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On the hydrogeology of the coastal region of southeastern Finland

by Pertti Lahermo

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ON THE HYDROGEOLOGY OF THE COASTAL REGION OF SOUTHEASTERN FINLAND

BY
PERTTI LAHERMO

WITH 31 FIGURES AND 2 TABLES IN THE TEXT

GEOLOGINEN TUTKIMUSLAITOS
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Thresholds of rock separate from eskers and other glaciofluvial deposits rather small basins the ground-water yield of which usually ranges from 200 to 500 cu.m a day (24 hours). Wells drilled into nearly cubically fractured rapakivi granite yield an average of 50 cu.m of ground water a day. The deepening of a drilled well frequently increases the amount of ground water, although depth and yield have no significant correlation one to another.

The amount of dissolved matter, particularly iron, diminishes when pumping is started and becomes later stabilized at a certain level. The concentrations, especially Cl, are greater deep in bedrock than in water closer to the surface. To some extent, this is probably due to sea water left in the bedrock during post-glacial marine stages. The composition of the relict sea water has undergone considerable changes. The supplies of salt water are depleted during constant use.

The amount of dissolved matter contained in ground water is in inverse proportion to the rate of percolation, which in turn depends on the structure of the geological formation.

In the weathering process sodium is released more effectively than potassium and alkaline earths are released in relatively larger amounts than are alkalies. The high fluoride content of rapakivi is reflected in the ground water. It contains ten times larger amounts of fluorides than the ground waters of the country as a whole. The contents of F and SiO_2 do not change considerably in relation to other components.

Contamination of ground water is most sensitively indicated by nitrogen compounds, chlorides, sodium and potassium.

Helsinki 1971. Valtion painatuskeskus

INTRODUCTION

The study set forth in the present paper had as its aim the geological elucidation of the ground-water conditions in southwestern Finland (Fig. 1). With respect to structure and origin, the Quaternary deposits of the region are similar to those elsewhere along the Finnish coast. The modes of occurrence of the ground water in the surficial deposits and bedrock of the study area are thus applicable to the rest of the subaquatic regions of the country.

The bedrock of the study area is of homogeneous composition, consisting as it does solely of rapakivi granite (Viborg rapakivi). The homogeneity of the bedrock opens up the possibility of ascertaining the effect of the structure of different geological formations on the chemical nature of the ground water, because it is not necessary to take into account variation in rock composition as a factor regulating the chemical composition of the water. On the other hand, the broad extent of the homogeneous bedrock enables one to determine the effect on the quality of the water specifically of rapakivi granite bedrock. One important question in this connection is the reflection in the ground water of the uncommonly large fluoride content of rapakivi granite. The location of the study area on the coast of the Gulf of Finland affords the researcher an opportunity to analyze the effect on the composition of the ground water of sea

FIG. 1. The area investigated, which is situated on the coast of the Gulf of Finland, is marked off with a rectangle. The bedrock of the shaded area consists of rapakivi granite.

water percolating into the soil and the bedrock — some of the sea water in the ground being of a relict nature, dating back many thousands of years. Also in this respect, the results of the present study are applicable to other coastal areas of Finland.

The study area is densely populated and industrialized. For this reason, the need for water for household and industrial purposes is great. This in turn has made necessary the carrying out of investigations with a view to obtaining all utilizable ground water. Numerous ground-water searches and drillings of wells have, as a matter of fact, been conducted in the study area. Test pumpings and analyses of the quality of the water have been included in the research activities by several engineering firms.

The most important formations from the standpoint of the occurrence of ground water, such as eskers and other glaciofluvial deposits, have been re-mapped by the author on the basis of the maps of Quaternary deposits published by Mölder (1958, 1965). The water samples were collected by the author during the summers of 1965—1966 as part of the work connected with the mapping of Quaternary deposits by the Geological Survey.

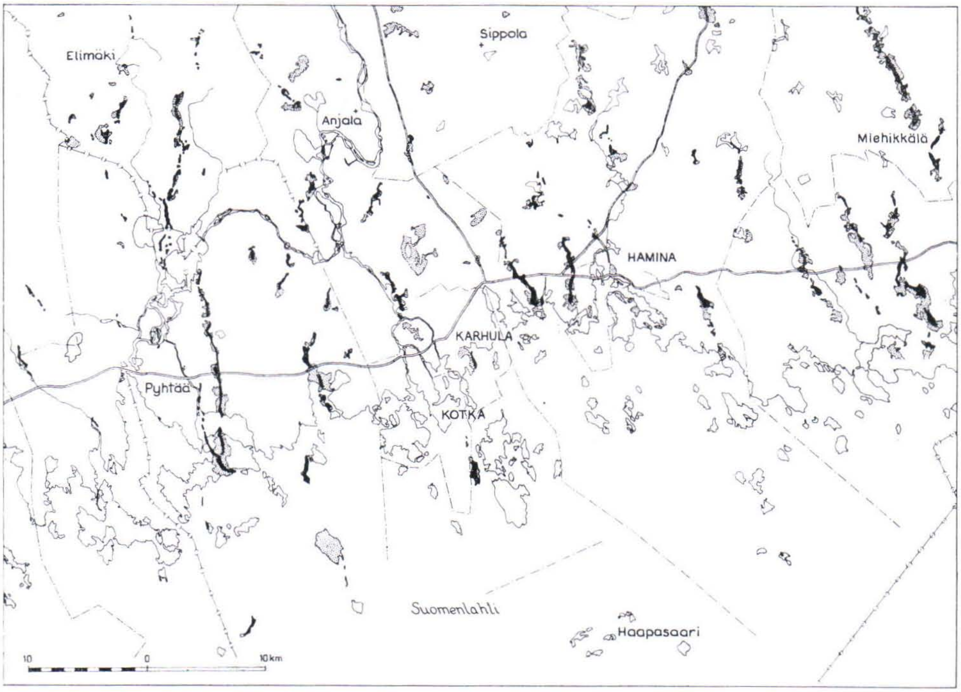

FIG. 2. The eskers and other glaciofluvial deposits of the area investigated. The Quaternary deposits were remapped on the basis of the Quaternary map sheets (Mölder 1958, 1965) of Hamina and Karhula (1 : 100 000). The area included in the map sheet of Kotka (Gardemeister 1963) is reproduced unchanged.

OCCURRENCE OF GROUND WATER

The ground water in Quaternary deposits

In the region surveyed (Fig. 1) eskers, which are important as sources of ground water, are a common occurrence, although the majority of them is not very large. Moreover, most of the esker sequences are lacking in continuity; thus in many cases the formations can be indentified as eskers only by their approximate southeast-northwest trend (Fig. 2). The material of the eskers varies greatly, but most commonly it consists of gravelly sand. The interior usually contains stony gravel, whereas the mantle on top and the sides are of finer material (Fig. 3). It has been observed that the glaciofluvial deposits lie directly over the striated bedrock (Fig. 4).

The clay sediments that were deposited on the bottom of the late-glacial and postglacial sea had originally covered the eskers almost entirely. After the eskers were raised into the shore zone by the land uplift, the ridges were worn down heavily by the littoral forces. The result was to have part of the glaciofluvial material of the ridges redeposited at a lower level over the clay beds at the foot of the eskers. The levelling out of the eskers and the formation of extensive shore deposits in the study area has been promoted by the slow rate of the shore displacement, which is due to the slight land uplift (see Kääriäinen 1964, Appendix 1). In the proximity of the present coast, most of the eskers of the study area were flattened out into level tracts.

With respect to the occurrence of ground water, clay beds rising up the lower slopes of eskers are of fundamental significance because they may dam up ground water in the eskers (Fig. 5 a, c). For this reason, eskers are apt to act as, in a sense, »blind drains» through which ground waters run. On the other hand, the clay beds reduce the esker area on which rain water forms ground water.

Ground water discharged over the edges of the clay beds forms springs along the foot of eskers (Fig. 5 a) (see, Hausen 1948, Fig. 4). In the shore deposit overlying the clay beds, there is apt to occur a small amount of perched water. Perched water is discharged as little springs at the foot of the shore deposit (Fig. 5 c), but such springs often run dry in the winter or during dry spells in the summer. Glaciofluvial esker deposits commonly extend laterally beneath the clay beds, which means that springs are likely to form also at a distance from the ridge formation (Fig. 5 c). Under slight pressure, the ground water discharges to the surface of the ground wherever the clay cover is not continuous or where it has been dug through (Fig. 6).

With respect to the occurrence of ground water the extent and the thickness of the esker deposits are important. Areas most favorable to the formation of ground water are broad eskers with level surfaces and with interior composed of coarse, highly permeable material (Fig. 7 a, cf., Fig. 3). An example of such an extensive esker with a levelled surface is Härmänkangas in the commune of Virolahti (Fig. 8). The esker is bounded on both sides by rocky terrain partly mantled with till as well as, in some places, by tracts of clay. The ground water formed on the esker discharges at Vilkkilä over the margin of the clay beds via the spring of Heijer (4 to 6 l per sec).

FIG. 3. Section through a broad, level esker. Layer indicated by broken line consists of clay, which is overlain by shore deposits. Interior of esker consists of stony material. Siltakylä, Pyhtää.

FIG. 4. Esker deposits resting on glacially schulptured bedrock. This kind of esker contains no ground water. Siltakylä, Pyhtää.

Thresholds of rock divide the eskers into many separate, smaller ground-water basins. An example of an esker chain levelled out by littoral forces and embracing separate ground-water basins is Summanharju, situated on the west end of the town of Hamina (Fig. 9). Practically speaking, all the ground water contained in the esker is utilized, being drawn from eight separate points of supply. From two points on Summanharju on the south side of the highway, a maximum of about 1 400 cu. m of ground water a day can be drawn, the amount on the north side of the road being

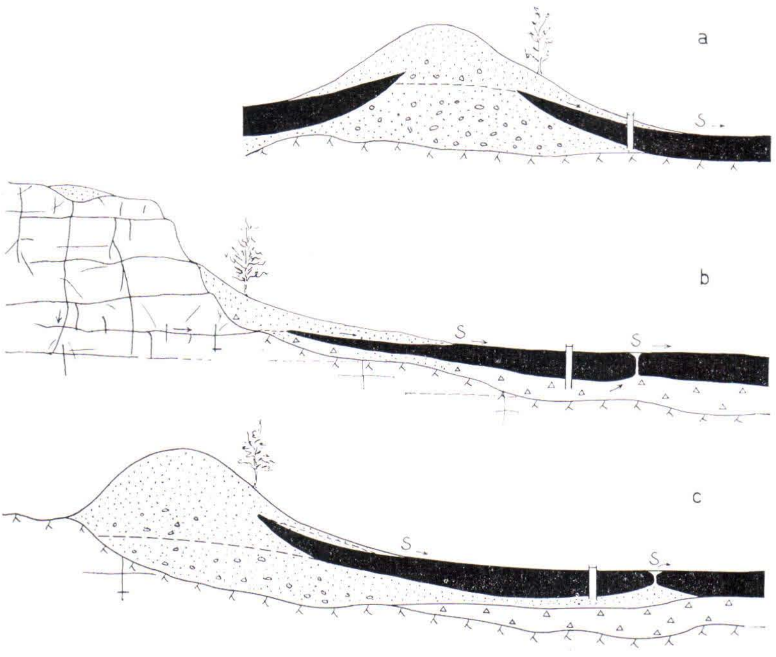

FIG. 5. Hydrogeological conditions in typical eskers (a, c) and in a shore deposit (b) represented in cross profile. Points, circles = sand, gravel. Triangles = till. Blacked area = clay. S = springs. Broken line = ground-water table. Underneath deposits, fractured bedrock.

FIG. 6. Ditch dug down to esker layers through clay. Ground water is discharged into ditch. In right background, gravel pit in esker. Siltakylä, Pyhtää.

