters as pH, turbidity, colour, conductivity, concentrations of sulphate and total phosphate in samples collected together with samples for the present investigation (Table 2). Except for turbidity and in some cases colour, the given values are very close to the mean values based on monthly samples during

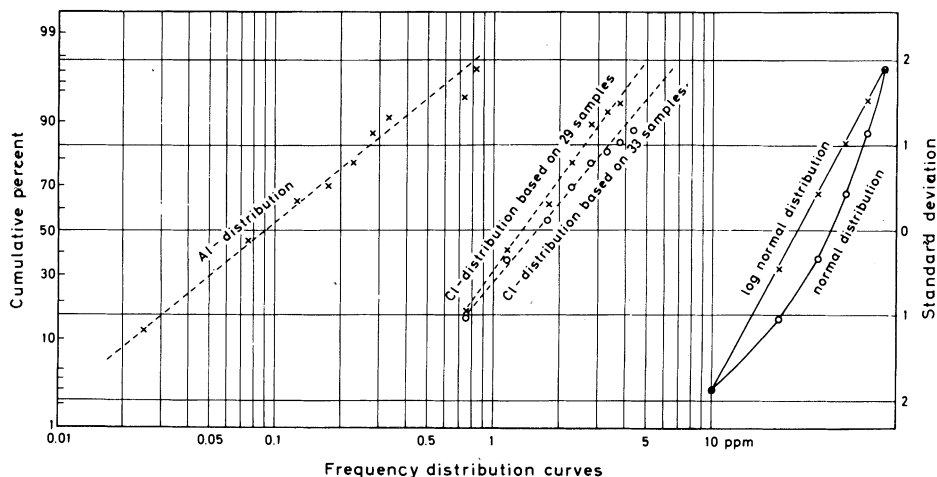


Fig. 2. Cumulative frequency distribution plots of aluminium and chlorine based on all individual observations.

Table 2 - Elemental composition of surface water from eleven Norwegian rivers (33 samples).

River	Na mg/l	K mg/l	Rb µg/l	Cs µg/l	Mg mg/l	Ca mg/l	Sr µg/l	Ba µg/l	Se µg/l	La µg/l	Ce µg/l	Sm µg/l	Eu µg/l	Dy µg/l	Yb µg/l				
Tana	2.13	0.70	≤1.5	0.049	0.98	3.8	19	≤8	0.016	0.23	≤0.12	0.042	0.008	<0.02	<0.1				
Namsen	2.05	0.34	≤1.2	0.105	0.63	2.5	18	≤8	0.021	0.62	0.37	0.15	0.017	≤0.03	≤0.2				
Forra	1.69	0.27	≤1.2	0.071	0.42	2.9	22	≤8	0.033	0.43	0.28	0.079	0.010	≤0.03	<0.1				
Gaula	2.06	0.89	2.4	0.155	1.02	6.2	14	15	0.045	0.68	0.29	0.15	0.017	0.05	≤0.2				
Rauma	1.32	0.35	≤1.1	0.167	0.16	1.8	12	<6	0.022	0.50	0.21	0.072	0.009	<0.01	<0.1				
Jostedalselva	0.65	0.58	2.3	0.086	0.34	1.9	24	10	0.036	2.2	1.18	0.30	0.023	0.04	<0.1				
Glomma	1.32	0.73	<0.9	0.056	0.79	4.7	34	21	0.014	0.32	≤0.12	0.089	0.009	<0.01	<0.1				
Drammenselva	1.00	0.53	≤1.0	0.096	0.62	4.7	28	15	0.012	0.23	≤0.12	0.082	0.006	<0.01	≤0.2				
Aulielva	13.7	3.9	2.6	0.112	3.3	10.8	78	11	0.042	1.10	0.36	0.36	0.015	≤0.05	<0.2				
Skienelva	0.72	0.50	1.1	0.088	0.33	2.3	23	13	0.013	0.29	0.11	0.093	0.008	<0.01	<0.2				
Mandalselva	2.03	0.45	≤1.4	0.118	0.37	1.0	23	12	0.024	0.49	0.40	0.12	0.012	≤0.05	≤0.2				
Weighted mean value	1.41	0.62	≤1.2	0.082	0.67	3.9	27	15	0.017	0.40	0.20	0.095	0.0098	<0.02	<0.2				
% removed by dialysis*																			
	0		0			6		6	90	>75				>67					
River	Ti µg/l	Hf µg/l	Th µg/l	U µg/l	V µg/l	Cr µg/l	Mo µg/l	W µg/l	Mn µg/l	Fe mg/l	Co µg/l	Cu µg/l	Ag µg/l	Au µg/l	Zn µg/l	Cd µg/l	Al mg/l	Ga µg/l	As µg/l
Tana	≤8	0.08	<0.03	<0.3	0.36	0.9	<0.5	<0.2	5.1	0.13	0.26	<5	0.2	0.008	8.9	<0.7	0.075	≤0.8	<0.3
Namsen	<8	0.08	0.05	<0.3	0.45	0.8	<0.5	≤0.2	8.8	0.23	0.27	≤9	0.2	0.018	9.4	<0.7	0.25	<0.7	<0.3
Forra	≤8	≤0.11	<0.03	<0.3	≤0.20	1.4	<0.5	<0.2	5.6	0.18	0.28	≤8	0.4	0.020	5.3	<0.7	0.13	<0.7	<0.3
Gaula	11	<0.06	<0.03	<0.3	0.53	2.0	<0.5	≤0.2	10.9	0.42	0.37	10	0.3	0.004	15.9	<0.7	0.13	<0.7	<0.3
Rauma	<6	≤0.07	<0.02	<0.3	0.18	0.9	<0.4	≤0.2	2.6	0.10	0.11	<4	≤0.2	0.014	8.7	<0.6	0.063	<0.6	<0.2
Jostedals.	12	≤0.07	0.17	0.36	0.78	1.3	<0.6	<0.2	14.7	0.37	0.40	≤9	0.3	0.012	15.9	<0.6	0.64	<0.5	<0.2
Glomma	<7	<0.05	<0.02	<0.2	0.27	0.6	<0.4	<0.1	26.2	0.15	0.16	≤6	0.2	0.003	39.6	≤0.6	0.080	<0.5	<0.3
Drammens.	<6	≤0.08	<0.02	<0.2	0.14	0.6	<0.4	<0.1	3.6	0.06	0.15	≤6	<0.1	0.005	5.4	<0.6	0.043	≤0.6	<0.2
Aulielva	<12	≥0.09	<0.03	0.58	≤0.30	≤1.0	1.9	<0.2	28.3	0.52	0.44	≤14	0.5	0.005	17.4	<0.6	0.24	<1.0	<0.5
Skienelva	<7	≤0.07	≤0.03	<0.3	≤0.12	1.5	<0.5	<0.1	27.0	0.08	0.10	≤6	0.2	0.011	6.0	<0.5	0.088	<0.5	0.27
Mandalselva	<8	0.12	<0.03	<0.4	0.13	0.8	<0.8	<0.2	14.4	0.13	0.24	<5	0.3	0.006	23.5	<0.8	0.16	≤0.6	≤0.3
Weighted mean value	≤8	<0.07	<0.03	<0.3	0.27	0.9	<0.5	<0.2	17.1	0.171	0.188	≤6	0.20	0.006	20.0	<0.6	0.113	<0.6	<0.3
% removed by dialysis*																			
			74			51		34	81	13				46		91			
River	Sb µg/l	Se µg/l	Cl mg/l	Br µg/l	I µg/l	pH	Turbidity JTU	Colour mgPt/l	Conductiv. 20°C/cm	SO <sub>4</sub> mg/l	PO <sub>4</sub> µgP/l	Illite	Chlorite	Vermic.	Smectite	Amphibole	Quartz	Microline	Na- phyllosilicate
Tana	0.19	<0.4	2.14	12.3	1.1	6.9	0.93	28	37.2	3.4	8.3	x				x			
Namsen	0.50	<0.4	2.87	14.0	3.2	6.9	2.12	56	29.1	3.0	9.4	x	x			x	x	x	x
Forra	0.53	<0.4	2.37	12.9	2.3	6.9	1.76	52	24.8	1.8	6.3	x	x			x	x	x	x
Gaula	0.27	<0.4	2.73	13.4	1.7	7.3	1.96	59	55.1	4.7	9.1	x	x			x	x	x	x
Rauma	0.68	<0.4	1.36	5.6	1.1	6.9	0.41	7	24.1	2.9	6.1								
Jostedals.	0.53	<0.5	0.59	3.3	0.9	6.8	7.72	100	18.8	2.4	161	x			x	x	x	x	x
Glomma	0.26	<0.4	1.32	5.7	1.3	6.7	1.41	32	38.1	5.0	12.2	x		x			x	x	x
Drammens.	0.34	<0.4	1.07	5.4	1.8	7.2	0.76	23	31.6	3.9	7.6	x	x				x	x	x
Aulielva	0.63	<0.5	15.7	55.0	26	7.6	3.05	103	150.1	10.9	113.1	x	x			x	x	x	x
Skienelva	0.39	<0.4	1.05	5.9	1.8	6.6	0.93	19	19.6	3.0	11.6	x							
Mandalselva	0.65	<0.5	2.95	17.3	1.4	5.3	0.97	27	25.1	3.3	12.1								
Weighted mean value	0.35	<0.4	1.63	8.1	1.61														
% removed by dialysis*																			
			4	6	16														

