Nordic Volcanological Institute 8701
University of Iceland

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THE CHEMISTRY OF GROUNDWATER IN THE LANGJÖKULL-THINGVELLIR DRAINAGE AREA, SOUTH ICELAND

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INTRODUCTION

This report describes the chemical characteristics of waters of the Thingvellir-Langjökull drainage area in southern Iceland. The area is largely covered by postglacial lava. Sampling sites were selected with the view to compare the chemistry of glacial meltwater, surface waters and cold groundwater emerging in natural springs. By virtue of the sparse settlement, the natural state of the ground- and surface water in the region has not been affected by human activities. The region, therefore, affords good opportunities to study the geological and meteorological factors controlling the origin of dissolved species in these natural waters.

The Thingvellir-Langjökull drainage area covers the interior of the country within and east of the Reykjanes-Langjökull rift zone. The area is devided into several watersheds by hyaloclastite mountain ridges. Large parts of the area north of The Lake Thingvallavatn and south of the Langjökull glacier are covered with porous and fissured postglacial lava fields with no visible water on the surface. Less permeable late quaternary basalt formations crop out on both sides of the lava fields (Fig. 1). Elevation varies from 103 m.a.s.l. at the Lake Thingvallavatn to 500 m.a.s.l. at the Lake Hagavatn on the southern edge of the Langjökull glacier. The highest mountains in the area are over 1000 m.a.s.l. Strata dip is about 10 m/km southwest to the Lake Thingvallavatn and the longest distance between recharge and discharge areas is about 40 km. The residence time of water which travel the longest distances underground are 2-3 months - 2-3 years as estimated using the permeability values of Tómasson

(1971). Secondary permeability such as tectonic fissures inevitably affect flow rates and, therefore, the age of the water.

Vegetation is rare in these fields and the northern part of the area is a desert. The southern part is covered by a thin humus layer and moss, grass, bushes and even small trees especially in Haukadalur area. In the recharge area towards north, the melt water and precipitation seeps almost immediately into the bedrock through surface morain and alluvial cover. A humus soil layer is practically absent and therefore the content of carbon dioxide in infiltrating water will not rise as much as it would if such a layer was present.

Water is discharged mainly through springs on the southern edge of the postglacial lavas or hyaloclastites on the border of early quaternary basalt formation. The so called spring-fed rivers originate in these springs. Usually this water has travelled long distances through subterraneous aquifers. The flow appears to be remarkably constant for some of the springs and seasonal variations are smoothed out and the water temperature is constant. The temperature of most springs is 3-5 °C, depending on the soil temperature of the drainage area. The climate is of cool maritime type. The mean annual temperature in two nearby meteorological stations, Haell and Hveravellir, is 3,7 and -0,9 °C, respectively (ten year average) and precipitation of the same stations is 1148 and 923 mm, respectively.

GENERAL GEOLOGY OF THE AREA (written by Páll Imsland)

Four stratigraphical formations, showing differences in lithofacies occupy the bedrock of the studied area, i.e. the border region of the southern lowland and the highland behind it, towards Langjökull. These formations range in from the fresh postglacial lavas to the mid-quaternary lava-beds of the older pile, apparently about 1,5 million years old. This area extends from the central axis of the active volcanic rift zone about 40 km, out into a slightly eroded and tilted lava pile.

During the formation of this crustal segment the quaternary ice-age occupied the northern hemisphere. In Iceland this meant the coming and going of cold and warm periods, when glaciers covered the country and melted away in turn, at least ten times during the last three million years (Saemundsson, 1979). The consequence of this on the rock formations is drastic. During glacial periods the volcanic eruptions took place under the ice-cover and the eruption materials were turned into fragments, which piled up over the eruption sites to form heaps (in contrast to beds (Jones, 1969 & 1970). These materials consolidated into clastic rocks called hyaloclastites, which range in lithofacies from fine-grained glassy tuffs, through a variety of breccias of glassy groundmass and aphanatic vesicular basalt clasts, to the more typical pillow lavas and irregular masses of enbe-jointed basalt. During interglacial periods the lavas were able to flow more freely and form a bedded lava pile.

Erosion, mostly glacial, of the hyaloclastites delivered masses of sediments. These deposited on the lavas and are now found as interbeds of sedimentary hyaloclastites (reworked hyaloclastites) between lavas in older sections of the pile. These reworked hyaloclastite sedimentary layers show a variety in lithology as f.i. fluvial and lacustrine tuffs, tillitic, glacifluvial or fluvial conglomerates and breccias.

