Suomen Geokemian Atlas, osa 1

The Geochemical Atlas of Finland, Part 1

SUOMEN POHJAVESIEN HYDROGEOKEMIALLINEN KARTOITUS

THE HYDROGEOCHEMICAL MAPPING OF FINNISH GROUNDWATER

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M. Ilmasti
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Geologian tutkimuskeskus
Espoo 1990

Geological Survey of Finland
Espoo 1990

Kansikuva
Geokemiallinen kartta Lounais-Suomesta. Alueen keskellä on jotuninen hiekkakivi (sininen), eteläosassa rapakivigraniitti (keltainen) ja pohjoisosassa svekokarjalaisia liuskeita (punainen). Väri esittää kromipitoisuutta (sininen on vähän ja punainen paljon), pallon koko nikkelipitoisuutta (iso on paljon) ja pallon harmaasävy kuparipitoisuutta (musta on paljon). Tutkittavana aineksena on ollut moreenin hienoaines (raekoko $<0{,}06$ mm) ja anlyysimenetelmänä on käytetty kuningasvesiliuotusta.

Cover
Geochemical map showing SW Finland. The blue band in the middle represents Jotnian sandstone, the yellow to the south rapakivi granite, and the red to the north Svecokarelian schists. The colour indicates the concentration of chromium (red is high and blue low concentration). The size of the superimposed circles is proportional to nickel concentration and the shade measures copper (black indicates high concentrations). The material studied was the fine franction of till (grain size <0.06 mm) and the analytical method aqua regia leach.

Kannen suunnittelu ***Leo Malinen & Co***
Cover lay-out ***Tapio Koljonen***

Suomen geokemian atlas osa 1

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THE HYDROGEOCHEMICAL MAPPING OF FINNISH GROUNDWATER

Pertti Lahermo, Maija Ilmasti, Risto Juntunen and Matti Taka

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ABSTRACT

Lahermo, P., Ilmasti, M., Juntunen, R. & Taka, M. 1990. The Geochemical Atlas of Finland: The hydrogeochemical mapping of Finnish groundwater. 66 pages, 42 figures and 6 tables.

During 1978–82 the Geological Survey of Finland carried out the hydrogeochemical mapping of groundwater from natural and captured springs and wells dug into overburden and drilled into bedrock. The purpose of the present study is to illustrate the regional distributions of the most important quality parameters in shallow groundwater and systematically to delineate the environmental factors that affect groundwater quality. At present, 20–25% of the population still rely on their own water supply, particularly in sparsely populated rural areas. Hence, it is important to show the quality constraints imposed on the use of these private water sources.

Immediately after sampling, pH, EC (electrical conductivity), Eh, dissolved O_2 and CO_2 were measured in the field. These measurements were supplemented with pH, EC, colour, COD ($KMnO_4$ consumption), total hardness (in German degrees), HCO_3, SO_4, Cl, F, SiO_2, NO_3, Ca, Mg, Na, K, Fe, Mn, Zn, Cu, Ni, Pb, Cd and U determinations in the laboratory.

An appreciable and, in many cases, dominant part of the SO_4, NO_3 and Cl in shallow groundwater derives from atmospheric fallout. In some cases there is more SO_4 in rain water than in diluted groundwater discharged from springs, implying partial destruction or adsorption of SO_4 in the biologically active topsoil.

The distribution patterns of chemical parameters shown by coloured-surface or black-and-white dot maps reveal conspicuous geological correlations. The EC, and the HCO_3, Ca and Mg concentrations in particular are higher in areas predominantly composed of mafic and ultramafic rocks than in silicic areas with similar hydrogeological conditions.

Occurring in anomalously high concentrations in areas composed of rapakivi granites and other coarse-grained, K-rich granites or migmatites intermingled with granitic veins F and U demonstrate the most striking correlation with bedrock composition. However, aquifer structure, i.e. the flow regime and the depth of occurrence and the confining clay, silt or peat beds, have a stronger influence on water quality than has the lithological environment. Hence, high concentrations of dissolved components tend to be found in confined aquifers in coastal areas, regardless of the bedrock composition.