\* Glomma water. (Beneš and Steinnes, 1974).

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1966-74 (NIVA 1976). The turbidity values corresponding to the present samples are generally lower and reflect the low content of suspended matter in the samples. Mean values for the contents of Ca, Cl, Fe, K, Mg, and Na, based on monthly samples collected during 1966-70 are also available (NIVA 1976). These values are compared with the present geometric mean values in Table 3. The generally good agreement for the individual rivers indicates that the present samples may be considered representative at least as far as these components are concerned.

In the case of the Tana river, however, Na, Mg, Cl, SO<sub>4</sub> and conductivity are lower in 1971 than the average of the previous years. This may be explained by the lower precipitation during spring 1971, (Meteorological Institute 1976), resulting in a reduced supply of wind-blown sea-salt from the Arctic Ocean. Also in the case of Gaula and Rauma, a certain relative deficiency of these elements seems to be present in the 1971 samples. In general low concentrations were obtained in samples collected at times when the discharge was high (Table 1). The present geometric mean values for K, Ca and Cl in Gaula and Namsen rivers are, however, within one standard deviation of those obtained from the data of Braadlie (1930).

On the basis of the values in Table 2 and the discharge data given in Table 1, an overall weighted mean is calculated for each element. The deficiencies mentioned above do not affect the weighted mean values to any great extent. Considering the eleven rivers to be a representative selection of rivers in Norway and assuming the concentrations in the seasons of the year not represented in the sampling scheme to be of the same order of magnitude as observed here (cf. Table 3), the calculated weighted means should quite well represent the composition of an *average* river water in the region of Norway and possibly the larger part of the Scandinavian peninsula.

Table 3 - Mean composition of some elements in Norwegian rivers based on monthly samples during 1966-70 (NIVA, 1976) compared to geometric mean values obtained from 3 samples collected in 1971 (present work) mg/l.

Rivers	Na		K		Mg		Ca		Fe		Cl	
	1966-70	1971	1966-70	1971	1966-70	1971	1966-70	1971	1966-70	1971	1966-70	1971
Tana	5.5	2.1	0.90	0.70	2.13	0.98	5.0	3.8	0.13	0.13	8.3	2.1
Namsen	2.2	2.1	0.37	0.34	0.82	0.63	3.5	2.5	0.20	0.23	3.7	2.9
Forra	1.9	1.7	0.33	0.27	0.73	0.42	3.9	2.9	0.15	0.18	3.4	2.4
Gaula	3.7	2.1	1.17	0.89	1.43	1.02	8.1	6.2	0.19	0.42	5.8	2.7
Rauma	1.7	1.3	0.52	0.35	0.37	0.16	2.0	1.8	0.07	0.10	2.7	1.4
Jostedalselva	0.8	0.7	0.81	0.58	0.38	0.34	3.1	1.9	0.36	0.37	1.6	0.6
Glomma	1.2	1.3	0.76	0.73	0.96	0.79	4.8	4.7	0.25	0.15	1.7	1.3
Drammenselva	1.0	1.0	0.52	0.53	0.75	0.62	4.5	4.7	0.08	0.06	1.3	1.1
Aulielva	13.7	13.7	3.09	3.9	4.61	3.3	11.3	10.8	0.73	0.52	20.1	15.7
Skienselva	0.8	0.7	0.33	0.50	0.38	0.33	2.2	2.3	0.51	0.08	1.2	1.1
Mandalselva	3.8	2.0	0.43	0.45	0.69	0.37	1.1	1.0	0.20	0.13	4.4	3.0
Weighted mean	1.77	1.41	0.63	0.62	0.89	0.67	4.0	3.9	0.25	0.17	2.6	1.63

Elements in natural water systems may often be interrelated due to common sources. In order to get some information about sources which may influence the water composition of the rivers investigated, cluster and factor analysis were performed. In addition the extensive information about these rivers makes it interesting to compare the obtained values with other reported results even though data available for several elements are limited. The "world estimates" selected by Turekian (1969) on the basis of the literature then available are for many elements based on few samples from areas which also do not represent a world averaged petrology (Sweden, Japan, etc.) nor the yearly discharge of the elements. In addition the rare earth elements are only estimated from the ocean distribution based on 3 single La values from Sweden (Landström and Wenner 1965). Nevertheless Turekian estimates are compared with the present values in Table 4. Data from two more recent investigations (Tanner, Rancitelli and Haller 1972; Reeder et al. 1972) are also included in the table. Furthermore, data are listed from the work of Landström and Wenner (1965), which seems to be the only investigation of river water carried out so far in Scandinavia, covering a spectrum of elements similar to the present work. In addition, the results from recent studies concerning different migration forms of trace elements in water from the Glomma river (Beneš and Steinnes 1974, 1975) are given in Table 2.