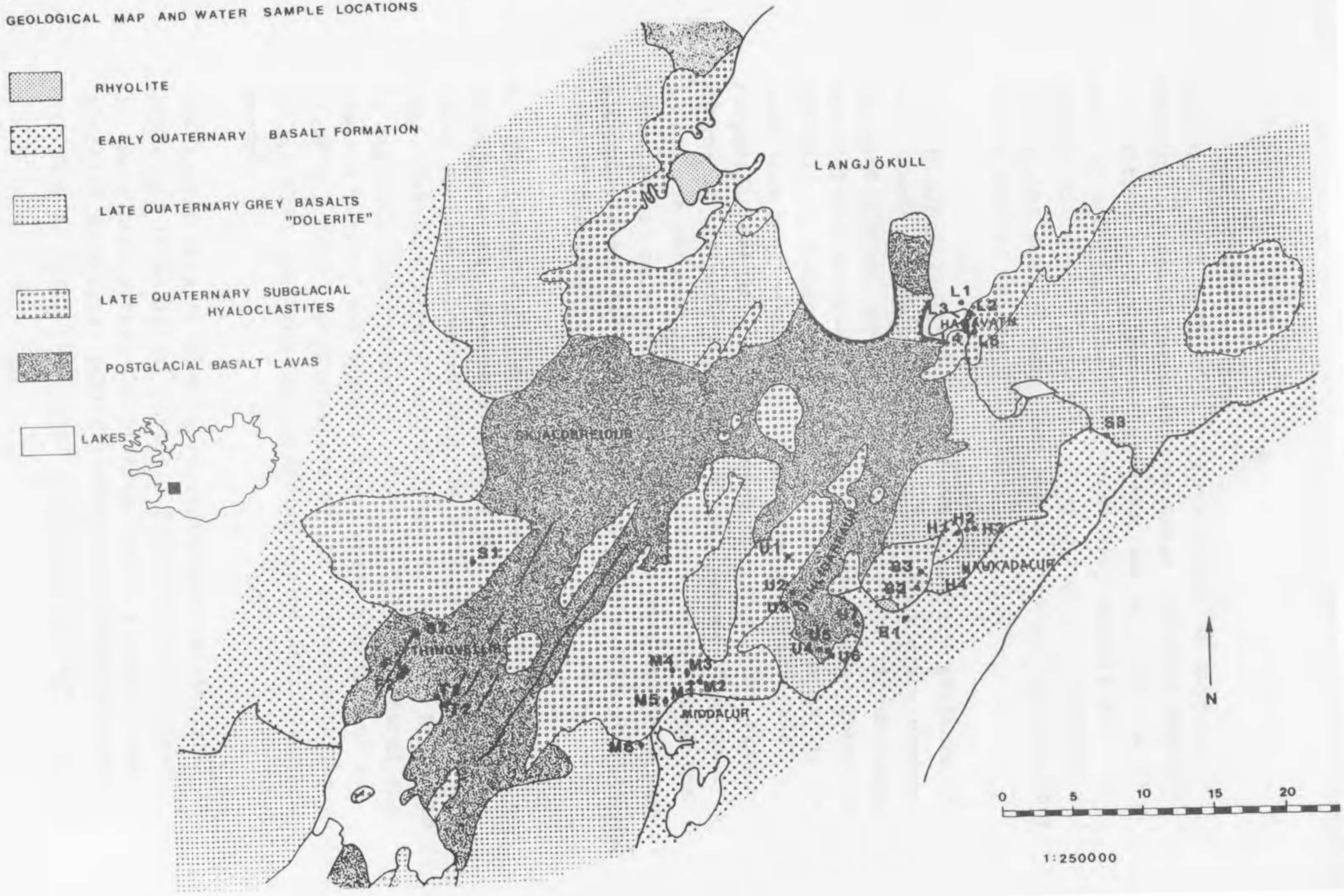
The four bedrock formations are shown on the following map, which is a simplified portion of the geological map of Iceland (Kjartansson, 1962, 1965, 1968 and Saemundsson & Einarsson, 1980). These formations are:

1. The old lavas. These occupy the basalt lava pile furthest towards east and west and lowest in the section. They are all quaternary in age, but older than 0,7 million years (i.e. the Brunhes-Matuyama magnetic pole reversal, see Saemundsson, 1979). They are primarily fissure lavas, which originate in fissure swarms, now extinct. Their original porosity is now decreased, as vesicles and cracks are partly filled by secondary minerals. This pile of lavas contains sedimentary horizons of the various types mentioned above. This formation does not appear within the sampled area but borders it. The groundwaterflow is apparently nowhere from these rocks and into the sampled area, so this formation apparently does not affect the composition of the water samples.

2. The grey basalts. These are interglacial lavas which mostly were produced during the two last interglacial periods. They are usually taken to originate in relatively large shield volcanoes. They are lighter in colour than basalts usually are. This results from a coarse-grained texture compared to most lavas, which is as well the reason for the doleritic name sometimes used for this rock type, especially in older literature. These basalts are

THINGVELLIR – LANGJÖKULL DRAINAGE AREA

GEOLOGICAL MAP AND WATER SAMPLE LOCATIONS



texturally more open as well, as a result of numerous intercrystal small cavities. As these cavities came as an addition to the decreasing vesicles, which are still empty of secondary minerals, these grey basalts are usually quite good aquifers. They occupy a considerable part of the studied area, and within them are located some of the sampled wells.

3. The hyaloclastites. These rocks are the products of the fissure and shield volcanism that took place during the last glacial period or two. Due to the circumstances the eruption materials were not able to flow as lavas and did heap up within the ice-sheet. Each hyaloclastite is thus much more restricted in horizontal section and comparably thicker, when compared to lavas. The clastic nature of the material causes a high degree of porosity in all the various lithological types. Being young the formation is only slightly eroded. It does occupy a considerable areal of the central part of the area, containing some of the sampled wells.

4. The postglacial lavas. These are the basalt lavas produced by the fissure eruptions and shield volcanoes after the ice retreated from the area, around 10000 years ago. They are highly vesicular and in addition fractured by the rift zone tectonics. They occupy the central and western part of the sampled area, where the flow of the lavas has been highly affected by the graben-tectonics in the rift zone and the bordering hyaloclastite topography.

The entire area is thus characterized by basalts of different lithological facies. Rhyolites only appear in two places within the studied area. A young (last glacial) subglacial peslitic formation (Prestahnjukur) is found in the northwestern corner of the area, but this does apparently not affect the sampled waters. Another older rhyolite occurence, an eroded small extinct central volcano, is found in Bjarnasfell in the southeastern corner of the area, close to some of the sampling localities. The process of obtaining a chemical equilibrium between the basalt and the groundwater may be slightly affected by the difference in lithology of the various basalts within the area, which range from 100 % crystalline lavas to 100 % glassy tuffs. The basalts do as well range somewhat in chemical composition and mineralogy, within the range allowed for by the tholeiitic suite restriction. This may as well affect the chemical equilibrium. The loose materials covering the bedrock are, on the other hand, unlikely to be of much importance, as they are mostly of local, or nearly so, origin; morainic material. The soil and vegetation were avoided as much as possible, during sampling.