Statistical grouping of the hydrogeochemical parameters by rock type reveals some discrepancies. The concentrations of dissolved components (e.g. HCO_3, Ca) are highest in the rapakivi granite areas. In coastal regions, where aquifers are often partly confined by impervious clay deposits, the SO_4 concentrations in particular are anomalously high. The pH values, however, are statistically higher in the least mineralized waters of granulite areas in northern Lapland.

In places, relict sea salts in clay and silt sediments and bedrock, mainly derived from the Postglacial Litorina Sea and later sea stages, have left their fingerprints on the groundwater in a broad coastal belt, particularly on the west and southwest coast. Cl, SO_4 and Na are the most common marine components, although virtually all the components have increased in abundance.

Anthropogenic contamination and pollution of shallow groundwater are ubiquitous as a consequence of slight regional fallout or more local point-source pollution. The NO_3 and K concentrations in particular indicate pollution, although all components tend to increase.

The varimax-rotated factor matrix suggests that the strongest impact on water quality is exerted by contamination, followed by marine relict components in a broad coastal belt and by geographical elevation. The effect of dissolved humus and redox conditions is secondary. The last two pairs of factors are causally linked together. The water-rock interaction or the buffering reactions regulating the pH level of water seem to be of minor significance.

Key words: groundwater, geochemistry, maps, chemical composition, chemical properties, distribution, soil, bedrock, pollution, Finland

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INTRODUCTION

EARLIER STUDIES AND THE OBJECTIVE OF THIS STUDY

The first studies of the chemical quality of groundwater in Finland were carried out at the beginning of this century, the aim being to analyse potable water in the few existing groundwater supply plants. The monitoring and supervision of chemical and bacteriological water quality intensified after the Second World War together with rapid developments in the communal water supply sector and water legislation, and with the establishment of the National Board of Waters. The Board and the Geological Survey of Finland have been practically the only organizations systematically to study the hydrogeochemistry of groundwater. At the National Board of Waters the main emphasis has been on the quality of economic groundwater resources and on the nationwide groundwater monitoring network (Soveri 1985), whereas the Geological Survey has concentrated on the correlations between water quality and the geological environment (see e.g. Lahermo 1970, 1971, 1988a and b). Abundant hydrogeochemical material has been collected in connection with the mapping of Quaternary deposits (see e.g. Lahermo 1980, 1981). Other groundwater investigations deal with water quality in glaciofluvial aquifers (Pönkkä 1981) and in bedrock (Laakso 1966, Snellman 1982, Rönkä 1983, Hyyppä 1984, 1986), natural radioactivity (Asikainen 1982) and pollution of groundwater (Lahermo and Parviainen 1979, 1984, 1987, 1988a and b).

Recently, the future storage of nuclear waste in Precambrian bedrock has encouraged investigations into bedrock groundwater. Attention has thus come to focus on the salinity and the radioactive and stable isotope composition of groundwater (Nurmi et al. 1985, 1988, Lahermo & Kankainen 1986, Blomqvist et al. 1986, Kankainen 1986, Nordström 1986, Wickström & Lampen 1986, Lahermo & Lampen 1987, Blomqvist et al. 1987).

In 1978 the Geological Survey started the nationwide hydrogeochemical mapping programme which produced the material for this report. The field work for the project took five years, in the course of which about 5900 water samples were collected from springs, dug wells and wells drilled into bedrock. Most of the wells were private and used by farms or other households. The communal water distribution network has been extended to include an increasing number of rural households, and many private wells are gradually being abandoned. Nevertheless the rural population still largely depends on private wells (20 to 25% of the total population), and there is a growing number of summer homes and cottages that also rely on their own water supply.

The present study seeks to improve understanding of the effect of natural and manmade environmental factors on the quality of groundwater in different types of aquifer in overburden and bedrock. It also aims to throw light on geochemical water-rock interaction processes, although this subject will be dealt with in greater detail in future papers. Apart from purely scientific ambitions the hydrogeochemical mapping of groundwater endeavours to gather information about the present state of the water and wells used by the rural population.