## **Discussion**

### **Sampling Procedure**

In investigations dealing with trace elements in water, filtration through a  $0.45 \mu\text{m}$  membrane filter before analysis is often employed as a standard procedure. Even if this separation is an artifact, it is normally supposed to distinguish between the "soluble" fraction of an element and that bound or adsorbed to colloidal or suspended matter, or incorporated in the mineral lattice of particles. Kennedy, Zellweger and Jones (1974) have shown, however, that fine graded material can pass through  $0.45 \mu\text{m}$  membrane filters and cause large errors in analysis of elements usually enriched in particulate matter (esp. Fe, Al, Ti). In addition sorbtion effects due to filtering and filter clogging may cause large errors in the determination of other trace elements (van der Sloot 1976).

In order to estimate the amount of the elements reaching the ocean, it is of importance to include the fraction of the element sorbed to fine graded matter in suspension, since a great part of this fraction may be released on contact with sea water (Kharkar, Turekian and Bertine 1968). Similarly, the amount of an element biologically available may by far exceed the fraction present in the water after filtration through  $0.45 \mu\text{m}$  membrane filters. For these reasons we decided to



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Table 4 - Comparison of elemental concentrations in Norwegian Rivers with other published results

Element	Present work Range (individual observations)	Weighted mean	Estimated world average (Turekian 1969) (Livingstone 1963)*	Reeder et al. (1972) MacKenzie River (M-44)	Tanner et al. (1971) Columbia River	Landström and Wenner (1965) Rivers in Northern Sweden <sup>1</sup>
Na, mg/l	0.63-15.3	1.41	6.3*	7.0	2.2	1.0-1.4
K, mg/l	<0.1-4.9	0.62	2.3*	0.8	1.19	n.d.-0.4
Rb, µg/l	<0.9-4.4	≤1.2	1		3.5	0.7-<1
Cs, µg/l	0.032-0.34	0.082	0.02		0.35	n.d.-0.7
Mg, mg/l	0.4-3.8	0.67	4.1*	7.8		n.d.-0.6
Ca, mg/l	0.9-19.4	4.5	15.0*	36.4		3.3-5.5
Sr, µg/l	<9-84	27	50	210		5-10
Ba, µg/l	<6-26	15	10			<3
Sc, µg/l	0.008-0.082	0.017	0.004		0.002	n.d.-0.06
La, µg/l	<0.1-3.5	0.40	0.2			0.2-0.33
Ce, µg/l	<0.06-2.1	0.20	0.06			
Sm, µg/l	<0.02-0.66	0.095	0.03			
Eu, µg/l	0.06-0.040	0.0098	0.007			
Dy, µg/l	<0.01-0.11	<0.02	0.05			
Yb, µg/l	<0.01-0.5	<0.2	0.05			
Ti, µg/l	<6-32	≤8	3			
Hf, µg/l	<0.04-0.51	≤0.07	-			
Th, µg/l	<0.02-0.64	≤0.03	0.1			
U, µg/l	<0.2-0.58	<0.3	0.4	0.5	0.7	0.04-0.09
V, µg/l	<0.1-1.7	0.27	0.9			
Cr, µg/l	<0.4-3.5	0.90	1		0.4	<0.5-1.7
Mo, µg/l	<0.4-1.9	<0.5	1			n.d.-0.3
W, µg/l	<0.1-0.5	<0.2	0.03			0.03-<0.05
Mn, µg/l	2.3-65	17.1	7	≤1	2.8	<50-150
Fe, mg/l	0.05-0.87	0.171	(0.67)*	0.04	0.013	0.10-0.38
Co, µg/l	0.07-0.63	0.188	0.2		0.02	n.d.-0.1
Cu, µg/l	<4-60	≤6	7	2		<1-2
Ag, µg/l	<0.1-1.1	0.20	0.3		0.5	n.d.-0.4
Au, µg/l	<0.002-0.112	0.0061	0.002			0.001-0.003
Zn, µg/l	<4-57	20.0	20	1	8	7-19
Cd, µg/l	<0.6	<0.6				
Al, mg/l	0.037-0.95	0.113	0.40			
Ga, µg/l	<0.5-0.9	<0.6	0.09			
As, µg/l	<0.3	<0.3	2		2.5	0.2-0.4
Sb, µg/l	<0.16-2.1	0.35	1		2.0	0.05-0.08
Se, µg/l	<0.3-0.7	<0.4	0.2			n.d.-1
Cl, mg/l	0.5-16.8	1.63	7.8*	9.6		3-9
Br, µg/l	2.7-70	8.1	20		5.6	6-11
I, µg/l	<0.5-35	1.6	7			

<sup>1</sup> n.d.: not detected.

avoid filtration and use the advantage of sedimentation. A settling time of 6 and 12 hours did not show any significant difference for the elements in question which indicates that the major fraction of colloids in solution is significantly lower than 1 µm.

During storage of acidified samples, elements will be released from particulate matter due to desorption effects and clay mineral alteration can occur. The turbidity values and mineral analysis showed, however, that except from the two samples mentioned below the content of suspended material was low. Illite was determined in almost all samples while the low content of vermiculite and possibly chlorite (Table 2) may indicate that these minerals were to some extent dissolved during storage. In addition to ions, molecules and colloids in solution the results

of the present work employing the sampling procedure described above are likely to include the major fraction of the elements originally sorbed to suspended material, but to a small extent that included in the mineral lattice of particles  $>1 \mu\text{m}$ .

Fractions and associated trace elements are distinguishable in the factor analysis below. The influence of acid conservation of water samples as well as effects due to filtering and sedimentation/centrifugation techniques have been studied and will be the issue of a separate publication (Salbu).

### **Sources of Chemical Elements in Rivers**

The relationship between elements can often be assigned to common sources and may also reflect the similarity of the chemical properties of different elements. It therefore seems convenient to define two main components:

A) A "terrestrial" component largely derived from the weathering of crustal rocks. Elements which are usually enriched in minerals or are easily sorbed from fresh water solutions are expected to be strongly associated with colloidal matter in the samples.