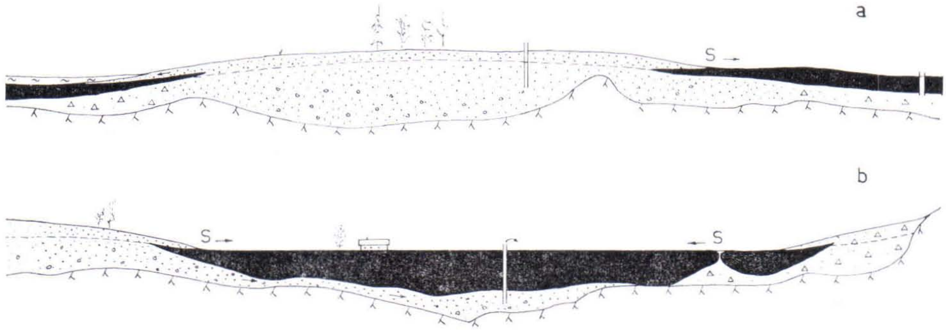

FIG. 7. Hydrogeological conditions in broad, level esker (a) and deposits underlying clay beds (b), represented as cross profiles. From deposits underlying clay, ground water under slight pressure is discharged through springs and artesian dug wells (Ar). Markings as in Fig. 5.

FIG. 8. Broad esker, leveled by littoral forces, the ground water forming in the esker is descharged through springs situated at the edge of clay deposits at Vilkkilä (see, Fig. 7 a). Härmänkangas, Virolahti commune.

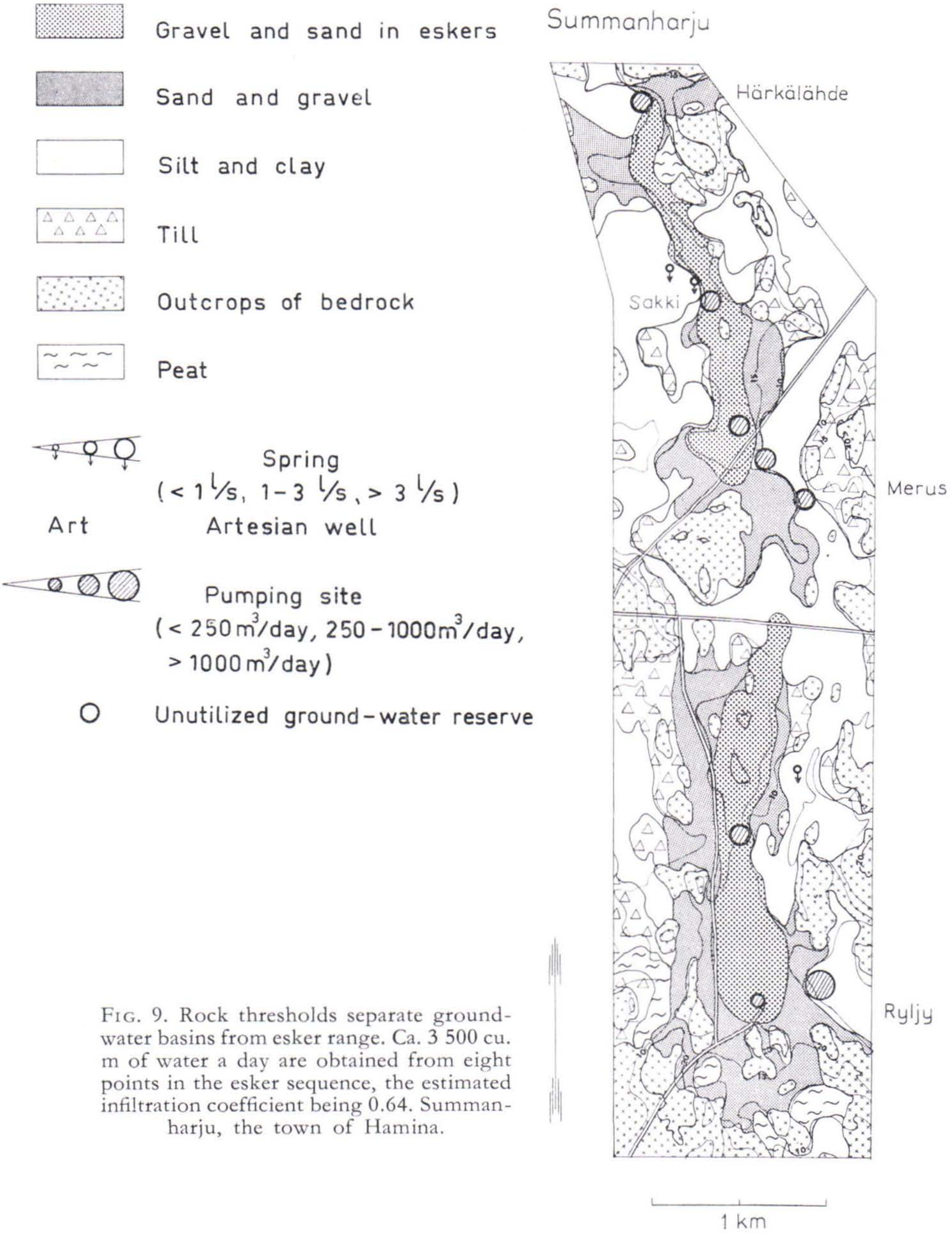

FIG. 9. Rock thresholds separate ground-water basins from esker range. Ca. 3 500 cu. m of water a day are obtained from eight points in the esker sequence, the estimated infiltration coefficient being 0.64. Summanharju, the town of Hamina.

some 2 150 cu. m a day from five points. The ground-water table is thereby maintained at an equilibrium. Judged in the light of topographic and geological observations, the extent of the area in which the ground water is collected is ca. 3.2 sq. km. Of the annual precipitation of 650 mm (HVK 1968, Appendix V), some 64 per cent forms ground water (infiltration coefficient 0.64), as calculated according to the foregoing data. The material of the esker is well-sorted gravelly sand. Topographically it is fairly level, so the surface runoff is slight.

The biggest factor of uncertainty in determining the infiltration coefficient is the true extent of the area of formation of ground water. In many cases, ground water is collected into an esker, when the ground-water table sinks considerably, from an extensive area in surrounding terrain through fractures and fissure zones in the bedrock (Fig. 10), which has been found also in surveys conducted in Sweden (see, von Brömssen 1968, p. 107). This is indicated by the fact that the quantity of water obtained by test pumping out of many of the eskers in the study area substantially exceeded the amount of precipitation in the estimated area of ground-water formation. In these instances, the coefficients of infiltration attain values in excess of 1.0, which naturally cannot represent the actual situation.

Elsewhere in Finland, little research has been done on the formation of ground water in esker areas. Sederholm (1909) decided that, in the typical sandy and gravelly tracts of the Salpausselkä marginal formations, at most 50 per cent of the annual precipitation can infiltrate the ground (infiltration coefficient at most 0.50). According to the investigations carried out by Ristola (1968), likewise in the Salpausselkä ranges, the corresponding estimate for sand and gravel deposits varies between 40 and 60 per cent. J. Hyyppä (1962), after surveying the variations in ground-water table in the north of Finland arrived at the values 42—61 per cent in sand tracts. According to von Brömssen (cf., above), the coefficient of infiltration varies in eskers from 0.34 to 0.80, assuming that ground water is not introduced to any fundamental extent through fissures in the bedrock from outside the main area of the ground-water formation. The research results summarized in the foregoing roughly correspond to the infiltration coefficient worked out at Summanharju. Vanhala (1959) arrived at lower infiltration amounts for areas covered with sand and gravel — namely, about 30 per cent of the annual precipitation.

Away from the coast the eskers are more distinctly ridges in form. Hämeenkylänharju, located in the southeast part of Elimäki commune, is an example of such a steep-sloped esker that littoral forces have not significantly deformed (Fig. 11). Ground water forms mainly out of water that has rained on the esker, and it is discharged over the clay beds as small springs at the foot of the esker (cf., Fig. 5 a). Little springs are also likely to occur farther away, for esker strata generally extend some distance underneath the clay beds (cf., Fig. 5 c).

The quantity of ground water obtainable from a single point in any of the eskers of the study area is generally between 200 and 500 cu. m a day (24 hours). In only rare instances does the amount of water exceed 1 000 cu. m a day.

In the northwest corner of the study area, there are broad level clay tracts. In sand and gravel deposits underlain by clay beds, appreciable amounts of ground water under slight pressure are apt to occur. An example of this is the esker belt of Mettälä in the commune of Elimäki (Fig. 12, cf., Fig. 7 b). At the borders of the extensive clay tract indicated in the figure, there are two glaciofluvial sequences

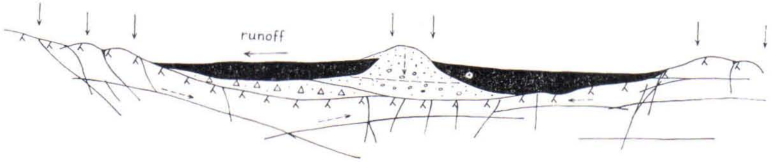

FIG. 10. Cross profile of esker, which receives additional supplies of ground water from distant parts through the fissures and fractures in the bedrock. In this case, the infiltration coefficient estimated on the basis of the apparent area of formation of ground water receives excessively high values.

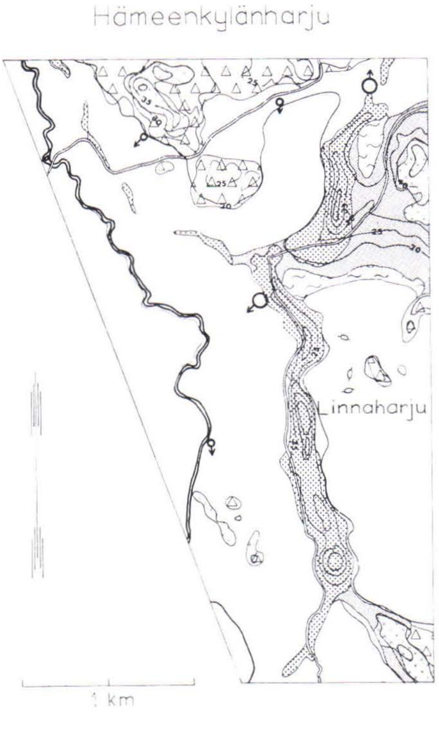

FIG. 11. Typical esker situated away from the coast and not notably deformed by littoral forces. At foot of esker ground water is discharged as little springs (cf. Fig. 5 a, c). Hämeenkylä, Elimäki.

that are either eskers or marginal formations. These sand and gravel deposits extend in places underneath the 15-m-thich clay bed. Ground water forms in the largest amounts on the flattened part of the formation situated on the southeast side of Mettälä. Since in the east tracts of bedrock and till constitute a barrier, the main portion of the ground water flows west and northwest, under the clay beds, in which there are numerous springs and artesian wells. It must nevertheless be remarked that elsewhere in the study area the deposits overlying clay beds are usually so poorly permeable that no appreciable amounts of ground water are obtainable.

There are only a few, minor till deposits in the region surveyed, and they are mainly concentrated along the rocky tracts. After the deglaciation, even the loftiest rocky heights were probably largely mantled with till. During the littoral stage, however, the till was to a large extent washed down to form shore deposits at the foot of cliffs (Fig. 5 b). Such generally small till deposits or littoral accumulations are classifiable either as washed till poor in fine components or poorly sorted sand and gravel (Fig. 13). Everywhere in the valley-like depressions between the rocky stretches, which have been washed bare, clay sediments occur.