RESEARCH METHODS

SAMPLING, ANALYTICAL METHODS AND COMPILATION OF DATA

The samples were collected in the field according to the following procedure. The original idea was to take two samples per basic 10 x 10 km topographic map sheet (1: 20 000). There was no difficulty about taking the samples needed in southern and central parts of the country but in remote areas farther north not all the map sheet areas were easily accessible within the time available and there are extensive areas without wells. The fact that the sampling density along roads may be higher than average is offset by the large tracks, especially in Lapland, where samples could not be collected at all. The different types of sampling site, i.e. springs, captured springs, dug wells and wells drilled into bedrock (see p.10), are represented according to their availability and thus unevenly, some areas having no springs but others having no drilled bedrock wells. Since dug wells are found practically everywhere in southern and central Finland they account for the largest number of sampling sites overall (c. 3600).

The samples were collected from springs and captured springs by simply scooping up the water with a bottle. In dug wells a Ruttner type sampler or plastic bucket was used, and in drilled bedrock wells the water was pumped up. As the water from the drilled bedrock wells was often poured from taps through presurized storage tanks, the quality may sometimes have changed to some extent.

A reporting form was designed for completion in the field and office with a view to collecting environmental, geological and chemical data on sampling sites and water (Fig. 1). The first section (V) gives the code of the sample, the map sheet, the date of sampling, the coordinates, the province and the municipality. Section 1 gives the type of sampling site and lining material (e.g. dug well with concrete rings), the condition of the well (1 to 3, good to poor) and the site-evaluated degree of human activities (0 to 4, natural state to strongly affected). Also recorded are the depth of sampling, the depth of the water table and the estimated or measured yield (springs, drilled bedrock wells). The thickness and type of Quaternary deposits and bedrock composition are important environmental factors. Therefore they, too, must be coded and considered in the interpretation of hydrogeochemical data. Section 2 records field estimations and determinations of water quality (estimated colour and turbidity 0 to 4, temperature, measured dissolved CO_2 and O_2, pH, Eh and electrical conductivity). The last sectors (3–5) are for the results of laboratory determinations.

The specific electrical conductivity (EC), pH and redox potential (Eh) values and contents of dissolved oxygen were determined at the sampling site. Electrical conductivity was measured using WTW LF 56 and 90 conductometers (West Germany), an EXTECH Digital conductivity meter (U.K.) and a Yellowsprings YSI Model 33 SCT meter (U.S.A). The pH measurements were made with Radiometer pH 29 and 80 meters (Denmark) equipped with separate calomel and glass electrodes or combined glass electrodes and WTW pH DIGI 88 and 90 meters equipped with Ingold U455 or corresponding WTW gel-electrodes. The redox potential was measured with an EIL Model 3030 pH meter (U.K.) equipped with a large-size industrial Pt-KCl electrode. The O_2 determinations were made with a Yellowspring YSI Model 54A oxygen meter with a Model 5739 electrode and a WTW OXI DIGI 88 meter with a Model D8120 electrode. The dissolved CO_2 content was also determined immediately after sampling in the field using conventional NaOH titration with a phenolphthalein indicator.

For laboratory analyses one untreated water sample was collected in a one-litre polyethene bottle. The water was analysed for colour, $KMnO_4$ consumption, alkalinity, total hardness, Cl, F, SiO_2 and NO_3 concentrations using standard procedures (Anon 1969, Anon 1980). SO_4 was analysed using indirect AAS method developed at the Geological Survey of Finland. The SO_4 in the sample was precipitated with $BaCrO_4$ and the liberated chromium (Cr) was measured with the flame method using Varian Techtron AA-5 and Perkin-Elmer 5000 atomic absorption spectrophotometers.

One 100 ml sample was filtered through a 0.45 μm membrane and acidified with concentrated suprapure HNO_3 (0.5 ml) for AA-spectrophotometric analyses. The flame technique was used for Ca, Mg, Na, K, Fe, Mn and Zn, but the graphite furnace technique was applied for Cu, Ni, Pb and Cd because of the low concentrations. Uranium was analysed from filtered (0.45 μm) and acidified (1 ml 10% H_2SO_4 into 500 ml of sampling water) sample enriched by ion-exchange, using the standard addition method and a Perkin-Elmer 204 fluorescence spectrophotometer.