B) A "marine" component due to airborne supply of oceanic salts or leaching of marine sediments. These elements are presumably to a great extent present in soluble forms and are expected to influence the conductivity of the samples.

In addition to other natural components, such as organics and volatiles, an anthropogenic component may also influence the relationship between elements.

### **Cluster Analysis**

A simple model for the relationship between the elements studied in this work is obtained by using a clustering technique based on the weighted pair-group method with arithmetic averages (Davis 1973). The variables are classified into more or less homogeneous groups using the correlation coefficients,  $r$ , as the similarity measure. Variables with the highest mutual similarity (highest correlation coefficients) are grouped together. Groups of variables are associated with other variables or group of variables which they closely resemble until all variables have been placed into a complete classification scheme. In cases where the elements were determined in 50% of the samples or more cluster analysis was performed. Data for As, Cd, Mo and U determined in the same samples using a radiochemical neutron activation method (Lenvik, Steinnes and Pappas 1978) and data for discharge,  $\text{NO}_3$  and the other variables given in Table 2 determined by NIVA (1973) on samples collected simultaneously were included in the analysis.

The results from the cluster analysis are given in Fig. 3 showing parts of the constructed dendrogram above the critical value of  $r$ . Assuming a two-sided significance level of 5% or 1% the critical value of  $r$  is 0.34 and 0.44 respectively.

## Elemental Composition of Norwegian Rivers

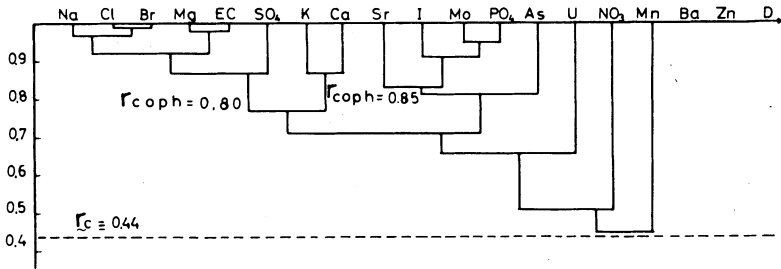


Fig. 3a. Results of cluster analysis based on 25 variables.

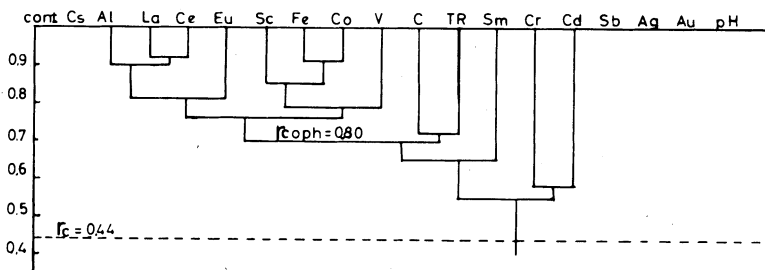


Fig. 3b. Results of cluster analysis based on 37 variables. In addition to chemical symbols: conductivity (EC), discharge (D), colour (C), turbidity (TR).

The cophenetic correlation coefficients given represent the deviation from the original correlation matrix and increase at lower linkages.

Two distinct groups of elements are seen in the figure, which is based on a data matrix containing the 37 variables mentioned. One group of Al, La, Ce, Eu, Sc, Fe, Co, Sm and Cr, i.e. elements which are usually enriched in terrestrial matter. Turbidity and colour cluster together with these elements. Therefore a contribution from terrestrial component is further supported and inorganic colloids present in river waters are assumed to be the main source contributing to the weighted mean values of these elements.

In the other group the correlation coefficients express strong linear relationship between Na, Cl, Br and K, Mg, Ca; elements which are abundant in the marine environment.

The conductivity and  $\text{SO}_4$  cluster together with this second group of elements as expected if a marine component is of importance. The subgroup containing Sr, I, Mo, total  $\text{PO}_4$  and As indicates, however, that other components may also play an important role.

### Factor Analysis

In order to obtain additional information about the relationship between the variables, factor analysis was also performed. The only previous application of this technique to hydrogeochemical studies of surface waters seems to be that of Reeder et al. (1972) performing Q-mode and R-mode techniques on a data matrix consisting of 14 variables and 100 samples.

The method used in the present study, P4M in BMDP, PCA for estimating the factor loadings and Biquartemin as the method of rotation is described by Dixon (1975).

The data are transformed to corresponding points in multidimensional space by extracting eigenvectors and eigenvalues from the matrix of variance and covariance. The sum of eigenvalues gives the lengths of the principal axes and represents the total variance of the data set. Scores and loadings are obtained when each observation is projected onto the principal axes.

Factor analysis based on the total data matrix, 37 variables, indicates extreme chemical characteristics for some of the samples. In order to obtain a better resolution, these samples having high estimated factor scores were considered to be outliers and therefore excluded.

Two samples (August, October) from the Jostedal river contribute most to the terrestrial factor. Due to the Jostedal glacier, still being in motion, the erosion in this area is high. Especially in late summer, when the ice-melting activity is high, a relatively high amount of suspended material is transported with the river and influences the water composition considerably. As the effect of acidification will increase with the amount of suspended material, these two samples are therefore not included in the analysis.

All samples from Aulielva river show high estimated scores for the marine factor which reflect the marine deposits present in the area. In addition high score is seen for the October sample of the Mandalselva river which reflects that upstream sea water contamination can occur at times when the discharge is low.

Factor analysis based on 27 samples and 37 variables were performed and the sorted, rotated factor matrix, with loadings for the variables, is shown in Table 5. Loadings less than 0.25 are omitted. Five factors account for nearly 70% of the information. The factor correlation coefficients, having values less than 0.16, indicate that the factors are uncorrelated. For a major number of variables the generally high communalities indicate that most of the variance is explained by these five factors. The low communalities especially for Cr, Cs, Sc, indicate, however, that the information which can be obtained on these variables is rather limited.

*Factor 1.* About one third of the variance among the variables is explained by this factor which is characterized by high positive loadings of Al and rare earth

*Elemental Composition of Norwegian Rivers*

Table 5 – Sorted, rotated factor matrix of 37 variables for 27 water samples from Norwegian rivers.