SAMPLING AND ANALYSIS

Water samples were collected during July and September, 1982. The pH, temperature, and usually also the total carbonate of the water were measured in the field. The pH probe and buffer solutions were allowed to equilibriate at the water temperature before a reading was recorded. Samples for chemical analysis were filtered through a hand held Millipore filter 0,45 μm after flushing with appr. 50 ml of fluid. Sample bottles of polyethylene were rinsed three times before filling up. One 100 ml sample bottle for cation analyses was acidified with 0.2 ml of concentrated HCl and another with 0,2 ml of concentrated HNO_3. Two samples were left untreated for pH, total carbonate, spesific conductance, silica, chloride and sulfate analysis (altogether 1,5 l). One 100 ml sample for total carbonate was treated with 0,5 ml of 0,05 M NaOH solution. Time lapse between collection and analysis varied from 3 hours to two days.

The necessity of filtering in the field has been emphasized by Eyles et al (1982). Especially electrolyte poor waters (glacial melt water) tend to dissolve various components from suspended unorganic matter upon storage. Eyles et al (1982) observed the largest increase in concentrations of Mg and silica in unfiltered samples.

Total carbonate was titrated potentiometrically with 0,05 N HCl solution from pH 8,2 to 3,8. A portable pH-meter was used to estimate the pH, and the correct pH value was then calculated. In the laboratory total carbonate was re-estimated by back titration which gave on the whole lower concentrations of total carbonate, or by about 10 % on average. The concentrations reported in table 1 are those measured in the field.

Analysis of total carbonate was undertaken immediately after arrival of the samples. Total carbonate of untreated and treated samples was titrated with HCl. The results compare well and with the field measurements. On the contrary the pH values measured in the field and in the laboratory sometimes differ many tenths of pH units. The phenomenon was observed earlier by Rist (1973). The general trend was that high pH values decreased and low values increased during storage.

Silicate was determined colorimetrically using the molybdosilicic acid complex. Spesific conductance was measured in the laboratory with a Griffin Conductance Bridge. Sodium and potassium were determined with a Beckman 495 atomic absorption spectrometer. Litium addition did not affect to results of randomly chosen samples, and that is why all the samples were measured without any addition. Samples acidified with HCl and HNO_3 as well as untreated samples gave identical concentrations within the precision of the method.

Calcium and magnesium were determined with the same AAS-instrument. La_2O_3 solution was added as a releasing agent before measurement.

Sulfate was measured by titration with barium perchlorate after concentration and cation exchange. In acid solution a column of activated alumina will retain sulfate more readily than most other anions, and it is possible to separate as little as 0,1 mg/l sulfate. The sulfate is then eluted from the column with 0,25 M ammonium hydroxide, passed through a small cation exchange column and titrated with 0,005 M barium perchlorade using Thorin indicator.

Chloride was determined argentometrically by titration with 0,02 M $AgNO_3$ solution and $K_2Cr_2O_4$ indicator. An ion-selective electrode (Orion Research 96-17) was also used to measure chloride. The results of the both methods are in good agreement.

Intercalibration of the sulfate and chloride methods with two Finnish laboratories (Food and Environmental Laboratory of the City of Helsinki and National Board of Waters, Research Laboratory) showed identical results with auto-analyzator (photometric Thorin method for sulfate and photometric mercury thiocyanate for chloride), whereas ion chromatography analysis gave lower concentrations.

DISCUSSION

Chemical analyses of 32 samples are presented in table 1. The glacial lake Hagavatn was chosen to represent precipitation and meltwater, i.e. the chemistry of the water in the recharge area. The northern edges of the postglacial lavas are porous and permeable without any humus layer. A great deal of meltwater and all precipitation therefore seep quickly down through the surface morain layer into the bedrock, and start to flow towards the southwest as subterraneously as groundwater.

Sample L1 is meltwater collected on the glacier. It´s main feature is low electrolyte content, although the water is very turbid, having a large amount of suspended material. The pH value (6,0) is in the same order of magnitude as in pure rain water (5,7). Meteoric water is always contaminated to some extent with seawater. Deviation in the ratios of some elements in sea water and in the glacial meltwater,

Table 1. Chemical analysis of 32 samples from the Thingvellir-Langjökull drainage area.

Sample number location	Date	Temp °C	Spesif. cond. µs/cm	pH	ΣCO_2 ppm	SiO_2 ppm	Na ppm	K ppm	Ca ppm	ppm	SO_4 ppm	Cl ppm	Ca/Mg	Na/K
L1 Langjökull glacial melt water	8.8.	0,0	4,8	6,00	2,3	0,9	0,20	0,02	0,50	0,20	0,1	0,4	2,5	10,0
L2 Hagavatn glacial lake	8.8.	9,5	12,0	6,10	4,5	2,7	0,96	0,09	1,02	0,40	0,4	1,0	2,5	10,7
L3 Hagavatn glacial stream	8.8.	7,0	10,0	6,10	4,0	3,0	0,82	0,08	0,88	0,34	0,4	1,0	2,6	10,3
L4 Hagavatn glacial stream	8.8.	7,5	9,0	6,10	5,8	2,6	0,61	0,07	1,00	0,48	0,3	0,7	2,1	8,7
L5 Hagavatn melt water, surface water	8.8.	10,5	45,0	6,50	15,0	6,1	3,0	0,16	2,90	1,3	1,6	4,6	2,2	18,7
S1 Sandkluftavatn lake	9.7.	11,5	24,0	6,40	4,9	1,9	2,8	0,22	0,57	0,49	0,8	4,8	1,2	12,7
S2 Leirulaekur river	9.7.	9,0	55	7,05	18,9	11,2	7,8	0,26	3,37	0,33	1,3	5,5	10,3	30,0
S3 Sandá river	28.9.	4 0	58	8,10	18,5	13,9	8,2	0,56	2,86	1,00	1,2	5,3	2,8	14,6
H1 Haukadalur spring	6.7.	3,2	51	8,70	15,2	16,8	5,8	0,56	3,67	0,83	1,1	4,5	4,5	10,4
H2 Beiná spring	28.9.	3,2	45	9,20	10,8	16,4	6,1	0,44	2,86	0,68	1,3	3,8	4,3	3,9
H3 Almenningsá spring	28.9.	2,8	41	9,25	9,5	14,3	5,1	0,35	2,86	0,72	1,1	4,0	4,0	14,6
H4 Hrisar spring-fed brook	14.7.	7,0	45	8,05	16,7	16,5	6,3	0,45	2,64	0,78	1,1	3,6	3,3	14,0