The ground water in bedrock

The bedrock of the study area consists wholly of rapakivi granite (Viborg rapakivi) (Fig. 1, Simonen 1960 a). In its surficial portions, the bedrock has been profusely

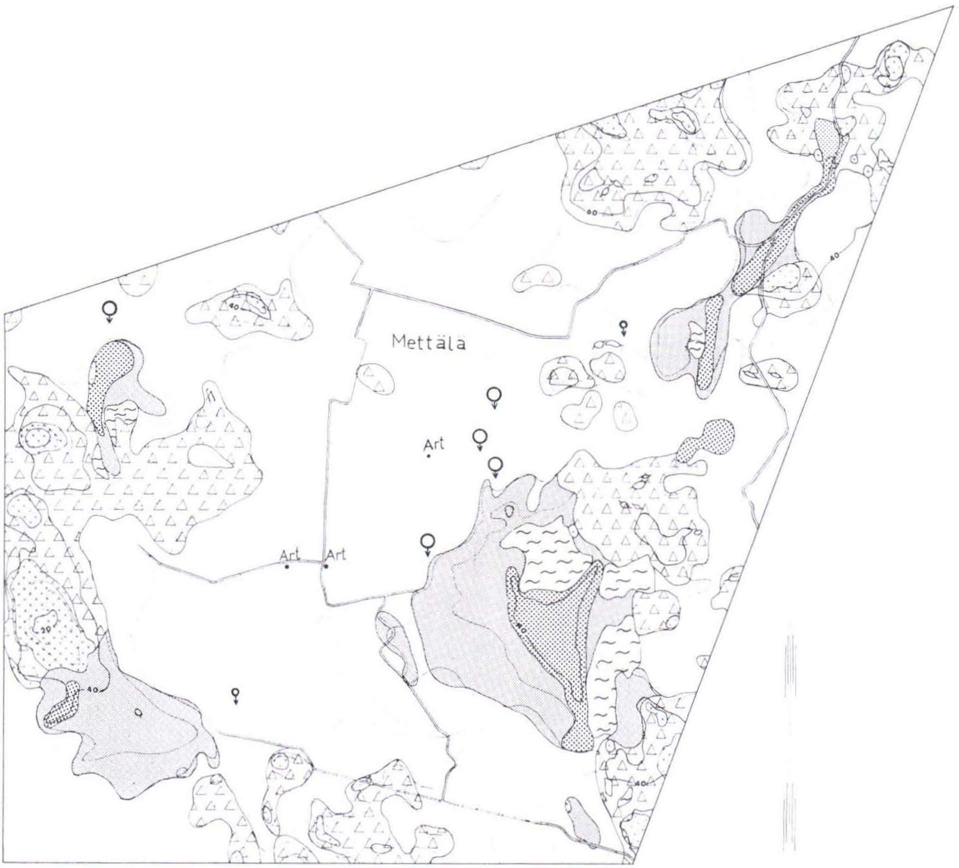

FIG. 12. Typical level clay tract. Ground water formed on glaciofluvial deposits is discharged from sand and gravel layers underlying clay beds as springs as well as from artesian dug wells. Mettälä, Elimäki.

fractured. The fracturing of the bedrock appears most consipicuously on a horizontal plane or one parallel to the surface — but it also appears clearly on two vertical planes at right angles to the horizontal one (Fig. 14). Another characteristic feature, is the locally heavy weathering undergone by the surficial portion. In many places, it has turned to a gravelly substance, known as »moro», which can actually be shovelled off (Fig. 15). »Moro» of this kind is apt to occur as a layer several meters thick either on the surface or, in some instances, underneath sounder bedrock at a depth of some meters.

Sound rapakivi granite is dense, like the rest of the plutonic rocks. It may contain only 0—1 % of water; hence its specific yield is nil. In fractures of the kind referred to in the foregoing, ground water is apt to be present even in some abundance, depending naturally on the profusion, openness and interconnections of the fractures. The most advantageous occurrences of ground water in bedrock are fissure zones and, in particular, the places where they intersect and where the bedrock is broken up most. The largest fissure zones are visible in the terrain as elongated, clay-covered valleys, some of them kilometers long. As the deep, vertical fractures are connected by strongly developed horizontal ones, the bedrock contains a broad, roughly cubical, fracture network (see, Hausen 1964, Fig. 13). When a drilled well cuts into a fracture deep in bedrock, pumping can draw ground water from quite an extensive area. The filtration of rain water into bedrock to form ground water is in some places promoted by a highly permeable weathered »moro» layer.

FIG. 13. Poorly sorted shore deposits overlying clay bed (marked with broken line) of foot of steep cliff. At bottom, till poor in fine-grained material. Neuvottoma, Vehkalahti.

FIG. 14. The strong fracturing of rapakivi enables water to collect in the bedrock. Two vertical fracture planes at right angles are intersected by strongly developed horizontal planes. Ahvenkoski, Ruotsinpyhtää.

FIG. 15. Weathered permeable rapakivi granite (»moro»), topped by a sound rapakivi erratic boulder. Törönkangas, Sippola.

Data on the depths of drilled wells in bedrock and on the amounts of water yielded by them give the best idea of the ground-water conditions prevailing in the bedrock. In the region surveyed, it has nearly always been possible to obtain sufficient water to satisfy the needs of small households from wells drilled into bedrock. Only very seldom have wells remained completely dry, which indicates that the bedrock consisting of rapakivi granite is almost everywhere more or less fractured. The average yield of 147 borings in the study area, calculated on the basis of test pumpings of short duration after the boring operations, is approximately 3 200 l per h; the average depth of the wells is 65 m (Fig. 16, column 1). Considerably more ground water is obtained from the rapakivi bedrock of the study area, on the average, than from the territory of Finland as a whole (column 3). Previously Laakso (1966) had observed that the drilled wells in areas of rapakivi granite averaged a higher yield of water (column 2) than the wells sunk in bedrock throughout the country (column 3). The yields of the drilled wells in the area investigated by the present author considerably exceed the values tabulated by Wenner (1951) in Sweden (column 4). For the sake of comparison, it is noteworthy that shallow drilled wells in Lapland have yielded ground water in relative abundance (column 5), which is due to the exceptionally high degree of fracturing undergone by the bedrock there as well as, in places, to the remarkably thick layer of weathered bedrock.

According to the commonly held belief, at depths exceeding 100 m, the fractures in the bedrock are so rare or so tight that the possibilities of obtaining ground water essentially diminish (e.g., Troedsson 1936, p. 205; Wenner 1951). In the region of the rapakivi granite, however, exceptions to this rule are commonplace. When the well for the Koskisto dairy at Elimäki was bored, it was necessary to go down some 400 m before ground water could be obtained in real abundance (Table 1; see also Laakso 1966, p. 84). At depths as great as this, therefore, there are likely to be open fractures and fissures containing large amounts of ground water. In the study area numerous other examples can be cited of the yield of water increasing with depth in borings. Laakso (1966) has likewise reported that in areas of homogeneous bedrock —

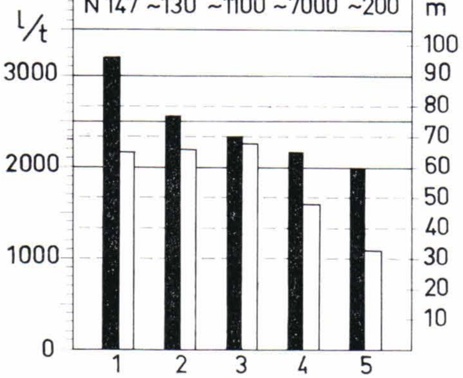

FIG. 16. Average yield of drilled wells (black column) as well as their depth (white column) in 1) study area (rapakivi), 2) rapakivi area of Kymi as a whole (Laakso 1966), 3) Finland as a whole (according to material presented by Laakso 1966), 4) bedrock (also Paleozoic sedimentary rocks) area of southern Sweden (Wenner 1951, p. 1102), and 5) Lapland (Lahermo 1970, p. 28). N = number of observations.

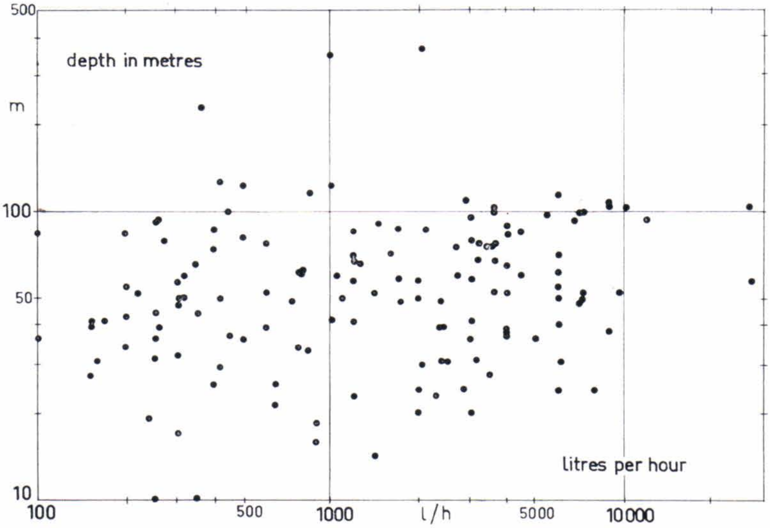

FIG. 17. Relationship between depth and yield of drilled wells in the study area (bulk of material obtained from Vesto Oy).

which the rapakivi area is — the quantities of ground water in many instances increase when a drilled well is deepened. In the light of the total material colleted from the study area, however, there exist no significant correlation between the depth and the yield of drilled wells (Fig. 17).

The temperature of the ground water obtained from wells sunk into rock varies between +5 and +7°C (66 determinations). This corresponds to the temperature of ground water occurring in esker deposits reported by Kahri (1963, Fig. 1). Ground water obtained from drilled wells comes from depths ranging from a few meters to hundreds of meters; hence its temperatures represent very probably the actual temperature of ground water. The mean annual temperature in the study area is +4—+5°C (Kolkki 1960), which means that the temperature of the ground water is between 1 and 3°C above the mean annual temperature. In Lapland, the temperature of the ground water discharged out of Quaternary deposits is on the average only +3.1°C in summer and +2.8 °C in winter (Lahermo 1970, p. 29). The corresponding temperature difference is 3—4 °C.

QUALITY OF GROUND WATER

The effect of pumping on the quality of the ground water contained in eskers

Ground water of eskers generally occurs in basins bounded by rocky ridges (Fig. 9). In the deepest portions of these basins, the percolation is likely to be slight

The most rapid flow and, thereby, the main exchange of water takes place in the upper part of the ground-water basins, from which water is discharged through springs or directly out of the esker deposits into surface waters. It is natural that the ground water is discharged into streams and lakes in the same amounts as new ground water is formed from precipitation. Ground water long retained in deep portions of esker deposits contains dissolved components in abundance. When a ground-water basin is pumped by using a well driven into an esker, the ground-water table generally sinks considerably in the pumping site. The percolation and exchange of the ground water is greatly accelerated as a result, and electrolyte-poorer ground water occurring closer to the surface percolates through the esker deposits toward the pumping site from distant parts, too. Thence the natural hydrogeological conditions undergo great change, which in turn affects the chemical composition of the ground water in the basin.

According to the afore mentioned it is natural that the ground water contains generally more electrolytes during early pumpings than later on, when the supply has been diluted by water poorer in electrolytes. This is illustrated by Fig. 18, which shows how the salinity decreases during pumpings down to a certain constant level. Thereafter, the variations in the quality of the ground water depend on the variations in the amounts of water pumped, climatic factors, such as varying precipitation, as well as contaminating activities in the area of formation of the ground water, which are quite sensitively reflected in its quality (see, Lahermo 1970).

The iron contents of water, which are important from the standpoint of its fitness for use, are likewise at their maximum on the whole at the very start of pumping; but they decrease steadily during the draft. In a certain test pumping in Summanharju, the iron concentration was at first 1.5 mg per l, but after two weeks it had decreased to 0.18 mg per l. In a test pumping carried out in the southern part of Neuvottomanharju, to the west of the town of Hamina, the iron content was in the beginning as high as 12.4 mg per l, but within only a few days it had fallen to a value of 4.0 mg per l. The reason for a high iron concentration at the beginning of pumping is that water long retained in the bottom portions of a ground-water basin contains but little oxygen, which in turn makes it possible for the occurrence of a large quantity of ferrous iron in solution. The acceleration of the percolation introduces an abundance of ground water richer in oxygen from esker deposits closer to the surface, with the result that, as the water becomes mixed with iron-rich water, a large proportion of the iron is precipitated. In certain cases, the iron content is apt to rise from the level registered at the beginning of pumping. This means that water poorer in oxygen and therefore richer in iron has become mixed from other parts of the surficial deposits and bedrock in the ground water being pumped.