Variables	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communalities
Al	0.84					0.81
Sm	0.83					0.72
La	0.82					0.75
Ce	0.80					0.80
Eu	0.79					0.74
colour	0.70	0.48				0.81
U	0.64				-0.27	0.46
turbidity	0.62	0.54				0.70
Ca	-0.28	0.82		-0.30		0.90
conductivity	-0.25	0.82				0.83
Mg		0.76		0.34		0.83
pH		0.70	-0.48	-0.53		0.79
V	0.33	0.70			0.26	0.73
Fe	0.44	0.58		0.26	0.27	0.79
Cd		-0.53	0.52	-0.29		0.63
As			0.37	0.27		0.73
Zn		0.27	0.78			0.73
Mn			0.75			0.59
NO <sub>3</sub>		-0.33	0.71	-0.38	0.36	0.81
discharge		-0.28	0.54			0.42
SO <sub>4</sub>	-0.36	0.37	0.50		0.34	0.62
Cl				0.90		0.87
Na				0.90		0.89
Br				0.87	0.32	0.89
Au					0.93	0.82
I					0.85	0.78
Ag					0.60	0.46
Ba		0.32	0.43	-0.31		0.58
Mo	-0.47			0.46		0.42
K	-0.47	0.33	0.30		-0.25	0.60
Cs		-0.26	-0.30			0.20
Sr	-0.33	0.29	0.49			0.35
Sb		-0.42		0.37		0.35
Cr						0.08
Co	0.37	0.50		0.45		0.67
Total PO <sub>4</sub>	0.36		0.42		-0.37	0.49
Sc					0.38	0.31
Cumulative per cent of information	21.9	38.5	51.7	61.3	69.4	

elements. Almost all variance of these variables is accounted for by factor 1. The high positive loadings for colour and turbidity indicate that these elements are mainly present in particulate form as expected from their chemical properties. This factor is therefore interpreted to represent the colloidal fraction ( $<1 \mu\text{m}$ ) of terrestrial matter, mainly clay minerals, present in the samples. The association with Fe, V, Co and total  $\text{PO}_4$  may also indicate an influence from the scavenger properties of iron.

High factor scores are associated with rivers situated in the area of Trøndelag where Cambro-Silurian sedimentary and volcanic deposits are present. From the petrography of metamorphosed sediments in the area it is known that the dominant rocks are argillites in different stages of metamorphism containing considerable amounts of chlorite and biotite (Strand 1960).

The mineral analysis showed that especially the chlorite content of the samples from these rivers was much higher than in the other samples investigated. In addition dissolution of chlorite is likely to occur during storage in acid solutions and elements associated with chlorite may be released and thus included in the analysis of the water samples. The rivers having a drainage area where Pre-Eocambrian rocks are dominant have low factor scores. No chlorite was identified in samples from these rivers except in the case of the Drammenselva river showing a very low content of chlorite in two of the samples.

*Factor 2.* The second factor exhibits high positive loadings for Ca, Mg and medium loadings for Fe, Co, V. The medium loadings for colour and turbidity indicate a certain association with particulate matter. The relation between Mg, Ca, Sr,  $\text{SO}_4$  may be assigned to weathering of carbonate rocks (Reeder et al. 1974), while the weathering of trioctahedral illite may account for the relation between Fe, Mg and K. According to Roaldset (1971) an increasing illite content leads to an increase in the  $\text{Fe}_2\text{O}_3$  (Fe total), MgO and  $\text{K}_2\text{O}$  content. In Scandinavian tills illite is the dominant clay mineral ( $<2\mu\text{m}$ ) and high factor scores are associated with the Tana, Gaula and Glomma rivers, where the illite content was generally higher than in the other samples investigated.

*Factor 3.* This factor shows high positive loadings for Zn and other elements which often are associated with this element, and is assumed to represent the influence of ore deposits present in the drainage area of some of the rivers investigated. In the area of the Glomma river, which contributes most to this factor, Zn-ore deposits are utilized for industrial purposes and the mining activity may have an influence on the water composition.

**Factor 4.** Essentially all variance of Na, Cl and Br in river waters in Norway is accounted for by this factor. High estimated factor scores are associated with the rivers having a drainage area situated near the coast, while the rivers having an inland drainage area have low scores. Presumably this factor represents an influence of marine origin. In the coastal areas one may assume that the marine component of the river water is mainly derived from airborne supply. The positive loading for Mg and the negative one for Ca supports this assumption, and is also in agreement with the work of Låg (1963, 1968) showing that the relative Na/Ca- and Mg/Ca-content in precipitation and in humus samples decrease with the distance from the sea. The same pattern was observed for halogen contents in soil samples (Låg and Steinnes 1976). In spite of the Jostedalselva and Rauma rivers being situated near the coast the shielding of high mountains in the western part of their drainage areas diminishes the contribution of airborne supply. Hence, low factor scores are also obtained for these rivers. Inland, especially in the case of Glomma, weathering of tills and underlying bedrocks is of great importance for the release of alkali and alkaline earth elements (Englund, Jørgensen, Roaldset and Aagaard 1976).

Considering all the chlorine present in the water to be of marine origin and assuming that no fractionation of chlorine and the major cations takes place at the sea/air interface or in the marine atmosphere, the weighted mean values indicate that the following fraction of the elements concerned is of marine origin: Na 55%; Mg 16%; K 5%; Sr 2%. In a river such as Namsen, whose drainage area is at a fairly short distance from the coast, the corresponding figures are: Na 78%; Mg 30%; K 17%; Sr 7%. Still, the unfractionated marine component is important only for a small number of elements.

**Factor 5.** This factor is characterized by high positive loadings for Au and I, medium for Ag and low for V, Fe, NO<sub>3</sub>, SO<sub>4</sub>, Br and possibly Sc. High positive scores are associated with rivers in the area of Trøndelag, especially Forra, while low scores are obtained for the other rivers investigated. The Cambro-Silurian sedimentary and volcanic rocks with syngenetic sedimentary and epigenetic sulphide ore deposits contribute much more to this factor than the Precambrian gneisses and granites. The data seems too limited for further discussion.

The influence of the different factors on the water chemistry of each of the rivers investigated is indicated in Fig. 4. The signs indicating the importance of the various factors for the chemistry of the waters, refer to positive and negative estimated factor scores.

The relationship between Sr, I, Mo, total PO<sub>4</sub> and As obtained from cluster analysis and factor analysis based on the extended data matrix, vanishes by removal of the samples from the Aulieelva river. Examination of the analytical

data shows that the high numerical values of the samples removed are essential for obtaining high correlation coefficients. The relationship between these variables is therefore only relevant for characterizing waters of the Aulielva river.