Table 1. continued

	Date	Temp °C	Spesif. cond. µs/cm	pH	ΣCO_2 ppm	SiO_2 ppm	Na ppm	K ppm	Ca ppm	Mg ppm	SO_4 ppm	Cl ppm	Ca/Mg	Na/K
B1 Stakksá river	21.9.	2,9	68,0	6,70	24,3	22,4	6,5	0,39	5,00	2,00	3,0	6,5	2,5	16,7
B2 Hellisgil mountain stream	28.9.	6,0	75	8,75	21,6	22,4	10,2	0,49	4,8	0,83	2,2	6,2	5,9	20,8
B3 Margargil mountain stream	14.7.	12,0	77	8,55	26,4	20,4	12,8	0,38	4,10	0,40	2,8	6,3	10,0	33,7
U1 Brúará spring-fed river	14.7.	4,0	36	8,55	10,6	12,4	5,4	0,34	1,80	0,42	1,6	4,1	4,3	15,9
U2 Kalfá Femri spring	28.9.	2,5	49	9,85	7,5	15,9	7,6	0,34	2,40	0,36	1,6	3,8	6,7	22,4
U3 Hvútá spring	28.9.	2,3	47	9,50	8,9	14,6	6,1	0,29	2,36	0,58	1,6	3,9	4,1	21,0
U4 Brekka spring	21.9.	5,0	56	7,35	18,8	15,7	5,5	0,41	4,50	1,24	1,8	5,5	3,7	13,4
U5 Brekka spring	21. 9.	4,2	55	7,35	19,4	15,7	5,6	0,42	4,53	1,26	1,7	5,8	3,5	13,3
U6 Brekka spring-fed brook	9.7.	10,0	57	8,65	17,2	14,6	5,9	0,43	4,19	0,99	1,7	5,4	4,2	13,7
U7 Brekka spring	14.7.	4,2	80	7,20	30,4	19,0	7,6	0,70	5,50	1,85	2,7	6,6	3,1	10,9
M1 Middalur spring	9.7.	3,7	58	9,65	10,8	15,2	11,3	0,10	2,18	0,05	1,3	4,4	44	113
M2 Middalur spring	7.8.	3,5	60	9,60	11,5	15,1	11,2	0,08	2,54	0,06	1,3	4,5	42	140
M3 Middalur spring	7.8.	3,5	58	9,65	11,1	14,7	11,2	0,08	2,20	0,15	1,4	4,5	15	140

Table 1. continued

	Date	Temp ^{o}C	Spesif. cond. µs/cm	pH	ΣCO_2	SiO_2	Na	K	Ca	Mg	SO_4	Cl	Ca/Mg	Na/K
M4 Middalur mountain stream	21.9.	6,0	41,0	6,80	15,9	16,1	3,8	0,29	3,12	1,40	1,6	3,9	2,1	13,1
M5 Laugardalur spring	9.7.	4,3	75	9,55	14,1	15,9	13,0	0,22	2,40	0,34	2,5	5,6	7,1	59
M6 Laugardalur well	28.9.	4,0	75	9,15	16,3	16,7	12,5	0,20	3,47	0,25	1,9	5,6	14,0	62
T1 Thingvallavatn spring	6.7.	3,0	50	8,75	12,8	14,9	6,0	0,49	2,92	0,86	1,7	5,2	3,4	12,0
T2 Thingvallavatn spring	21.9.	3,1	49	8,80	12,8	15,4	6,0	0,50	2,97	0,89	1,7	5,0	3,4	12,0
F1 Flosagjá fissure (from pump)	9.7.	5,0	68	9,25	15,4	14,2	10,3	0,39	4,03	0,59	1,8	6,9	6,8	26,4
F2 Flosagjá fissure	7.8.	3,5	68	9,20	15,5	15,5	9,4	0,43	4,29	0,74	1,8	6,8	5,8	21,9

which are shown in figures 2,3 and 4, can be used to evaluate reactions between the meltwater and the suspended solids.

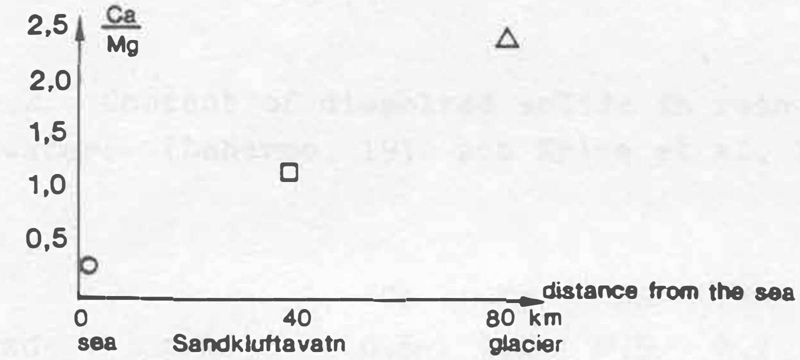


Fig.2. Ca/Mg–ratios as a function of the distance from the sea.