The alteration of the chemical composition of ground water during the period of pumping does not nearly always, however, follow the rules described in the foregoing. Special conditions are apt in many ways to affect the quality of water pumped out of the ground. An example is the test pumping carried out at Neuvottoman-

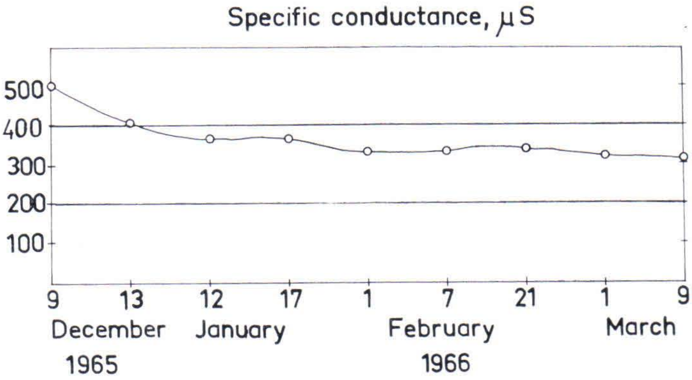

FIG. 18. Effect of drawing of water on specific conductance value of ground water obtained from esker (test pumping and analyses carried by Vesi-Hydro Ky). Husula, Vehkalahti.

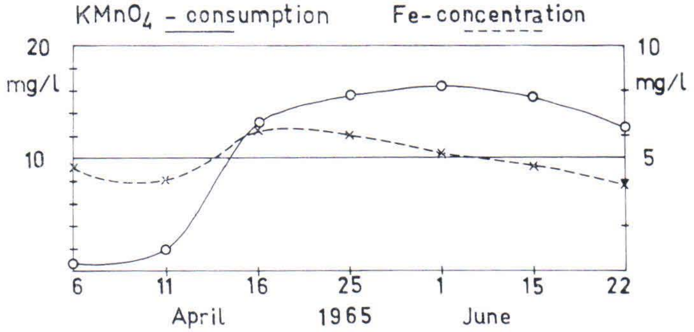

FIG. 19. Relationship of $KMnO_4$ consumption values and Fe contents during test pumping. From a small bog situated adjacent to esker, water containing abundant organic matter percolates, raising Fe content of water at first. Subsequently, as ground-water table sinks, the amounts of organic matter and iron diminish (test pumping and analyses carried out by Vesi-Hydro Ky). Neuvottomanharju, Vehkalahti.

harju, where ground water containing iron in abundance was drawn from a point in the esker adjacent to a small bog. During pumping, the iron content by no means diminished, for from the peat beds of the adjacent bog oxygen-poor; and thus iron-rich, humus-bearing water was introduced into the ground water in ever increasing amounts as the flow accelerated. This was reflected distinctly in the rise of the $KMnO_4$ consumption value (Fig. 19, cf., p. 31), which accompanies the increase in the concentrations of organic matter. Also at another, nearby point, the $KMnO_4$ consumption values proportional to the humus content were observed to rise during a couple of days' test pumping from 0.7 mg per l to 5.1 mg per l. Later, when the ground-water table sinks considerably, the humus and iron contents diminish.

The results reported in the foregoing are generally applicable to areas where highly permeable deposits of sand and gravel containing ground water are located in boggy tracts. Gustafsson, Eriksson and Arnborg (1966, pp. 842—843) have observed that iron- and humus-bearing ground water is frequently drawn from eskers bounded by bogs, provided the amounts of water pumped exceed the quantity formed in the eskers themselves.

The effect of depth and pumping of drilled wells on the quality of ground water

The ground water drawn from borings close to the coast frequently contains chlorides in exceptional abundance, thereby giving the water a salty taste. In the case of wells located in the immediate proximity of the shoreline, this is naturally due to the sea water seeping through fractures in the bedrock directly from the sea. The percolation of ground water formed from precipitation normally takes place in the direction of the coast; but as the ground-water table sinks during pumping, the direction of the flow is apt to take opposite turn, with the foregoing consequences. On islands far out at sea, fresh water can frequently be drawn out of the surficial deposits and the bedrock (Table 1, Kirkonmaa, cf., Nordenskiöld 1896). The rain falling on the islands forms »islets» of light, fresh water, which flows mainly toward the shoreline along the upper layer of the ground-water occurrences. Abundant consumption of water on small islands often causes it to turn gradually salty — this is because heavier sea water works its way into the lower layers of the ground water.

Saline sea water has also been obtained from exceptionally deep borings rather far from the coast. The study area affords numerous instances of this (Table 1). The drilled well of the Koskisto dairy, which is more than 400 m deep and yields quite saline water, is located some 15 km from the nearest point on the coast, which is part of the delta of the Kymi river where the water is only slightly saline. In general, the deepening of a drilled well in the area surveyed has caused a marked increase in the dissolved components of the ground water, especially chloride (Table 1). The same phenomenon has been observed in many wells sunk into the bedrock in the coastal region of Sweden (see, Nilsson 1968, Fig. 2). It is evident that this is due to the salts left deep in the bedrock during the postglacial Littorina stage (p. 34). During steady and abundant utilization of water, the chloride concentration constantly diminishes from the peak values registered during test pumping. The supplies of saline water in bedrock thus appear to be in a process of depletion (cf., Richert 1918, Hyyppä 1963, Salmi 1963). When a boring is deepened, in addition to the increase in the chloride content, also the total hardness values rise steeply (Table 1). This rise is due primarily to the high Ca concentration (p. 35).

In the areas situated above the highest Littorina shore (see, Hyyppä, E. 1963, Fig. 1), the chloride concentration in the water generally does not increase when a well drilled in bedrock is deepened but actually tends to diminish. This is because the rapidly flowing and changing ground water close to the surface of the ground is

TABLE 1

Examples of drilled wells in which the yield of water and the amount of dissolved matter increases with depth. Borings and analyses carried out by Vesto Oy.

Locality	Date	Yield litres per hour	Depth m	Specific conductance μS	Total hardness dH	Cl mg/l	Fe mg/l
Karhula	25. 8. —58		66	710	2.0	156	2.6
	23. 3. —61		85	1 848	15.8	623	1.2
	5. 4. —61		85	2 290	19.9	765	0.8
	17. 4. —61	4 000	85	2 260	20.6	755	0.2
Karhula	2. 10. —59	450	37	333	4.7	26	0.7
	9. 9. —61	3 500	75	480	3.7	22	0.2
Korkeakoski	30. 6. —61	500	81	451	7.8	57	1.7
	8. 11. —61	1 000	350	706	7.2	138	1.0
Korkeakoski	4. 12. —61	1 700	49	1 531	13.2	495	0.8
	19. 12. —61	4 000	75	1 486	12.2	485	1.8
Koskisto	22. 8. —58	360	232	543	14.5	94	0.2
	3. 12. —59	2 040	360	—	—	89	1.7
	7. 12. —59	60 000	403	4 900	72.5	1 920	1.3
Kirkonmaa	15. 1. —58		80	507	3.4	110	19.0
	24. 1. —58		100	521	2.0	87	0.7

liable to be more heavily polluted and for this reason contains chlorides in greater abundance than does the ground water deeper down.

The fractures and fissures in bedrock can often be detected during boring operations from the very rusty rocky material obtained from the hole. The first water samples taken from wells generally yield quite high iron concentrations, for the samples contain an abundance of iron precipitate washed out of fractures. Furthermore, ground water long retained in bedrock is poor in oxygen and is apt to contain considerable amounts of dissolved iron. While the water is being used, the iron content generally decreases, for the seepage of the ground water through the bedrock is accelerated, just as in the case of the ground water occurring in eskers (p. 19). The deepening of wells drilled in bedrock does not clearly affect the iron content one way or another, although in many instances the iron content does decrease when a well is sunk deeper (Table 1; see also Salmi 1963, Table 1).

The effect of geological formations on the quality of ground water

Classification of material

The chemical composition of ground water occurring in Quaternary deposits and bedrock varies greatly, depending on the structure of the geological formations involved. The homogeneous rapakivi-granite bedrock offers a chance to determine the effect of the geological conditions on the character of the ground water without additional factors difficult to evaluate being introduced by great lithological variety. For the determination of the nature of the ground water contained in the surficial deposits and bedrock of the study area, the present material, which consists of over 5 400 chemical determinations, is divided into four groups. In each group, representing different geological conditions, the frequency distributions of the different properties of the water and its contents of dissolved matter were calculated by a computer. The frequency distributions are presented graphically as histograms. Thereby and by the calculation of correlations, the author was enabled to evaluate the relationship of the properties and dissolved material contents of waters to one another as well as, above all, to the geological environment. These were the four groups into which the material was divided:

Group 1: The perched water and the ground water occurring in small shore deposits or till deposits (Fig. 20). The material consists primarily of sand and gravel or till poor in fine fractions.

Group 2: Ground water contained in eskers or other glaciofluvial formations. The material is most commonly sandy gravel.

Group 3: Ground water occurring in sand and gravel deposits underlain by clay.

Group 4: Ground water occurring in fractures and fissures of bedrock.

The water analyses were performed by application of generally used standard methods (see, Lahermo 1970, pp. 9—11).

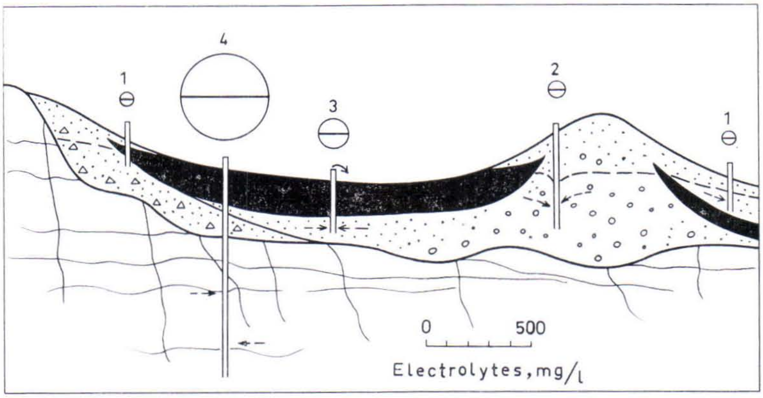

FIG. 20. Effect of the structure of the geological formation on amounts of dissolved electrolytes in ground water. The amount of electrolytes increasey greatly when ground water is retained in surficial deposits and bedrock. Ground water contained in 1) small shore and till deposits, 2) eskers, 3) deposits underlying clay beds, and 4) bedrock. The diameter of the circles placed above the wells indicates the average amount of electrolytes (calculated from the specific conductance multiplied by 0.75) contained in the ground water of the geological formations in question.

Specific conductance and pH value

Specific electrical conductance is in direct ratio to the quantity of dissolved electrolytes in the water. The average electrolyte concentration of ground water increases greatly from Group 1 to Group 4 (Fig. 21, Table 2). Thus the ground water occurring in bedrock contains on the average from 8 to 9 times as many dissolved electrolytes as do the perched or ground water contained in shore deposits. Natukka (1960) has likewise observed that the ground waters of eskers contain considerably less electrolytes than do the ground waters occurring in deposits underlain by clay. Also Hyyppä (1969, Table 5) reports that the ground waters in the areas of sand and gravel are less electrolytic than those of clay tracts. The rate of percolation and changing of ground water are more rapid in shore deposits and eskers than in the deposits underlying extensive areas of clay or deep in the bedrock. The length of time the ground water is retained in surficial deposits or bedrock, i.e., the »time factor», thus is of great importance in regulating the quantities of dissolved material (Fig. 20, cf., Lahermo 1970, p. 43).

Specific conductance is clearly correlated in highly electrolytic ground waters with the content of calcium (Group 3, $r = 0.70$, Group 4, $r = 0.90$), magnesium (3. $r = 0.55$, 4. $r = 0.81$) and sodium (3. $r = 0.73$, 4. $r = 0.48$). In ground water occurring in deposits underlying by clay beds, the specific conductance is also correlated with the HCO_3 content (3. $r = 0.63$). The last-mentioned correlation does not exist, however, in the ground water of bedrock in which, besides other anions, there occur chlorides in abundance. The afore-mentioned cations and anions are the main com-

TABLE 2

Chemical properties and components of ground water.