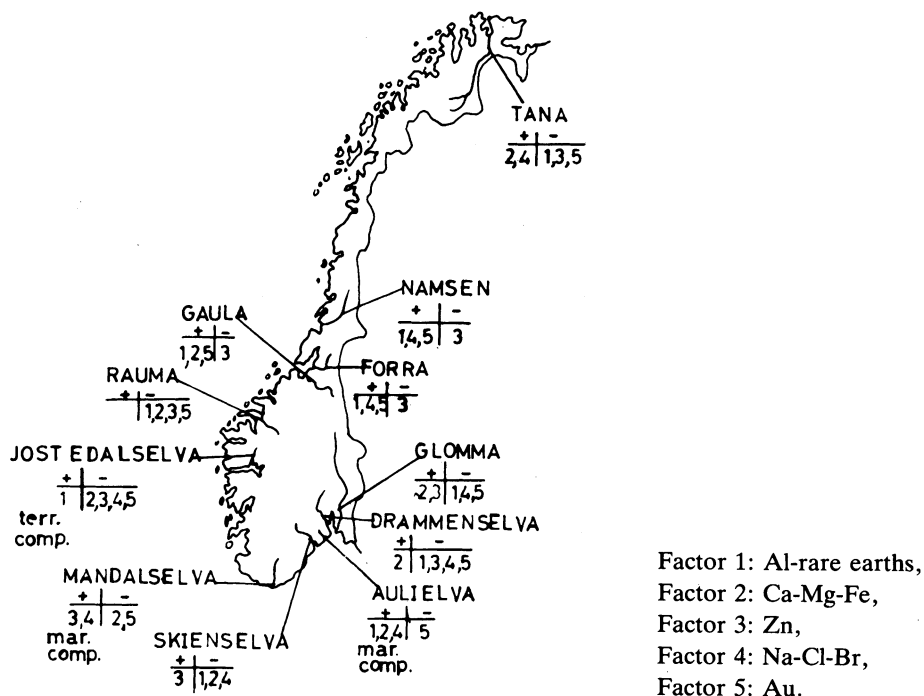


Fig. 4. Influence of different factors on the water chemistry of the rivers investigated.

### Element Abundances and Comparison with Literature Values

*Major elements.* In all cases the weighted mean values for the 5 major elements, notably Na, K, Mg, Ca, and Cl are considerably lower than the published world average values (Livingstone 1963), the ratios varying from about 4 to about 6. This difference is probably explained by a lower abundance of marine deposits and sedimentary rocks in Norway and possibly Scandinavia compared to the drainage basins of some of the large rivers of the world. This would imply that lower concentrations than the world averages might also be expected for associated trace elements. The present values are in agreement with those obtained from rivers in Northern Sweden (Landström and Wenner 1965).



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*Alkalies (sodium, potassium, rubidium, cesium).* The present weighted mean values show an increasing trend, relative to Turekian's estimated world averages, with increasing atomic number. While Na and K are lower by about a factor of 4, Rb is about the same and Cs is a factor of 4 higher than the corresponding Turekian averages. The different alkali element distribution is not easily explained on the basis of a different abundance distribution of major rock types in the present study area as compared with world average. The alkali element distribution shows large variation among different rivers studied in this work, as demonstrated by the K/Cs ratios varying in the range 2,100-35,000. However, the ratio based on the weighted mean values for these elements is 7,500 which is close to the value of 7,000 obtained from average crustal values (Taylor 1964). The Turekian average for Cs in rivers is based on the work by Kharkar et al (1968) where filtered samples were analyzed. A large part of the Cs detected in the present work may have been adsorbed to suspended material in the original samples. If Cs is to a great extent adsorbed to suspended material in rivers and subsequently released to a certain extent upon contact with ocean water due to ion exchange, the estimated average of  $0.02 \mu\text{g/l}$  Cs in river waters and the mean oceanic residence time of  $6 \cdot 10^5$  y reported by Kharkar et al. (1968) are subject to revision.

*Alkaline earths (magnesium, calcium, strontium, barium).* The trend of increasing ratios between the present weighted means and the Turekian averages with increasing atomic number is evident also for the alkaline earths, but not to the same extent as observed for the alkali elements. According to Durum and Haffty (1963) the median ratio of Ba/Sr, in contrast to other alkaline earth elements, seems to remain relatively stable, globally, in waters of lower reaches of large rivers. The ratio of 0.56 obtained in this work is in agreement with those observed in waters from large North-American rivers, varying between 0.55-1.2 (Durum and Haffty 1963).

The values of Sr ( $27 \mu\text{g/l}$ ) and Ba ( $15 \mu\text{g/l}$ ) are low compared to the reported values of  $217 \mu\text{g/l}$  Sr and  $43 \mu\text{g/l}$  Ba in waters from USA given by Kopp and Kroner (1968). The present value of Ba is, however, close to the  $11 \mu\text{g/l}$  value of Turekian (1966) forming the basis for his estimated average. In contrast to the work of Kopp and Kroner (1968) who found almost equal amounts of Ba in the filtrate and in the suspended fraction, Ba was shown to be present in the Glomma river almost entirely as soluble species, probably in simple cationic form (Beneš and Steinnes 1974, 1975).

*Scandium.* The values are in the same range as those obtained for unfiltered water from Swedish rivers (Landström and Wenner 1965). The Turekian average of

0.004  $\mu\text{g}/\text{l}$ , which is based on the work of Silker (1964) involving filtered samples from the Columbia river, is substantially lower than the 0.17  $\mu\text{g}/\text{l}$  of the present work. If, however, the experience from Glomma (Beneš and Steinnes 1974, 1975), indicating only 10-20% Sc present in dialyzable form, is representative of the present material as a whole, a closer agreement with the values from Columbia river (Silker 1964; Tanner et al. 1972) is obtained. The total amount of Sc supplied to the oceans may be significantly higher than indicated by the Turekian average.

*Rare earth elements.* Among the six rare earth elements (REE) studied, Dy and Yb were mostly present in concentrations below the analytical detection limit. The other four elements, La, Ce, Sm and Eu were present in concentrations deviating considerably from the Turekian averages. The weighted mean value for La is of the same order of magnitude as the few available literature values (Silker 1964; Landström and Wenner 1965). The slope of the REE distribution curve, as indicated by La/Sm ratio, is however, somewhat different from that of the oceanic REE distribution (Högdahl 1967) which forms the basis of Turekian's estimated world averages for streams. While the oceanic La/Sm ratio is 7.6, the ratio based on the present weighted means is 4.2. A certain depletion of Ce relative to the other REE, which is known from oceanic waters, is also evident for the rivers studied. The Ce/Sm ratio determined in oceanic water is about 2.7 (Högdahl 1967) while in the present work the ratio is 2.1. In Norwegian coastal water the ratio is about 2.2 (Nawapong 1977). This seems to contradict the experience from a study of REE distributions at the river-ocean boundary in the Gironde estuary (Martin, Høgdal and Philippot 1976) where no Ce depletion was evident in the river water. However, while the Scandinavian peninsula was subjected to extensive glacial erosion, Central Europe was not ice-covered during the Quaternary glacial periods. Thus, the processes of weathering and soil formation have been quite different in the two areas, which may have led to different chemical behaviour of Ce relative to other REE in the soils, sediments and waters of the two areas. Studies of tills and clays from Eastern-Norway indicate that a relative fractionation of Ce may occur in some cases. (Roaldset 1978). The association with particulate matter is indicated in the factor analysis and is further supported by the work of Beneš and Steinnes (1974, 1975) showing more than 75% Ce and 67% Sm in nondialyzable form. Assuming about 70% of these elements associated with colloids, one obtains 0.12  $\mu\text{g}/\text{l}$ , 0.06  $\mu\text{g}/\text{l}$ , 0.029  $\mu\text{g}/\text{l}$  and 0.003  $\mu\text{g}/\text{l}$  of soluble La, Ce, Sm and Eu respectively. For Ce and Sm the values obtained are in agreement with the Turekian estimates while in the case of La and Eu the estimates are somewhat higher. Anyhow, the total amount of rare earths supplied to the ocean seems to exceed that predicted from the estimates.