Most of the large maps give the chemistry of the water from dug wells, as these accounted for the largest number of samples (c. 3600, against c. 1300 springs and c. 1000 drilled bedrock wells) and were thus considered to be the most representative. The dug wells are also the most important source of water in rural areas not catered for by public water works. Furthermore, the cost of printing forced us to be strict in selecting which material to use. Springs and drilled bedrock wells, although representing quite different groundwater regimes, show often similiar interrelationships between chemical parameters and the environment. Therefore the maps of spring waters or of

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Laboratorionumero

VESINÄYTEPISTEEN TUNNISTETIEDOT

V — Näytetunnus: N:o, Ryhmä, Vuosi — Näytteenottopvm.: Pv., Kk., Vuosi — Kortin täyttäjät

Karttalehti — X — Y — Z m — Lääni — Kunta

Kylä, tila, henkilö, puhelinnumero

NÄYTTEENOTTOPAIKAN KUVAUS

1 — Näytepaikka — A — Otto-tapa — Kaivon kunto — Ihmis-toiminta — Näytteenotto-syvyys m — Veden pin. syvyys m — Kaivon kok. syvyys m — Maaperän > paksuus m

Vesimäärä m³/vrk — Maap. muod. — Maalajit — Alue-tekijä — Aika- ja ilm.tek. — Kivilaji

Lisätietoja

KENTTÄMÄÄRITYKSET

2 — Väri — Sameus — Lämpö-tila °C — CO_2 mg/l — pH — Sähkönjohtavuus mS/m, 25 °C — Mittausarvo — Lämpötila °C — Kerroin

Redox mV — Mittausarvo mV — Vakio — O_2 % — Mittausarvo ppm — Suodatus

Lisätietoja

LABORATORIOMÄÄRITYKSET

3 — Väriluku > Pt mg/l — pH — Sähkönjohtavuus mS/m, 25 °C — Alkaliteetti < m mol/l — $KMnO_4$-luku mg/l — < NH_4 mg/l — < NO_2 mg/l

< NO_3 mg/l — Cl mg/l — < F mg/l — < PO_4 mg/l — SiO_2 mg/l

4 — SO_4 mg/l — < Ca mg/l — < Mg mg/l — < Na mg/l — < K mg/l

< Fe mg/l — < Mn mg/l — < Zn µg/l — < Cu µg/l — < Ni µg/l

5 — < Pb µg/l — < Cd µg/l — < U µg/l — Rn Bq/l — < Cr µg/l — < Co µg/l

< Hg µg/l

Lisätietoja

☐ KPL SEURAAVIA LABORATORIOMÄÄRITYKSIÄ TALLENNETAAN:

Ioni — Määritystulos — Laatu — Ioni — Määritystulos — Laatu

Lisätietoja

Fig. 1. Reporting form for coding the environmental and geological features of the water sampling sites and for chemical field and laboratory analyses.

Kuva 1. Ympäristötekijöiden ja veden laadun havaintoja varten laadittu vesinäytekortti.

waters from drilled bedrock wells are often given as small inserted maps.

The analytical results with supporting environmental and geological data were assembled in a data file. This enabled us to make statistical calculations and to process different kinds of graph and black-and -white dotted and coloured surface maps covering the whole country. The data base was compiled by the Department of Quaternary Geology, while the data presentation was developed and carried out by N. Gustavsson (see Björklund & Gustavsson 1987).