Group	Specific conductance μS				pH				HCO_3 mg/l				CO_2 mg/l				Total hardness (dH				Ca mg/l			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
M ...	68	86	196	590	5.97	6.42	6.64	7.23	21	18	93	120	23	21	35	21	1.34	1.65	4.36	7.66	6.4	7.1	21.6	34.2
D	46	112	138	875	0.31	0.73	0.67	0.69	16	41	70	60	21	21	18	24	1.01	1.42	2.74	11.58	4.1	5.6	14.7	53.7
N	113	93	103	142	115	95	102	169	59	74	70	154	53	64	59	110	54	73	69	167	53	57	66	164

Group	Mg mg/l				Na mg/l				K mg/l				Fe mg/l				Mn mg/l				$KMnO_4$consumption mg/l			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
M ...	1.8	2.4	5.6	11.2	3.5	3.1	13.4	78	1.7	1.5	3.4	13.9	0.002	0.04	0.53	3.31		0.004	0.013	0.34	4	6	6	14
D	1.9	2.2	4.4	15.2	2.0	2.1	15.3	179	2.6	1.3	2.4	34.6	0.012	0.13	1.59	6.21		0.010	0.019	0.41	4	5	8	11
N	53	55	65	164	45	40	52	34	44	39	52	33	112	91	101	165	47	57	64	153	54	74	69	162

Group	SiO_2 mg/l				SO_2 mg/l				NH_4 mg/l				NO_3 mg/l				Cl mg/l				F mg/l			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
M ...	14.4	12.8	17.9	13.6	8.1	9.9	13.7	30.3	0.12	0.13	0.18	0.33	2.9	3.4	4.9	7.8	5.7	8.1	19.1	136	1.45	1.39	1.93	1.84
D	2.7	4.5	4.0	4.4	6.6	7.7	11.7	29.0	0.14	0.17	0.30	0.59	6.3	9.8	7.6	12.2	4.8	10.3	28.2	313	0.78	0.86	0.65	0.85
N	49	56	66	151	32	54	30	150	47	68	61	120	54	68	68	122	55	75	69	169	49	53	64	115

Ground water 1, in small shore and till deposits; 2, in esker deposits; 3, in deposits underlain by clay beds; 4, in bedrock.

M = Arithmetic mean; D = Standard deviation; N = Number of determinations.

ponents of the water and for this reason strongly affect its specific conductance. The same correlations can also be observed in the ground and surface waters of Lapland (Lahermo 1970, Appendix 2) as well as in the surface water throughout the country (Laaksonen 1970, Figs. 94, 97). The ground waters contained in the deposits underlying by clay beds and, especially, in the bedrock deviate, on account of the abundant chloride content in places, from the HCO_3-dominant ground water of the rest of the country. This becomes evident also as the correlation of specific conductance with the Cl content (3. r = 0.66; 4. r = 0.89).

The frequency distribution of the pH value in the different groups adheres in its main features to the specific conductance distribution (Fig. 22, Table 2), signifying that the pH values are on the average lowest in slightly electrolytic (Group 1) and highest in highly electrolytic ground waters (Group 4). The pH value is clearly correlated with the HCO_3 content (1. r = 0.46, 2. r = 0.75, 3. r = 0.48, 4. r = 0.49), and in ground waters with abundant electrolytes negatively with the free CO_2 content (3. r = —0.12, 4. r = —0.54). Particularly in the ground water in bedrock, the pH value is in fairly direct proportion to the HCO_3 content and in inverse proportion to the free CO_2 content, which is in agreement with the carbonic acid-bicarbonate equilibrium (cf., e.g., Hutchinson 1957, p. 657). The contents of free carbon dioxide are not clearly dependent on the geological conditions (Table 2). The results of the CO_2 determinations are only approximate, for carbon dioxide is partly released during the sampling and transportation.

Total hardness and bicarbonate

The frequency distributions of total hardness and bicarbonate follow in their main features the distributions of specific conductance and pH values (Table 2). Total hardness is closely correlated with the calcium (1. r = 0.91, 2. r = 0.67, 3. r = 0.86, 4. r = 0.97) and magnesium (1. r = 0.88, 2. r = 0.52, 3. r = 0.79, 4. r = 0.92) contents, which in themselves produce the hardness, as well as, with the HCO_3 (3. r = 0.85). The same correlations are likewise to be noted in the ground and surface waters of Lapland (see Lahermo 1970, Appendix 2) as well as in the surface waters of the country taken as a whole (Laaksonen 1970, Figs. 99, 105). This is only natural in view of the fact that the alkaline earths occur principally as bicarbonates. There exists no correlation, however, between total hardness and bicarbonate in the ground water of bedrock, for in coastal regions the hardness may be largely associated with the occurrence of chloride.

Alkaline earths and alkali metals

The frequency distributions of the calcium and the magnesium, which are nearly alike with respect to their chemical properties, are highly similar to each other (Figs. 23, 24, Table 2). There is a fairly close correlation between these metals (1. r = 0.80,

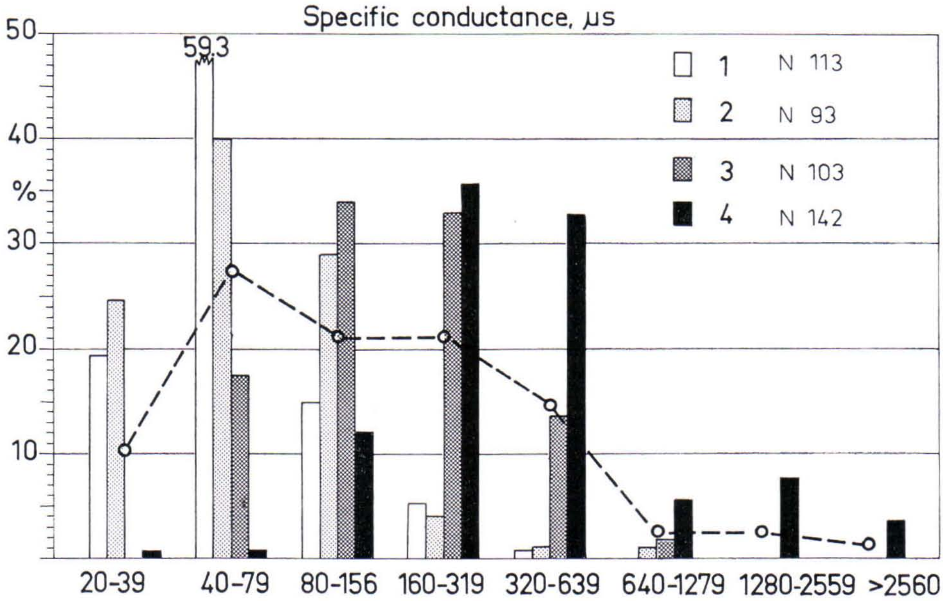

FIG. 21. Frequency distributions of specific conductance calues (S = cm 1 ohm 1 10 1) in different grounps. Ground water contained in: Group 1) small shore and till deposits, 2) eskers, 3) deposits underlying clay beds and 4) bedrock. N = number of determinations. Dash lines indicate the distribution of the whole material.

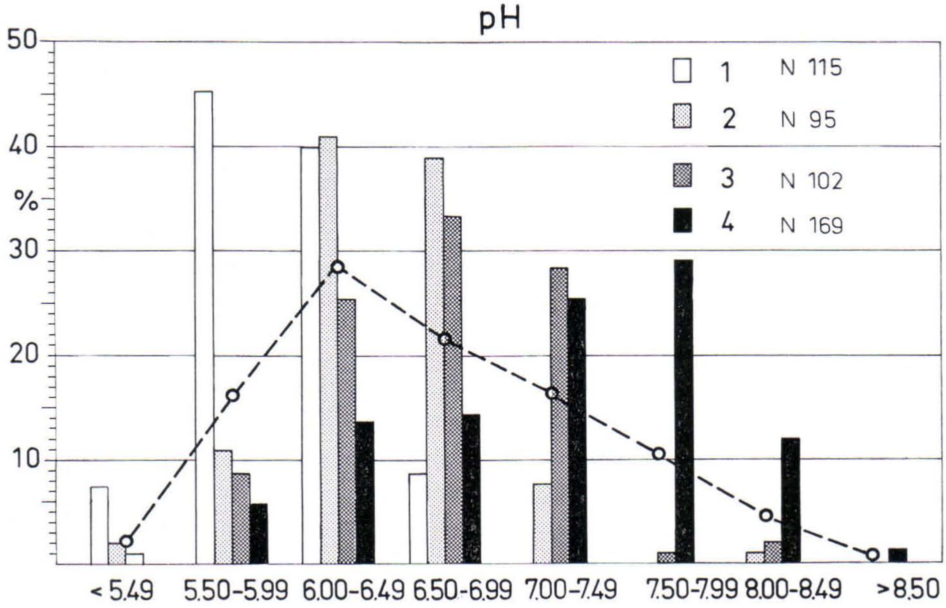

FIG. 22. Frequency distributions of pH-values in different groups. Symbols as in Fig. 21.

2. r = 0.60, 3. r = 0.56, 4. r = 0.89). This kind of observation has also been made in the ground and surface waters of Lapland (Lahermo 1970, Appendix 2) and in the surface waters of the country as a whole (Laaksonen 1970, Fig. 134).

The frequency distributions of sodium and potassium likewise resemble each other closely (Figs. 25, 26, Table 2); and these alkali metals also exhibit a clear mutual correlation (1. r = 0.75, 2. r = 0.66. 3. r = 0.41, 4. r = 0.26). This correlation, however, diminishes as the electrolyte content of the water increases from Group 1 to Group 4. When the electrolyte content of the ground water of bedrock and of deposits overlain by clay beds increases, the Na contents generally increase, as revealed by their correlation with specific conductance (3. r = 0.73, 4. r = 0.48). These correlations are likewise to be observed in the surface waters of the whole country (Laaksonen 1970, Figs. 97, 131). There exists no corresponding correlation with the K contents.

Typical of the rapakivi granites is their high content of alkalis (especially potassium) and low content of alkaline earths (cf., Sahama 1945, Table VI; Simonen 1960 b, p. 42; Vorma 1971, Table 1). The abundance of potassium over sodium both in rapakivi and in local ground water is shown by the low Na/K ratio (Fig. 27, columns 1 and 4). Moreover, the low Ca+Mg/Na+K ratio in both indicates a richness in alkalies in relation to alkaline earths. Granites in general contain more sodium and alkaline earths and this is also reflected in the corresponding ground waters (columns 2 and 5). The alkali ratio in the Finnish bedrock on the average is similar to that calculated for granite areas but the alkaline earth-alkali ratio is distinctly greater (columns 3 and 2). The same trend is repreated in the values for ground water (columns 6 and 5). Both ratios, Na/K and Ca+Mg/Na+K, show higher numerical values for ground water than for the corresponding rock. The pollution caused by agriculture settlement in the region investigated has presumably increased the alkali contents more than the alkaline earths in the ground water. This, again, is apt to affect the ratios to a slight extent.

The abundant potassium of the rapakivi granite is dominantly present in the potash feldspar, which is fairly resistant to weathering, whereas the sodium, occurring in smaller amounts, is present in the less resistant plagioclase (cf., Goldich 1938, p. 56). For this reason, more sodium was introduced into the ground water. It is possible, however, that the potassium released during weathering is adsorbed into the fine-grained mineral matter or the clay minerals. The alkaline earths are released in weathering more readily than the alkalis, as is indicated by the relative abundance of the first-mentioned substances in ground water in comparison with the bedrock itself. This, in turn, is induced by the occurrence of calcium and magnesium in the Ca-plagioclases and micas, which weather rather readily. It has been observed, on the basis of the composition of the natural ground water of Lapland that calcium is released during the weathering process in relatively larger amounts than is magnesium (Lahermo 1970, p. 48).