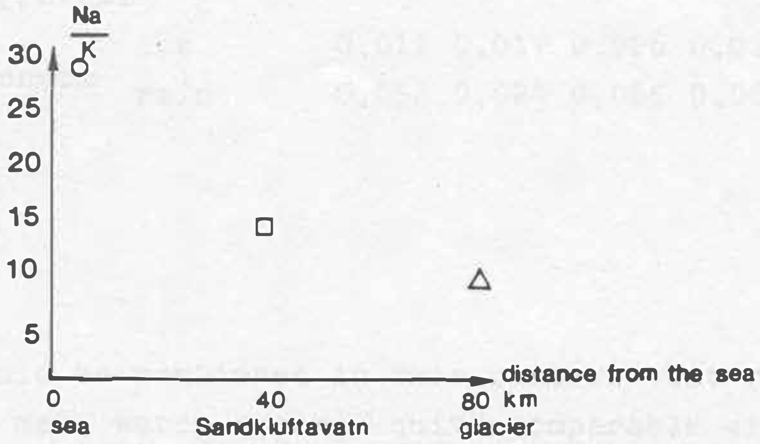


Fig.3. Na/K–ratios as a function of the distance from the sea.

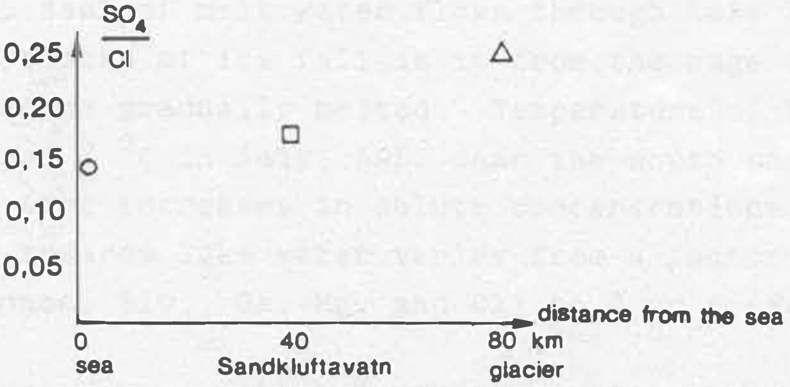


Fig.4. SO /Cl–ratios as a function of the distance from the sea.

As compared to precipitation in Finnish Lapland the Ca, Mg, Na and chloride contents are quite similar to those shown in table 2. The potassium content is somewhat higher in Lapland but sulfate concentrations are still higher, about 10-30 times (Lahermo, 1970). The main reason for high sulfate values is human activity, burning of fossil fuels.

Table 2. Content of dissolved solids in rain water and melt water. (Lahermo, 1970 and Eyles et al, 1982.)

		Ca		Na	K	Cl	SO_4	SiO_2
Finland Lapland	rain	0,5	0,1	0,5	0,2	0,2	1,0 -3,0	0,4
Iceland Langjökull	meltwater	0,5	0,2	0,2	0,02	0,4	0,1	0,9
Canada Berendom	ice	0,011	0,017	0,026	0,015	0,95	-	0,14
	rain	0,052	0,024	0,065	0,065	0,98	-	-

It should be mentioned in this context that rain water and ice or melt water are not quite comparable with each other

A good deal of melt water flows through Lake Hagavatn and large blocks of ice fall in it from the edge of the glacier and become gradually melted. Temperature of the lake was measured 8 ^{o}C in July, 1982 near the south shore. Table 1 shows that increases in solute concentrations from melt water towards lake water varies from a factor of 2 (total carbonate, SiO_2, Ca, Mg, and Cl) to 4 or 5 (Na, K, SO_4).

These results give rise to some ideas on geochemical denudation. Sodium and calcium are the principal elements leached from glacier basin. The majority of Canadian denudation (Eyles et al, 1982) is shown to be the result of calcium loss.

The chemistry of the glacial streams at their source has not undergone modification from meteoric water to the same extent as the lake water. However, the amount of dissolved solids has increased much at a sample site tens of kilometers downstream (table 3). Still the concentration of sodium is highest among cations.

Table 3. The increase of dissolved matter in a glacial river (Árnason, 1976).

	Na	K	Ca	Mg	SiO_2	SO_4	Cl	pH
Far L3	0,82	0,08	0,88	0,34	3,0	0,4	1,0	6,1
Hvitá Gullfoss	8,12	0,58	3,66	1,31	10,2	5,0	3,9	7,5

Bragi Árnason (1976) has shown that the waters issuing from the springs in the Thingvellir-Haukadalur area originate, at least partly, in the Langjökull glacier. The changes in chemical composition during this subterraneous flow warrants some discussion. When the water flows underground it may react with the rocks. The chemical composition of spring waters is determined by ion supply from the atmosphere and what is leached from the rocks in contact with the water. The atmospheric supply is determined by two factors, sea water contamination in the precipitation and carbon dioxide, which is dissolved in the water. The concentrations of solutes in groundwaters of terrains covered with humus is largely controlled by a few parameters. Among these probably the most important is the quantity of CO_2 (and organic acids) generated in the soil zones by root respiration and the bacterial decay of organic matter. Virtually all of the CO_2 that dissolves in groundwater is neutralized to HCO_3^- by reaction with silicate minerals. The total dissolved solids of groundwaters in such terrains therefore depends in the main on the H_2CO_3 content of soil water as it leaves the zone rich in decaying organic matter, and on the extent to which H_2CO_3 used in silicate weathering below this zone is replenished by the downward transport of CO_2. On the bases of this one would expect low content of dissolved inorganic matter in the discharge area.

pH values of the samples under discussion increase from 6,0 to 9,85. The highest values are found in springs at the southern end of Uthlidahraun. These springs have also the lowest total carbonite concentrations (below 10 mg/l). This is in accordance with early laboratory experiments (Nesbitt et al, 1980), which show that CO_2 reacts with silicates the products being silicic acid and bicarbonate. At the same time pH increases. These waters have apparently flown deep enough to prevent dissolution of atmospheric CO_2 during their travel between recharge and discharge areas and have reached or approached equilibrium with some secondary minerals in the basalt at 4 °C. Silica concentrations are normally around 15 mg/l in distant origin springs. Sodium concentrations are 6±1 mg/l, potassium 0,3±0,1 mg/l, calcium 2,4±0,5 mg/l and magnesium 0,5±0,3 mg/l. Sulfate concentrations seem to increase with the distance of underground flow from 1,1 to 1,8 mg/l. Chloride show the same trend; from 3,8 to 5,6 mg/l.