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*Titanium, hafnium, thorium, uranium.* These elements were in most cases present in concentrations close to or below the analytical detection limits. No values of Hf in river water seem to have been reported before. Data concerning Th are scarce and the level obtained in present work is lower than the value of  $0.096 \mu\text{g}/1$  from the Amazon River (Moore 1967). The level of U is significantly lower than the value from Canada (Reeder et al. 1972) based on unfiltered acidified samples. It is also lower than the revised world-wide average for rivers suggested by Turekian and Chan (1971).

As pointed out by Kennedy et al. (1974) the presence of more than  $1 \mu\text{g}/1$  Ti indicates clay minerals in the sample. A certain association with colloidal material may also be assumed for the other elements being predominantly stable in tetravalent state. In Glomma water more than 75% of Th was found to be present in nondialyzable form (Beneš and Steinnes 1975). U, even in the form of  $\text{UO}_2^{2+}$ , is known to be sorbed from solutions by clays (Goldztaub and Wey 1955) and in the factor analysis a certain association of U and terrestrial matter is indicated.

*Vanadium, chromium, molybdenum.* Reliable information about V in fresh water seems scarce and mostly restricted to Japanese rivers. The weighted mean value of  $0.27 \mu\text{g}/1$  is significantly lower than the value of  $0.9 \mu\text{g}/1$  reported by Sugawara, Naito and Yamada (1956) forming the basis of the Turekian average. During weathering V remains in the rock forming minerals and/or enters the minerals in the silt and clay fractions where it can be incorporated in the mineral structure (Wedepohl 1974). The association with clay minerals which is indicated in the factor analysis is therefore expected.

As  $\text{Cr}^{3+}$  is easily sorbed from solutions and the ratio  $\text{Cr}^{3+}/\text{CrO}_4^-$  is high in waters with high content of organic matter (Canter and Gloyna 1968) deviating results for Cr could have been expected. The present weighted mean value is, however, in agreement with the Turekian estimate. In the Glomma river 50% of Cr was present in nondialyzable form (Beneš and Steinnes 1974). The Mo content in Scandinavian rivers is low compared to the Turekian value, but closer to the value of  $0.6 \mu\text{g}/1$  reported from Japan (Sugawara 1967). The concentrations of all these elements, especially Mo, reported from USA (Kopp and Kroner 1968) seem to be too high to be representative.

*Manganese.* For this element the weighted mean reported here is considerably higher than the available literature data, except for a value of  $12 \mu/1$  from USSR (Konovalow 1959) and the value of  $58 \mu\text{g}/1$  for U.S. rivers (Kopp and Kroner 1968). The association with colloidal matter might account for much of the variation in reported Mn-values.

The variation of Mn among the different rivers studied in this work is also quite large. In the case of the Glomma river, which contributes heavily to the weighted mean value the factor analysis indicates a certain association with ore deposits. In samples collected in 1974 about 70% of Mn was found to be present in dialyzable form (Beneš and Steinnes 1974). On the other hand, Mn may be easily lost from water samples by adsorption, which could in part be responsible for the low values obtained in investigations employing filtration techniques.

*Iron.* As stated by Turekian (1969) the average value for Fe in streams of 670  $\mu\text{g}/\text{l}$  listed by Livingstone (1963) may be rather questionable. The present value of total Fe (171  $\mu\text{g}/\text{l}$ ) is at the same level as the values reported from Sweden by Landström and Wenner (1965) based on unfiltered samples. Appreciably lower values were found in North-American rivers (Tanner et al. 1972, (unfiltered samples); Reeder et al. 1972 (0.45  $\mu\text{m}$  filters and acidified filtrates)). The differences may be partly explained by the association of Fe with particulate matter. Colloids containing Fe can penetrate 0.45  $\mu\text{m}$  filters as pointed out by Kennedy et al. (1974) and association with colloids is indicated if Fe values significantly exceed the values expected from the most soluble mineral phase (Jones, Kennedy and Zellweger 1974). Using 0.1  $\mu\text{m}$  filters Jones et al. (1974) determined dissolved Fe in the range of 0.3-8.8  $\mu\text{g}/\text{l}$  in samples from USA. As the Fe concentrations predicted from the solubility of amorphous  $\text{Fe}(\text{OH})_3$ , were close to, but below, the analytical values, association of Fe with organics might account for the differences.

From the factor analysis it is seen that most of the variance of Fe, colour and turbidity is explained by factor 1 and factor 2, indicating that most of Fe is present in particulate form. In Glomma water about 80% of Fe was present in nondialyzable form (Beneš and Steinnes 1974). Assuming this fraction to be representative one obtains 34  $\mu\text{g}/\text{l}$  dissolved Fe. At pH 7 and Eh about 200 mV the concentration of soluble Fe estimated from the solubility of amorphous  $\text{Fe}(\text{OH})_3$  is about 20  $\mu\text{g}/\text{l}$  (Jones et al. 1974). In addition to release of Fe during storage of acidified samples the slight deviation may in part be explained by association with organics.

*Cobalt.* The weighted mean value is in agreement with the Turekian average, based on the work by Kharkar et al., (1968). The 0.19  $\mu\text{g}/\text{l}$  value of Kharkar et al. is, however, the average of analyses based on filtered samples. When the amount of Co sorbed on suspended sediments in river water and desorbed in contact with sea water was considered, they obtained an average of 0.54  $\mu\text{g}/\text{l}$  for the "total soluble load", which is a more proper basis of comparison with the present values.

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In contrast to Kopp and Kroner (1968) reporting that Co was mainly adsorbed to sediments, Beneš and Steinnes (1974) found that 87% of Co was present in dialyzable form in water from the Glomma River. The low Co-content and the apparently different chemical forms of Co in Norwegian rivers could be associated with the relatively high frequency of acidic rocks in the present study area.