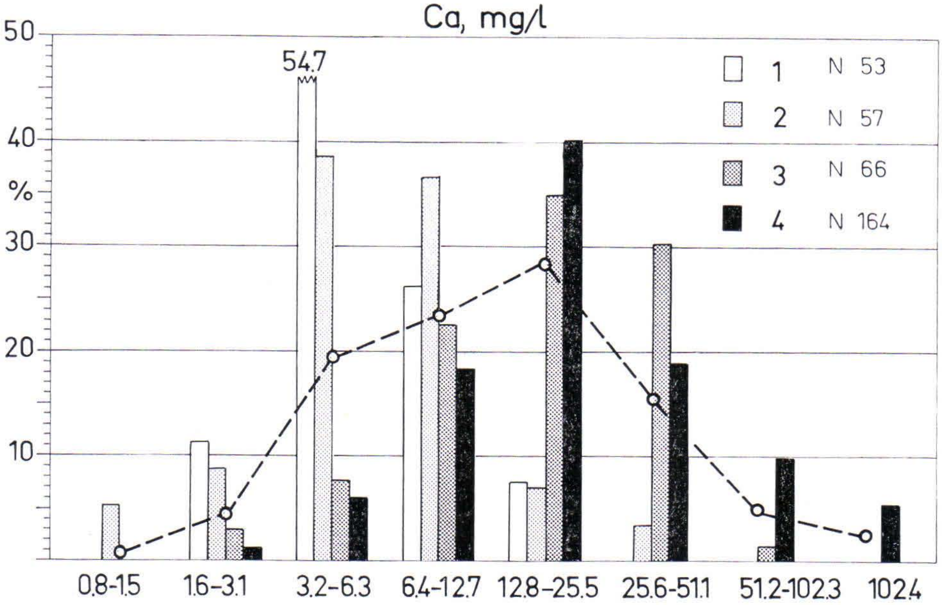

FIG. 23. Frequency distributions of Ca concentrations in different groups. Symbols as in Fig. 21.

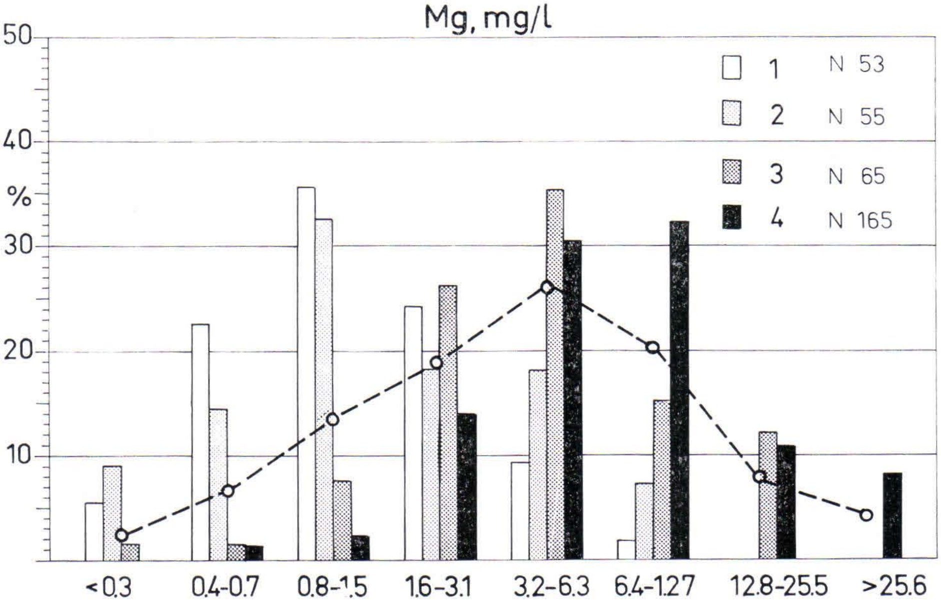

Fig. 24. Frequency distributions of Mg concenrtations in different groups. Symbols as in Fig. 21.

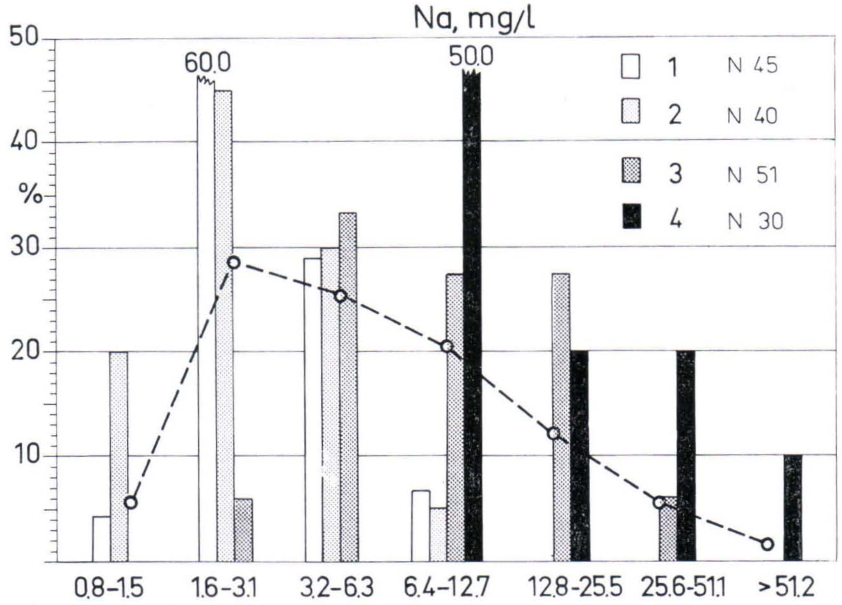

FIG. 25. Frequency distributions of Na concentrations in different groups. Symbols as in Fig. 21.

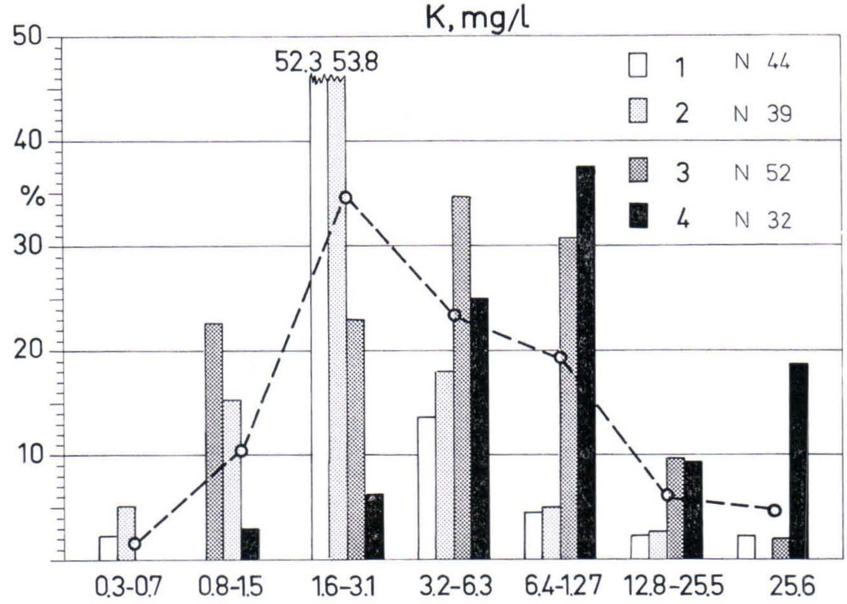

FIG. 26. Frequency distributions of K concentrations in different grounps. Symbols as in Fig. 21.

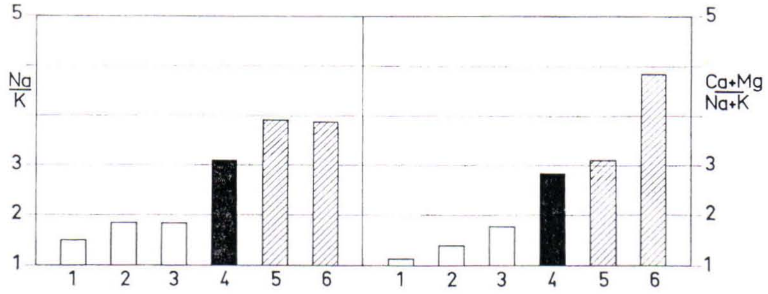

FIG. 27. Rations of Na/K and Ca+Mg/Na+K in 1) rapakivi granite (after Rankama, Sahama 1950, Table 5.33), 2) granites in general (*ibid.*, Table 5.32) and 3) average bedrock in Finland (Sederholm 1925). The same rations in ground water in 4) rapakivi area (Groups 1, 2), 5) granite area of Lapland (Lahermo 1970, Appendix 1, Group 2) and 6) areas of varying rock in Lapland (as above, Groups 1—12, 15—17). Columns represent the ratios of the mean values.

Iron, manganese, and $KMnO_4$ consumption

The distributions of iron and manganese in the ground waters occurring in various geological formations are largely alike (Table 2). In the ground water of shore deposits (Group 1), the contents of these metals are very low. This is due to the high oxygen content of the water, as a consequence of which iron and manganese do not dissolve out of the mineral components to any noteworthy degree or they are precipitated into the soil. In the ground water occurring in deposits underlying clay, the iron and manganese contents are manifold (Group 3), which in turn is due to the low oxygen content of the water. In these instances, the iron and the manganese occur in the soluble ferro- and mangano-ion form. According to analyses presented in Table 2 the highest Fe and Mn contents are in the ground water occurring in bedrock (Group 4), one factor contributing to this being the taking of samples in connection with test pumpings. The concentrations have on such occasions been higher than later on, after the wells have been in continuous use for some time (p. 23).

As elements with similar properties, iron and manganese are likely to be correlated with each other (2. $r = 0.66$, 3. $r = 0.59$), as well as slightly with the $KMnO_4$ consumption values (3. $r = 0.34$, $r = 0.20$, 4. $r = 0.27$, $r = 0.34$). Corresponding correlations have also been noted in the surface waters of central Lapland (Lahermo 1970, Appendix 2, Laaksonen 1970, Figs. 117, 137). Inasmuch as the $KMnO_4$ consumption expresses the quantity of substances subject to oxidation, nitrogen compounds of a lower degree of oxidation are involved, in addition to humus, and ferrous and manganous compounds. The significance of the last-mentioned substances is indicated by the fact that the $KMnO_4$ consumption values are on the average highest in the iron-bearing ground waters present in bedrock (Group 4, Table 2). In humus-bearing surface waters, the correlation of iron and manganese with the

$KMnO_4$consumption values finds its explanation in the tendency of these metals to occur as humus complexes. This comes but seldom into question in the humus-poor ground waters of the study area. In reaching the foregoing correlations, one should take into account the fact that the determinations of $KMnO_4$ consumption were carried out in several laboratories by the application of slightly differing methods, which in turn yield somewhat differing results.

Silica and sulphate

The distribution of silica is not of the same kind as that of the other main components of ground water (Fig. 28). In electrolyte-poor ground water occurring in shore deposits (Table 2, Group 1), the SiO_2 contents are on the average slightly higher than in ground water of bedrock (Group 4). The latter, however, tends to have instances of high concentrations, with the result that the standard deviation is wide. The highest average SiO_2 contents are in ground waters occurring in deposits underlying clay beds (Group 3).

Rapidly percolating perched or ground water retained only a short time in the surficial deposits soon attains a certain SiO_2 concentration, which is not essentially higher in ground water containing electrolytes in abundance. An increase in the amount of other components dissolved in the water does not thereby affect the silica content. Also in the natural ground waters of Finnish Lapland, silica occurs in greatest abundance in the slightly electrolytic waters of silicic bedrock areas (Lahermo 1970, p. 57).

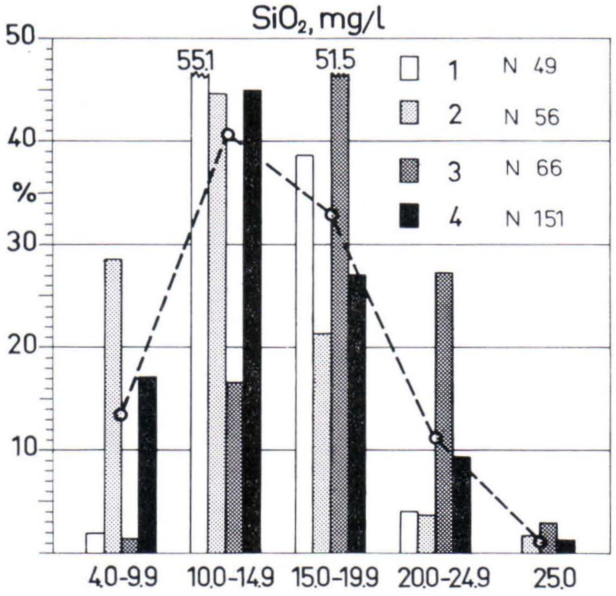

FIG. 28. Frequency distributions of SiO^2 concentrations in different groups. Symbols as in Fig. 21.