Springs in Haukadalur are similar to those at Uthlidahraun, but have not reacted as much as infeared from their higher magnesium content and lower pH. Mixing of local waters with distant origin groundwater is probably seen in sample number H1.

The chemistry of mountain streams in Bjarnarfell differs much from the spring waters. Samples B2 and B3 have a little lower pH values, 8,75 and 8,55 respectively, and higher ΣCO_2 content, 21,6 and 26,4 mg/l, compared to the spring waters. Silica concentrations are the highest in the studied area, 22,4 and 20,4 mg/l, sodium (10,2 and 12,8 mg/l), calcium (4,86 and 4,10 mg/l) and sulfate (2,2 and 2,8 mg/l) are almost twice as high as in nearby (Haukadalur) springs.

Sample B1 was collected from a river, draining a rhyolitic part of the mountain Bjarnarfell. It has a unique chemistry among the samples: pH is low (6,70); alkalies are low but alkaline earths high, especially magnesium (2,0 mg/l) and sulfate (3,0 mg/l) concentrations, which are the highest found in the study.

The Middalur and Laugardalur palagonite formation has a distinct effect on the water composition. The highest Ca/Mg ratios (44) and Na/K ratios (140) are found in this region. "Normal" Ca/Mg ratios of spring waters are 3-6 and Na/K ratios 15-20. Magnesium and potassium concentrations are extremely low; magnesium concentrations are lower than in melt water in Langjökull. pH values are also high: 9,60. One explanation is the cation exchange with certain minerals. Cation exchange theory (Nesbitt et al, 1980) and experimental studies (Malmqvist et al, 1978) confirm that large cations are retained on clay minerals.

The high Na/K and Ca/Mg ratios probably result from cation exchange and fixation on clay minerals where larger ions are retained in preference to smaller ones. Water samples M5 and M6 show a similar tendency, but the respective ratios are lower. Surface water H4 from the same area does not show high Ca/Mg and Na/K ratios.

Springs in the northeastern shore of the Lake Thingvallavatn are typical grounwater discharges of distant origin (Langjökull), but they have a little lower pH and a higher total carbonate concentration than the springs by Uthlidahraun, which might be due to the mixing of precipitation with groundwater.

The water in Flosagjá originates from mountains to the North and North-West of the Lake Thingvallavatn (Árnason, 1976). Samples F1 and F2 have high pH values (9,25 and 9,20) although total carbonate concentrations are also high (15,5 mg/l). So sodium and calcium concentrations have reached a higher level as compared to the springs in Uthlidahraun, Haukadalur and Thingvallavatn. Chloride content is the highest in the present study.

Typical features of surface water in the Thingvellir-Langjökull drainage area are a low pH, high temperature (over 5 ^{o}C) and high magnesium content with high pH values. Low Ca/Mg and Na/K ratios are typical of the local surface water. Surface and groundwater can thus be separated from each other by chemical methods.

The weathering of the basaltic rocks in the study area is shown in the figure 5, and the relative mobility of cations during the chemical weathering of basalts is presented in table 4.

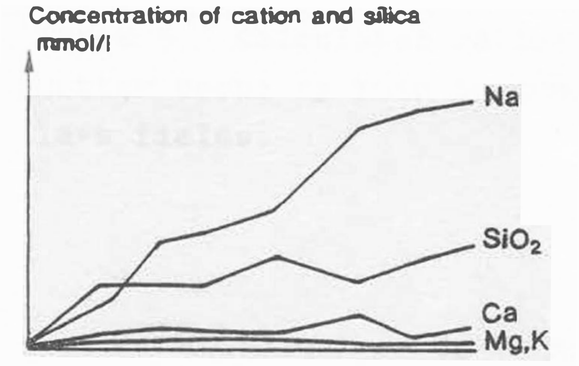


Fig.5. The concentration of the major cations and dissolved silica.

Table 4. Relative mobility of cations.

Basaltic lava RSG44**)   Groundwater sample T1

	wt %	M*)	cation % A		mg/l	mmol/l	cation % B	B/A
SiO_2	55,55	8,42	46,7	SiO_2	14,9	0,25	39,7	0,85
Al_2O_3	9,37	1,84	10,2					
TiO_2	1,05	0,13						
Fe_2O_3	0,42	0,05						
FeO	8,96	1,25						
MnO	0,19	0,03						
MgO	12,29	3,05	16,9	Mg	0,86	0,04	6,4	0,38
CaO	14,65	2,61	14,5	Ca	2,92	0,07	11,1	0,77
Na_2O	1,98	0,64	3,5	Na	6,00	0,26	41,3	11,80
K_2O	0,07	0,03	0,17	K	0,49	0,01	1,6	9,40
P_2O_5	0,07							
H_2O	0,34							

*) M = moles of oxides per kilogram of rock

**) From the data bank of The Nordic Volcanological Institute

From table 4 the weathering sequence is Na>K>Si>Ca>Mg. Table 5 shows the portion of atmospheric origin in groundwater.

Table 5. Calculated ratios, in percent, of inorganic matter borne by rain in groundwater discharged from basalt lava fields.

	Ca	Mg	Na	K	SO_4	Cl	SiO_2
T1	2,92	0,86	6,0	0,49	1,7	5,2	14,9
L1	0,50	0,20	0,2	0,02	0,1	0,4	0,9
L1/T1 100%	17	23	3	4	6	8	8
*) silicic %	10-15	5-10	30	40	30-100	30	5
*) subsilicic %	5	5	40	40	10-40	30	5

*) Finnish Lapland (Lahermo, 1970)

From table 5 it can be seen that the portions of atmospheric origin in groundwater are low. They might be higher if evaporation and respiration are estimated.

The next three figures show the most significant correlations found among values of table 1. Figure 6 illustrates correlation between pH values and silica concentrations, figure 7 pH values and total carbonate concentrations and figure 8 the correlation between the ratious Na/K and Ca/Mg.