*Copper, silver, gold.* The weighted mean values for Cu and Ag are not distinctly different from Turekian averages, but far below the values reported by Kopp and Kroner (1968). In the case of Au, the weighted mean value is a factor of 3 higher than the Turekian estimate based on the values from Sweden (Landström and Wenner 1965). The present value is, however, identical with the value predicted from dissociation constants of pertinent aqueous Au complexes in fresh surface waters of 25°C in contact with air (Ong and Swanson 1969).

A median value for Au of 0.010  $\mu\text{g}/\text{l}$  was obtained by analysis of surface water samples from Colorado, USA, and it was found that the Au content in water was generally higher than that in the suspended fraction (0.1  $\mu\text{m}$ ) (Gosling, Jeune and Chao 1971).

*Zinc, cadmium.* The Turekian average for Zn is the same as the weighted mean value from the present work and good agreement is also observed with data from Swedish rivers (Landström and Wenner 1965). Reeder et al., (1972), who obtained a value of 1  $\mu\text{g}/\text{l}$  of Zn in the MacKenzie river, ascribed this value to the fact that membrane filtered samples were analyzed in their case. Experience from studies of Norwegian river water indicates, however, that more than 50% of Zn is present in soluble form (Beneš and Steinnes 1974, 1975). This is also reported by Kopp and Kroner (1968) concerning rivers in USA, but their reported mean value is a factor of 3 higher than the present value. In the case of Cd no world average was estimated by Turekian (1969). In the work of Kopp and Kroner (1968) Cd was only determined in the higher 3% of the filtered samples showing a mean value for Cd slightly below 10  $\mu\text{g}/\text{l}$  which is probably too high to be representative. The relationship between Zn and Cd is indicated in the factor analysis.

*Aluminium.* In view of the high abundance of Al in the geosphere, surprisingly little is known about its concentration in natural waters. The association with particulate matter is obviously one of the reasons and as reported by Kennedy et al. (1974) finely dispersed particles can pass even through a 0.1  $\mu\text{m}$  filter. The Turekian average is based on a value of 0.3 mg/l from Japan (Sugawara 1967). Based on filtered samples a median concentration of 238  $\mu\text{g}/\text{l}$  was observed for

rivers in North-America (Durum and Haffty 1962) while in a more recent investigation from USA, Al in filtrate was found in the range of 1-2,760  $\mu\text{g}/1$  with a mean of 74  $\mu\text{g}/1$  (Kopp and Kroner 1968).

Based on samples filtered through 0.1  $\mu\text{m}$  filters dissolved Al is reported in the ranges 1-3  $\mu\text{g}/1$  during low flow periods, 10  $\mu\text{g}/1$  at moderate flow and higher values at high discharge rate (Jones et al. 1974). From their solubility-derived estimates of Al based on different natural minerals, the kaolinite solubility provides concentration estimates closest to their analytical values. The weighted mean value of total Al of this work is 113  $\mu\text{g}/1$  and the variation among the most important rivers is rather small. The association with particulate matter is indicated in the factor analysis and in the Glomma river only 9% of Al was present in dialyzable form (Beneš and Steinnes 1974). Assuming this fraction to be representative the estimated amount of dissolved Al is about 10  $\mu\text{g}/1$ . This value is probably high, as Al may have been released from clays, mainly chlorite and vermiculite, during storage in acid solution. As the Scandinavian weathering profiles have a very low content of kaolinite and no kaolinite was found in the suspended fractions other Al-compounds and minerals should be considered as controlling factors for the solubility of Al.

*Arsenic, antimony.* The values presented for As in this work are far below the Turekian average even though association with Zn-ore deposits are indicated in the factor analysis. For Sb the weighted mean value of 0.35  $\mu\text{g}/1$  is between the Turekian average, based mainly on the work of Kharkar et al. (1968), and the level of 0.05-0.08  $\mu\text{g}/1$  found in Swedish rivers by Landström and Wenner (1965). It is interesting to note that the arithmetic mean of the seven U.S. rivers investigated in the work by Kharkar et al. is as low as 0.51  $\mu\text{g}/1$  and the value for the Mississippi river is 0.32  $\mu\text{g}/1$ , which is in good agreement with the present work. The 1.1  $\mu\text{g}/1$  average value for Sb cited by Kharkar et al. depends much on a high value of 4.9  $\mu\text{g}/1$  reported for the Amazon river.

*Halogens (chlorine, bromine, iodine).* The concentrations of chlorine and bromine are about twice as high in rivers draining areas in the vicinity of the coast as in the main rivers having inland draining areas. This was also suggested in the factor analysis and the contribution of airborne supply may play an important role especially in coastal districts. The weighted mean values are, however, lower than Turekian's estimated averages by factors of 4.5, 2.5, and 4.4 for Cl, Br and I respectively. The most plausible reason for this seems to be the scarcity of marine deposits in the drainage areas of the rivers studied in this work. In the case of the river Aulielva, which drains such an area, the mean values of the halogens are about a factor of 3 higher than the Turekian averages.

### **Some General Remarks**

The total dissolved solids, i.e. the sum of the main constituents, in Scandinavian river waters is lower than in waters of large rivers of the world. The ionic composition of large rivers is characterized by  $\text{Ca} > \text{Mg} > \text{Na} > \text{K}$  while  $\text{Ca} > \text{Na} > \text{Mg} > \text{K}$  is typical for Norwegian rivers. River water with low salt content is found in mountain areas while higher values are associated with rivers having a lowland drainage area with sedimentary rocks. In addition a contribution from airborne supply influences the ionic composition of rivers situated near the coast.

In the case of trace elements in river waters few data are available. Even though these data do not represent world average petrology nor the yearly discharge of the elements, reported data (Table 4) from different rivers agree within a factor 10. Scattering results may not totally be due to differences in drainage regions, but may also reflect differences in sampling, storage conditions and preanalysis handling. This work shows that association with small-size particulate matter ( $< 1\mu\text{m}$ ), is important especially for Al, rare-earths, U, Fe, V, Co. Introduction of filtering techniques will obviously affect the determination of these elements, but low values may also be expected for other, especially multivalent, elements which are easily sorbed from solution.

The combination of chemical analysis giving a large and broad data matrix, with statistical methods allows useful information to be obtained. Water from different rivers are characterized by interrelations of certain trace elements. Thus, trace elements pattern reflects common sources and/or transport mechanisms and may thereby increase our knowledge about the physico-chemical states of trace elements in natural water systems.

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**Address:**

B. Salbu and A. C. Pappas,  
Department of Nuclear Chemistry,  
Institute of Chemistry,  
University of Oslo,  
P. O. Box 1033, Blindern,  
Oslo 3, Norway.

E. Steinnes,  
Institutt for Atomenergi,  
Isotope Laboratories,  
Kjeller,  
Norway.