Silica exhibits a slight correlation with bicarbonate (1. r = 0.59, 3. r = 0.51) and calcium (1. r = 0.44, 2. r = 0.47). The closest correlation, however, is in slightly electrolytic ground waters with sodium (1. r = 0.65). In part this may be due to the fact that silica is released, in addition to calcium and sodium, in conjunction with the weathering of plagioclases. The pollution caused by agricultural activity does not fundamentally add to the SiO_2 contents, which appears in ground water occurring in deposits underlying clay beds as a distinct negative correlation with the NO_3 content (3. r = —0.47).

Contrary to the case of silica, the sulphate concentrations are lowest in slightly electrolytic waters (Table 2, Group 1) and much higher in bedrock water (Group 4). In the case of the latter, the SO_4 concentrations are in close correlation with specific conductance (4. r = 0.61). The same correlation obtains to a slight extent also in the ground waters of Lapland (Lahermo 1970, Appendix 2) as well as in the surface waters of the country as a whole (Laaksonen 1970, Fig. 96).

Ammonia and nitrate

Under reducing circumstances lacking in oxygen, the nitrogen compounds occur in part in the lowest oxidizing states of nitrogen, as nitrites and ammonia, whereas under oxidizing conditions they occur mainly as nitrates. For this reason, especially in the oxygen-rich ground waters of shore deposits as well as of eskers, the nitrogen compounds occur in the main as nitrates, whereas considerable ammonia occurs in the oxygen-poor ground waters of deposits overlain by clay beds as well as of bedrock. The differences are slight, however, for the quantity of all the nitrogen compounds increases conspicuously from Group 1 to Group 4 (Table 2). Pönkkä (1970) has likewise observed that the NO_3 concentrations are higher in the ground waters of eskers than of deposits underlying clay beds, whereas the NH_4 concentrations are distributed contrarywise.

The NO_3 concentrations of the oxygen-rich ground waters of shore and esker deposits and the NH_4 concentrations of oxygen-poor ground water of deposits underlying clay beds are clearly correlated with the Cl contents (1. r = 0.53, 2. r = 0.64, 3. r = 0.72). In the surface waters of southeastern Finland, the total nitrogen has been observed to be likewise correlated with the Cl contents (see Laaksonen 1970, Fig. 126). The foregoing correlations are due to the increase of the nitrogen compounds and chloride in conjunction with the pollution accompanying agricultural activity (cf., Lahermo 1970, pp. 68—70). On the other hand, in the ground water contained in bedrock, there exists no such correlation; thus the abundance of chlorides in bedrock water cannot be attributed to any noteworthy extent to pollution.

In the ground water of shore deposits, nitrate is in slight correlation with sodium (1. r = 0.55) and potassium (2. r = 0.66). The same correlation can be observed in the surface waters of southeastern Finland (Laaksonen 1970, Fig. 125). Pollution increases the concentrations of all these substances. The nitrate in the ground water

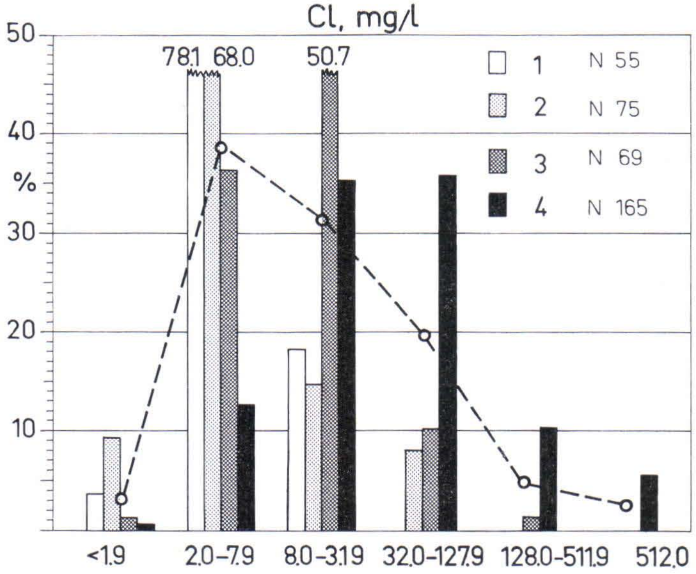

FIG. 29. Frequency distributions of Cl concentrations in different groups. Symbols as in Fig. 21.

of deposits overlain by clay beds and of bedrock has a distinctly negative correlation with the pH value (3. r = —0.26, 4. r = —0.47). The pollution of ground waters caused by agricultural activity is thus reflected in the slight decline in the pH values, which has previously also been noted in the ground waters of Finnish Lapland (Lahermo 1970, p. 33).

Chloride

The chloride concentrations increase conspicuously from Group 1 to Group 4 (Table 2, Fig. 29). It is in the ground water of bedrock that the concentrations are by far the highest and the standard deviation the widest (Group 4). The high Cl content of the water, which is drawn from drilled wells close to the shoreline, is naturally likely to be due to the flow of recent sea water into wells through fractures in the bedrock (p. 21). On the other hand, the bedrock water farther inland and, to a lesser extent, also the ground water of the deposits underlying extensive clay beds and even the connate water in the clay itself are apt to contain remnants of salts dating back to the postglacial Littorina Sea or the subsequent sea (see, Richert 1918, J. Hyyppä 1963, Salmi 1963). The preservation of such relict salinity may be explained by the exceedingly slow percolation and changeability of the ground water in the formations involved, which have thus been capable of storing sea water for many thousands of years. When the pumping of ground water is begun, the percolation is accelerated and the salts are extracted from the surficial deposits and the bedrock.

The Cl content of the ground water occurring in deposits underlying clay beds and in bedrock is correlated with specific conductance (3. $r = 0.66$, 4. $r = 0.89$), which indicates that the marine salts significantly increase the electrolyte content of the ground water. On the other hand, the correlation is not equally close in the ground waters of shore deposits and eskers. In such waters, the chloride derives mainly from pollution, in view of the fact that a marine origin of the chloride is generally out of the question. This is further indicated by the correlation of the chloride with other substances, such as nitrate, associated with pollution (p. 33). Lahermo (1970, Appendix 2) has observed in the polluted ground waters of Finnish Lapland and Laaksonen (1970, Fig. 97) in the surface waters of the southern half of Finland a close correlation between the chloride concentrations and specific conductance. No such correlation exists, however, in the ground and surface waters of northern Finland occurring in a natural state.

Chloride is significantly correlated with total hardness (1. $r = 0.40$, 2. $r = 0.70$, 3. $r = 0.49$, 4. $r = 0.90$). The correlation is closest in bedrock water, where salts of marine origin are apt to increase the hardness of the water greatly (p. 26). In other ground waters, increasing hardness can be partly attributed to the pollution caused by agricultural activity. In the ground water of eskers, this is indicated by the close correlation of total hardness with the NO_3 concentration (2. $r = 0.85$). In the ground and surface waters of Lapland occurring in a natural state, there is no correlation between total hardness and the chloride content (see Lahermo 1970, Appendix 2; Laaksonen 1970, Fig. 106).

Of the alkaline earths producing total hardness, calcium is in closest correlation to the Cl content of bedrock water ($r = 0.90$). This indicates that any increase in the proportion of sea water causes a strong increase in the Ca concentrations. There is relatively little calcium, however, in the water of the Gulf of Finland (see Gripenberg 1937); — or in sea water in general — this means that, stored for several thousand years deep in fractures of the bedrock, the relict sea water has changed greatly in composition. Elsewhere in Finland, too, salty water has been drawn from deep wells drilled into bedrock. The Ca content of such water is regularly found to be quite high compared to the sea water of the present day or the brackish water of coastal regions (cf., J. Hyyppä 1963, Salmi 1963). Love (1944, p. 955) has reported that the Ca concentration of sea water mixed in ground water is likely to increase substantially in ground largely as a consequence of the phenomenon of ion exchange. Considering the geological conditions peculiar to this country, the high concentration of Ca in relict sea water cannot, however, be exchange reactions (J. Hyyppä 1963). The chloride content has a slight correlation also to the SO_4 content (4. $r = 0.59$), which means that the occurrence of marine chloride is frequently also associated with a sulphate content exceeding the usual.

In ground water occurring in deposits underneath clay beds, the chloride is in significant correlation to the sodium content (3. $r = 0.77$), which likewise points to the influence of saline sea water. The corresponding correlation in ground water of bedrock is apparently considerably less distinct, possibly owing to the paucity of data. The chloride is not significantly correlated with the potassium concentrations, which means that the occurrence of marine sodium is not invariably associated with the presence of potassium.

Fluoride

The fluoride contents of ground water vary only slightly. Hence the standard deviation is slight (Table 2, Fig. 30). The F contents of the ground waters occurring in deposits underlying clay beds as well as in bedrock, with their abundant electrolyte content (Groups 3, 4), are not fundamentally higher than those of the slightly electrolytic ground waters of shore deposits and eskers (Groups 1, 2). This indicates that the fluoride contents attain nearly their maximum level quite rapidly as the ground water percolates through the surficial deposits. The increase of other substances while the ground water retains in the soil or the bedrock does not therefore essentially lead to an increase in the F contents, which is also indicated by the lack of a clear correlation to the main components of the water. A slight correlation to the SiO_2 content (1. r = 0.47, 2. r = 0.43) may be observed, however, in dilute ground waters, which points to the minerogenic origin of the dissolved silica. The SiO_2 contents, like those of fluoride, are also rather high in dilute ground waters (p. 32). A slight negative correlation to the NO_3 content in ground water occurring in

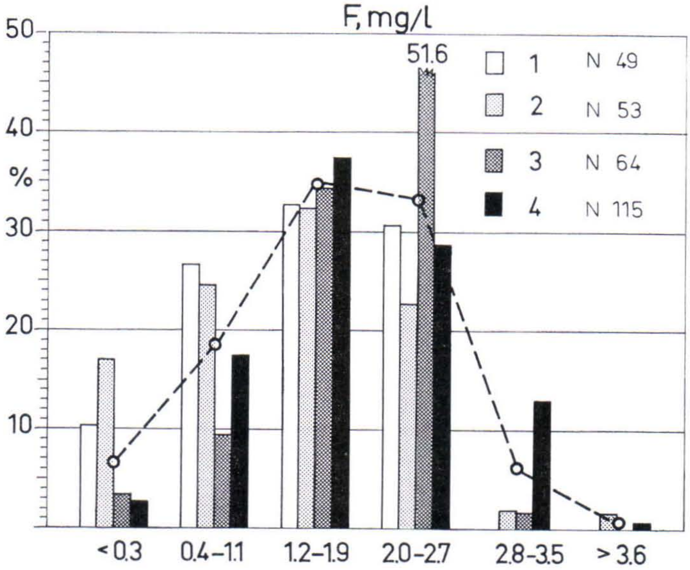

FIG. 30. Frequency distributions of F concentrations in different groups. Symbols as in Fig. 21.

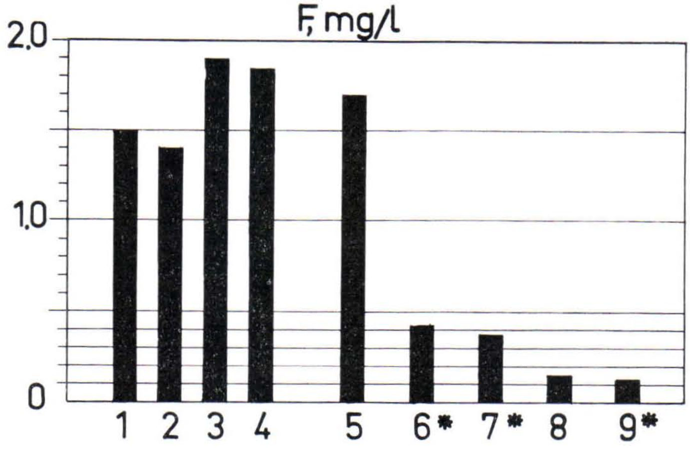

FIG. 31. Fluoride contents 1—4) in ground water of surficial deposits and bedrock of rapakivi area (Groups 1—4), 5) water of drilled wells of rapakivi area (Laakso 1966), 6) water of drilled wells in Finland as a whole (Laakso 1966), 7) water of dug wells of Kymi province (Väre 1961), 8) ground water of Lapland (Lahermo 1970, Appendix 1, Groups 1—12, 15—17), and 9) water of dug wells of Finland as a whole (Väre 1961). Columns represent mean values of contents, excepting median values marked by an asterisk.

deposits overlain by clay beds (3. r = —0.39) indicates, in turn, that the quantity of fluoride does not all increase with pollution. In this respect, the fluoride differs completely from chloride; thus there is no correlation between them, either.