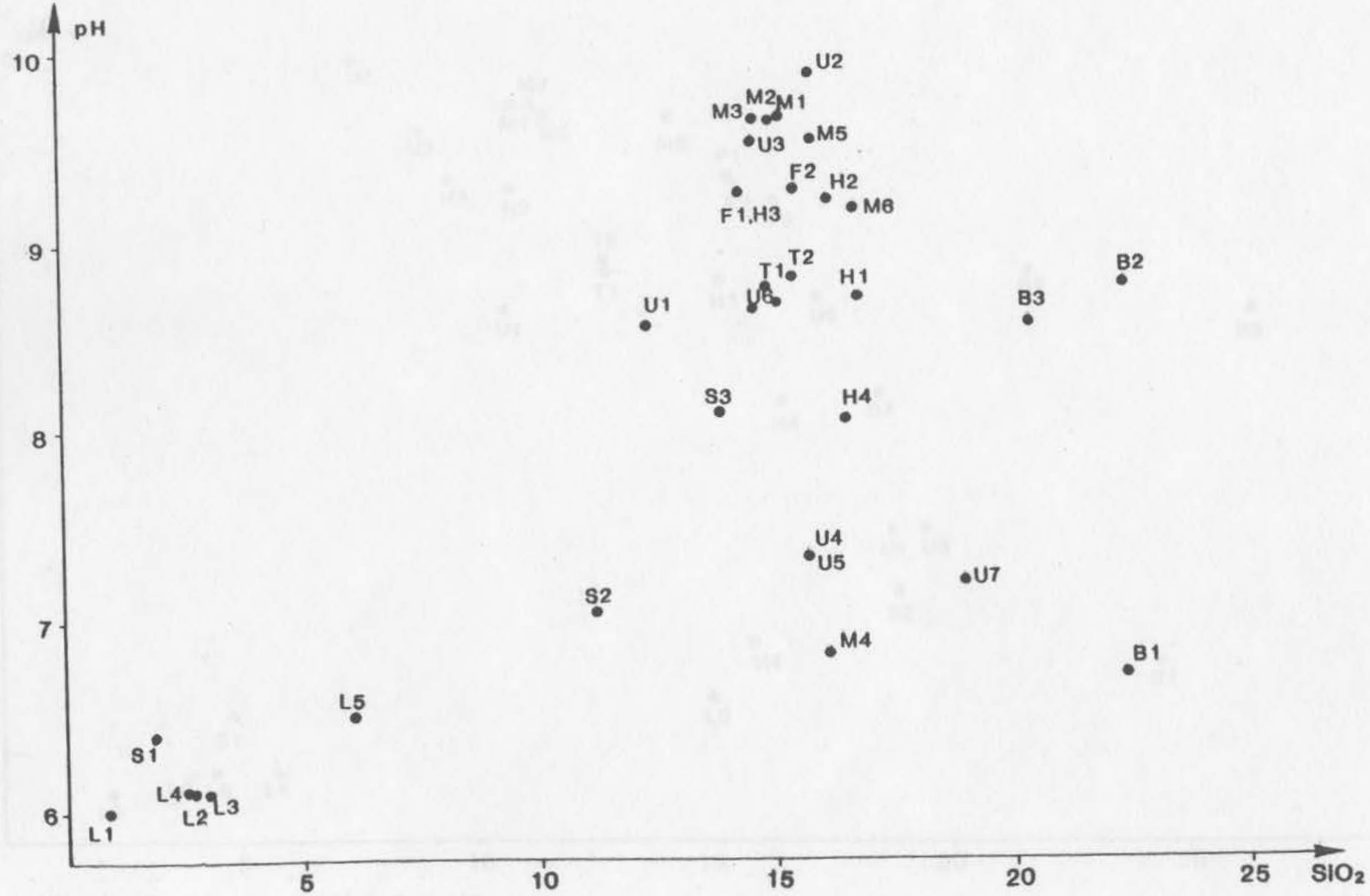


Fig. 6. pH values versus silica.