It has long been known that the F contents of the ground water of the rapakivi granite area are on the average higher than elsewhere in Finland (see, Väre 1959, p. 161, 1961, p. 25; Natukka 1963, p. 22). The same may be noted quite clearly in comparing the F contents of the ground waters of the study area (Fig. 31, columns 1—4) with those of the ground waters of Finland as a whole (columns 6, 9). Also Laakso (1966) has reported that the ground water contained in the bedrock of the rapakivi area has a higher fluoride concentration than that of Finland as a whole (columns 5, 6). According to the investigations of Väre (1961), too, the dug well waters of Kymi province taken as a whole contain higher concentrations of fluoride than the well waters of the whole country (columns 7, 9). The difference is fairly small, however, for the bedrock of Kymi province consists of other species of rock than rapakivi granite to a large extent. Fig. 31 further reveals that the ground water occurring in the bedrock of the country as a whole contains distinctly more fluoride than the water of dug wells does (columns 6, 9), the latter representing the ground water of surficial deposits. The average fluoride content of the natural ground water of the Quaternary deposits of Finnish Lapland (column 8) was used to make comparisons with the foregoing data. In this far northern region the observation has been made that the ground water contains slightly higher concentrations of fluoride in granite tracts than in areas of subsilicic bedrock, such as, for example, black schist or greenstone areas (Lahermo 1970, p. 70).

Not only ground waters but also surface waters contain appreciably higher concentrations of fluorides in rapakivi areas than in other parts of the country. For example: from two brooks situated in the rapakivi area, between 115 and 215 kg of fluoride are transported into the sea annually per square kilometer, whereas the corresponding figure for the brook waters of the country as a whole is only between 22 and 24 kg per sq. km a year (Väre 1961, Table 5, symbols 41 and 42). The same kind of result has been arrived at in a study carried out along the Mäntyharju watercourse, where the F concentrations in the lakes and rivers were found to increase substantially in rapakivi areas (see, Pankakoski 1969).

The reason for the high fluoride concentration of the ground and surface waters of the rapakivi area is the large quantity of fluoride-bearing minerals in the rock itself. Among these components is fluorite, above all, which commonly occurs as an accessory mineral and in some instances accounts for as much as 1.5 per cent of the rapakivi granite (see, Sahama 1945, p. 45). Fluorides probably also occur in the apatite, biotite and amphiboles commonly present in the rapakivi granite as well as in the rarer topaz (see, Sahama, as above, Rankama, Sahama 1950, pp. 758—759).

The following comparative figures reflect the rather large F content of rapakivi granite: Clarke and Washington (1924) as well as Goldschmidt (1938, p. 99) report that plutonic rocks contain an average of 0.03 to 0.08 per cent of fluoride (see also Rösler, Lange 1965, Table 87). The corresponding content of rapakivi granite averages 0.23 or even 0.36 per cent (Sahama, as in the foregoing). According to the analyses presented by Vorma (1971, Table 1), as much as 0.42 per cent of fluorides is apt to be present in rapakivi, although not nearly so high concentrations have been found in all specimens of the rock.

The high F contents of dilute ground waters indicate that minerals containing fluorides undergo heavy weathering. Fluorides probably are released most readily by fluorites, micas and amphiboles — but scarcely at all by topaz. The leaching effect of dilute ground waters on F-rich minerals is intensified by the abundant quantity of free carbon dioxide.

SUMMARY

Utilizable ground water occurs in greatest abundance in eskers and other glaciofluvial deposits where the percolation of water is facilitated by the coarse stony material inside the formations. The raised clay beds at the sides tend to dam the ground water in the eskers, which are thereby made to act like »blind drains». Esker deposits in many instances extend far underneath the surrounding clay beds, where ground water under slight pressure occurs. In general, however, the ground-water yield from deposits underlying clay beds is poor. Ground water discharged over the clay beds forms springs in many places at the foot of an esker. In shore deposits overlying the clay beds, there is apt to occur a little perched water, which in dry seasons frequently disappears altogether. The amounts of ground water in till deposits are slight.

Rocky thresholds separate smaller, ground water basins from the eskers. The yield of these basins generally varies between 200 and 500 cu. m of water a day (24 hours), and only in exceptional cases does it exceed 1 000 cu. m a day. The town of Hamina obtains ca. 3 500 cu. m of water a day from the esker known as Summanharju. The ground water is drawn from eight different points, and the amounts formed and pumped remain in balance. The coefficient of infiltration is estimated as 0.64.

The average drilling to the depth of 65 meters in rapakivi bedrock yields 50 cu. m of ground water a day, but some exceptional wells yield as much as between 600 and 1 000 cu. m a day. The amounts of water drawn from bedrock consisting of rapakivi clearly exceed the yield of other species of bedrock in Finland as a whole. This is primarily due to the roughly cubical fracturing typical of rapakivi granite, by virtue of which ground water is likely to collect in borings from quite extensive areas. Contrary to the situation elsewhere, the deepening of a well in homogeneous rapakivi bedrock has rather generally increased the yield of water. Judging by the total data gathered from the area investigated, the depth of borings is not, however, in significant correlation to the yield of ground water.

The temperature of the ground water drawn from bedrock varies between +5 and +7°C, which, is from 1 to 3°C higher than the mean annual atmospheric temperature.

When the ground-water basin of an esker is pumped, the amount of dissolved matter, especially iron, gradually diminishes. This is due to the acceleration of the flow of ground water, as a consequence of which oxygen-rich waters from closer to the surface are mixed with the highly electrolytic and Fe-bearing water that has been long retained deep in the ground. In the event that ground water is pumped constantly, the quantity of dissolved matter attains the level characteristic of the ground-water basin in question. Variations in it, again, depend particularly on changes in the utilization of the water, variations in the meteorological factors and possible contamination of the area in which the ground water forms.

When pumping is performed in eskers bounded by bogs, organic matter is liable to become mixed in the ground water. This is revealed in risen $KMnO_4$ consumption values and Fe concentrations.

When borings are deepened into the bedrock of the coastal region, the contents of dissolved matter of the ground water drawn from the wells increase. This observation applies especially to the Cl content, whereas the Fe content is in many instances apt to decrease. Where borings are close to the shoreline, the salinity generally derives from recent sea water. On the other hand, the salinity of exceptionally deep drilled wells farther inland may be attributed to water from the postglacial Littorina Sea or the subsequent marine stage, which salinity has been preserved in the bedrock. As this water is pumped out steadily, the relict Cl content diminishes, and the supplies of saline water are depleted.

An increase in the marine salinity of ground water drawn from a well drilled into bedrock can be felt also as a marked increase in its total hardness, which is due to the greatly increased Ca content. In sea water, however, there is relatively little calcium; hence the composition of the relict sea water preserved in soil and bedrock has substantially changed during a period of several thousand years. In the ground water of bedrock, the Cl is negatively correlated with the NO_3, which means that the former component is not significantly associated with pollution. In ground water occurring in the deposits underlying clay beds, the marine origin of the Cl is further indicated by the correlation with the Na. When drilled wells in areas situated above the level of the highest Littorina shore are deepened, the Cl contents of the ground water obtained do not invariably increase — but are even apt to decrease. In the rapidly percolating upper part of a horizon of ground water, there apt to be chlorides introduced by the pollution in greater abundance than in ground water at a deeper level.

In the slowly percolating and changing ground water of deposits underlying clay beds and, in particular, of bedrock, there are larger quantities of dissolved matter than in the more rapidly percolating ground water of shore deposits and eskers. The quantity of dissolved matter is thus dependent on the rate of percolation of the ground water, i.e., the length of time it is retained in the surficial deposits or the bedrock. This in turn depends on the structure of the geological formation. The connection between the chemical composition of the ground water and the structure of the geological formation can be observed plainly in a homogeneous bedrock area like the region investigated.

The specific conductance of ground water is closely correlated to the chief components, such as Ca, Mg, and HCO_3, which thus predominantly determine the level of the specific conductance. Its correlation to the Cl contents is clear in the ground water occurring in bedrock, because water with local heavy concentrations of Cl frequently occurs in the coastal region.

The pH-values are on the average highest in highly electrolytic and lowest in dilute ground waters. The pH-values are correlated to the HCO_3 contents and, in highly electrolytic waters, negatively to free CO_2 contents. This is accord with the CO_2-HCO_3 equilibrium.

The Ca, Mg and Na contents of ground water are correlated to the HCO_3 contents, inasmuch as the said elements occur mainly as bicarbonates. An exception, however, is ground water of bedrock containing chlorides in abundance. Correlated to each other are Ca and Mg, which have the same chemical properties, as are Na and K, too. The last-mentioned correlation does not occur in bedrock water in which the increase in marine Na brings about no significant rise in the K content.

The average Na/K-ratio of ground water is distinctly lower in the rapakivi area as in granite areas in general. In the ground waters of areas composed of varying types of rock, the Ca+Mg/Na+K ratio is considerably higher than in the ground waters of all granite areas. Both ratios are substantially higher in ground water than in the bedrock itself. The abundant K of rapakivi granite occurs principally in potash feldspar, which is fairly resistant to weathering. By contrast, Na occurs, though in smaller amounts, in plagioclase, which is less resistant to weathering; accordingly, relatively larger amounts of this element enter ground water than potassium. The last-mentioned component may, however, become partly adsorbed into the clay minerals. Alkaline earths are released from Ca-rich plagioclases and micas, which weather readily, into the water in larger amounts than their proportional occurrence in the bedrock itself would presuppose.

The distribution of the SiO_2 contents of ground water deviates from the other main components of the water. In the slightly electrolytic ground water of shore deposits, these contents are of the same magnitude or larger than in the highly electrolytic ground water of bedrock. The SiO_2 thus rapidly reaches a certain concentration, which does not essentially increase as a function of the length of time the water is retained in the ground. The SiO_2 is independent of the other components contained in the water and of the pollution caused by agricultural activity, which in some ground waters is indicated by a slight negative correlation to the NO_3-contents. The SO_4 concentrations are by far the highest in bedrock water, in which they are correlated to chlorides of marine origin.

Rapakivi granites contain more F-bearing minerals than do other rocks. This is sensitively reflected also in ground water, the F contents of which average 1.3—1.9 mg per l in the study area and only 0.06—0.13 mg per l in the ground waters of Finland as a whole. Ground water rapidly attains a relatively high F content, which does not fundamentally increase with the time the water is retained in the soil and bedrock and, therefore, its electrolytic content. The fluoride is independent of the other components dissolved in the water and degree of contamination, being in this respect like silica. Consequently, there is a distinct correlation between them in dilute waters. The abundant F content of dilute waters shows that fluorite dissolves effectively in CO_2-bearing waters. Fluorides are evidently introduced into ground water also when amphiboles, micas and apatite undergo weathering.

The pollution caused by agricultural activity is sensitively reflected in ground water through an increase in its nitrogen compounds. Nitrates predominate; but in the ground water contained in bedrock and deposits underlying clay beds with only a slight oxygen content, ammonia may also be present in notable amounts. Contamination appears in a slight decrease in the pH value, which can be noted in its negative correlation to the NO_3 content. In the ground water of shore deposits and eskers, the NO_3 is correlated with the Cl content, which indicates that the latter is also a product of pollution. In ground and surface waters occurring in a completely natural state, the Cl is not correlated with the other properties or contents of the water. In the ground water of shore deposits, pollution also appears as an increase in the contents of Na and K, which likewise are correlated with NO_3.

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