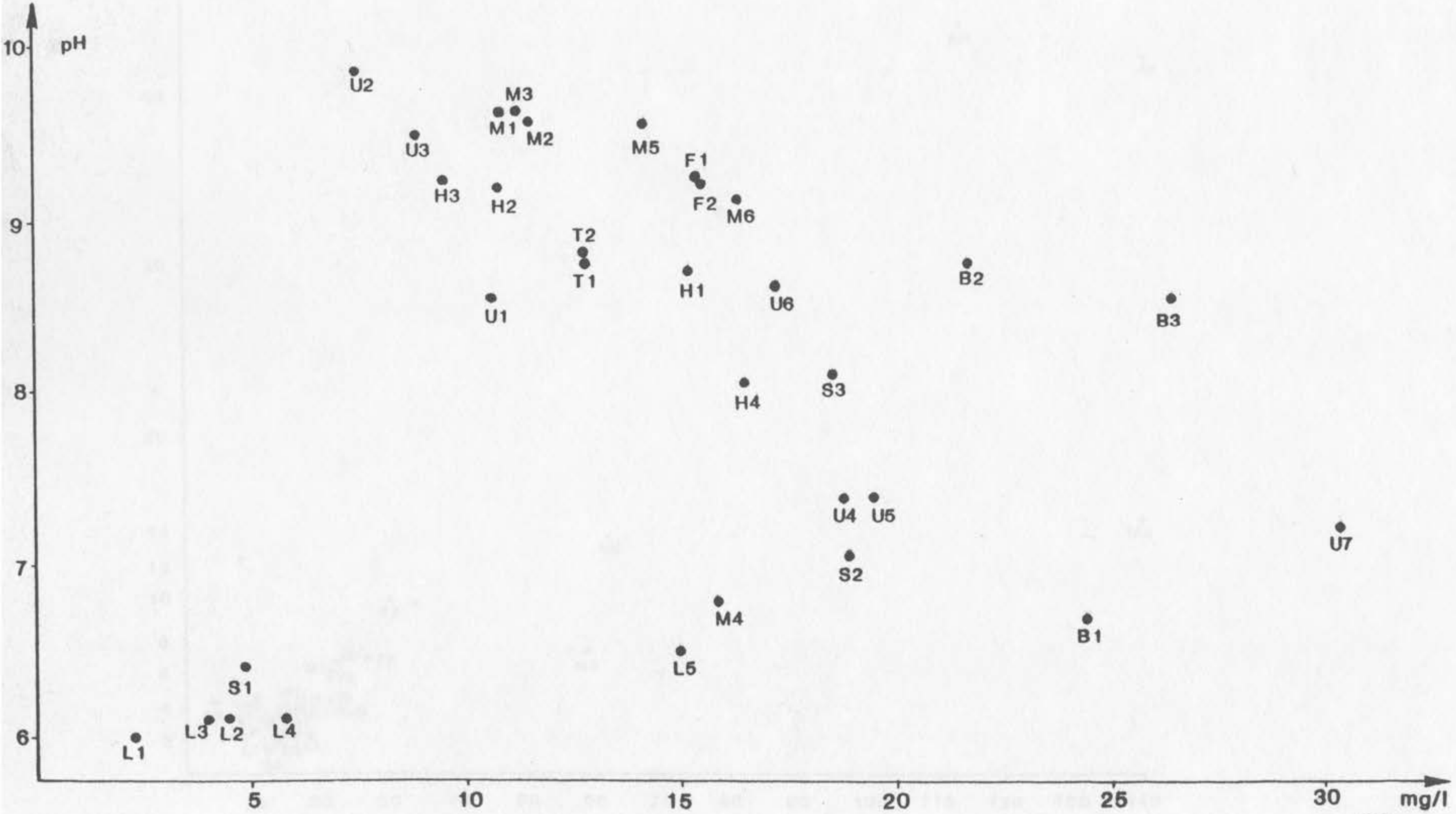


Fig.7. pH values versus total carbonate.

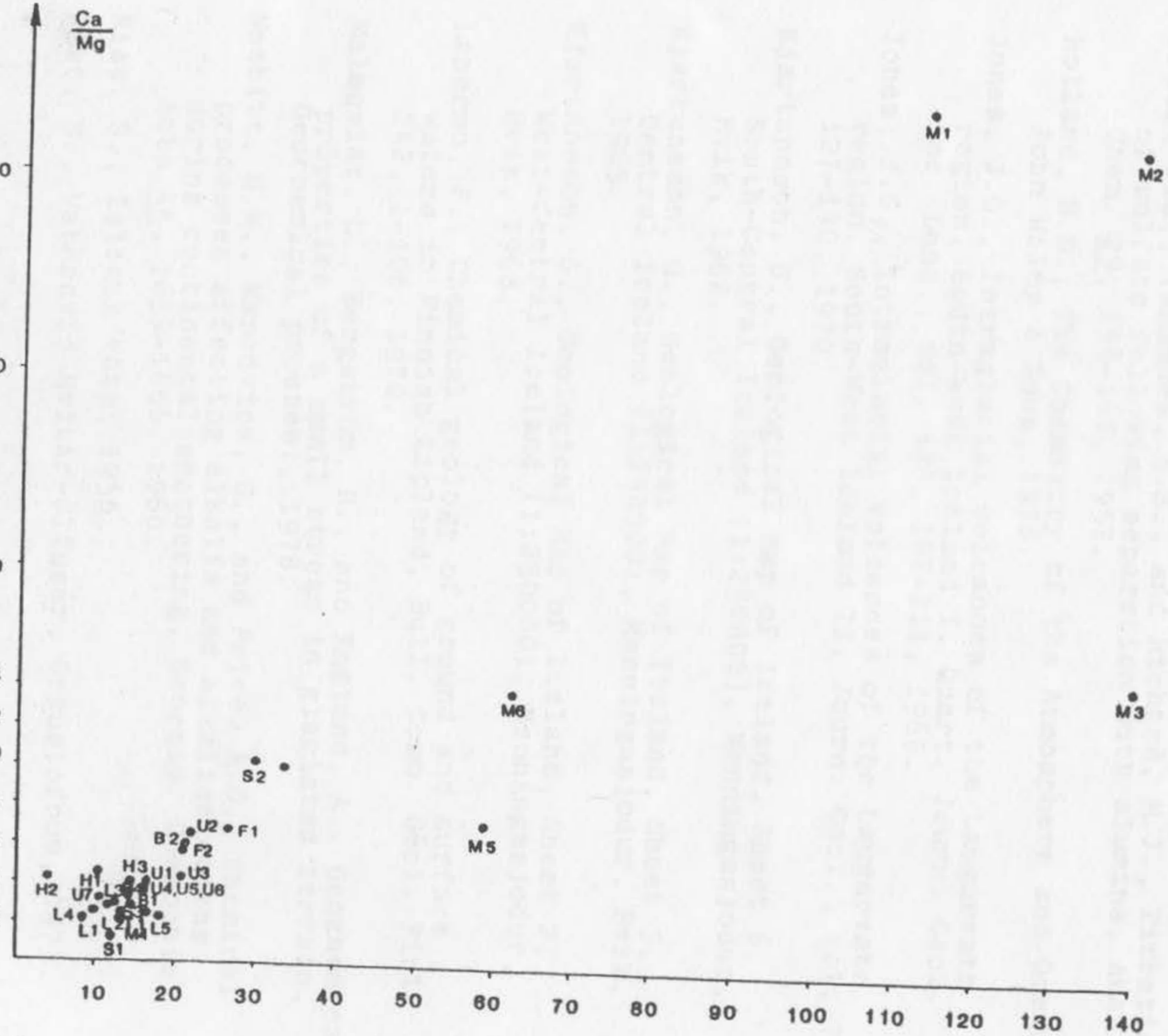


Fig. 8. Ca/Mg ratios versus Na/K ratios.

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