DESCRIPTION OF SAMPLING SITES AND AQUIFER TYPES

THE OCCURRENCE OF GROUNDWATER IN SURFICIAL DEPOSITS AND BEDROCK

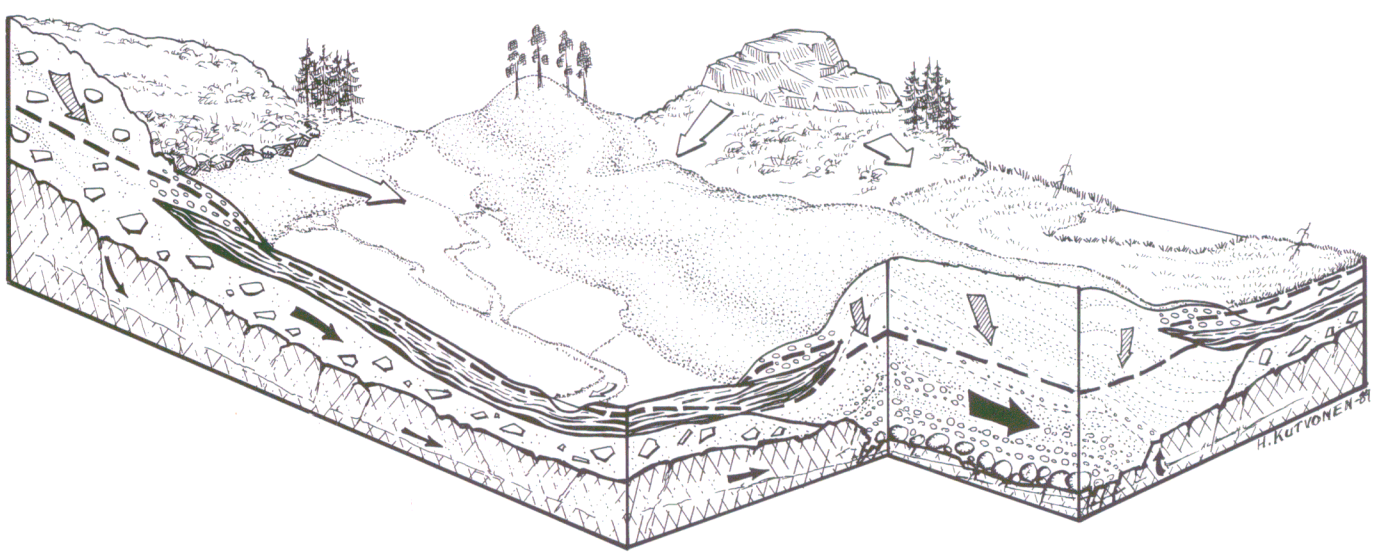
The Finnish Precambrian bedrock, which is composed of Archaean basement and Proterozoic complexes, is covered by a thin sheet of glacial and postglacial overburden. The average thickness of the surficial deposits, which are mainly composed of till, marine or lacustrine bottom sediments (clay, silt) and glaciofluvial or littoral sand and gravel deposits, varies from some metres in outcropping rocky areas to some tens of metres in depressions. The glaciofluvial eskers (Fig. 2), related esker deltas and ice marginal formations (e.g. the Salpausselkäs), which are composed of sand and gravel, constitute the most extensive aquifers. As they are unevenly distributed, are lacking near the largest population centres, e.g. Helsinki and Turku, and cover only an estimated 3 to 4% of the total area of the country, groundwater resources cannot supply more than 50% of the water volume distributed by public water works. The figure does not include the large volume of surface water used by the pulp and paper industries and the energy sector. However, if private one-household wells are included in the estimate, groundwater accounts for a somewhat higher proportion of total water consumption.

Most of the private household wells in rural areas draw water from till deposits, relatively poor aquifers that cover the bedrock nearly ubiquitously (Fig. 3 and 4). In coastal areas the surficial part of the till cover at the foot of hills is often composed of sorted or redeposited material to depth of some metres, hosting small amounts of perched or shallow groundwater. Many of the glaciofluvial sand and gravel deposits extend underneath the clay and silt layers thus making the occurrence of confined groundwater possible. Conspicuous artesian aquifers occur where large eskers are bounded and partly covered by clay deposits.

There is generally enough groundwater in the fractures of Precambrian bedrock composed of igneous and metamorphic "hard rocks" to feed drilled wells intended to supply water for one household only (Fig. 3 and 4). Statistically granitic rocks yield more water than metamorphic schists and basic intrusives (Lahermo 1971).

Fig. 2. A schematic block diagram of the hydrogeological conditions in a glaciofluvial esker situated in a valley and bordered by till. The esker is covered by clay deposits in the topographically lowest part of the valley. There are major springs at the foot of the esker ridge and hill. The arrows indicate the flow directions of surface runoff, infiltration and groundwater (cf. also Fig. 5).

Kuva 2. Kaavamainen esitys harjun ja sitä ympäröivien muodostumien pohjavesioloista. Harju sijaitsee kallioperän murroslaaksossa ja sitä rajoittaa ja osittain peittää maaston alavissa kohdissa savi- ja turvekerrostumat. Harju saa pohjavesitäydennystä ympäristön kallioperän raoista ja moreenikerrostumista pääosan virtauksesta tapahtuessa harjun pituussuunnassa (ns. synkliininen harju). Katso merkkien selitykset kuvasta 5.



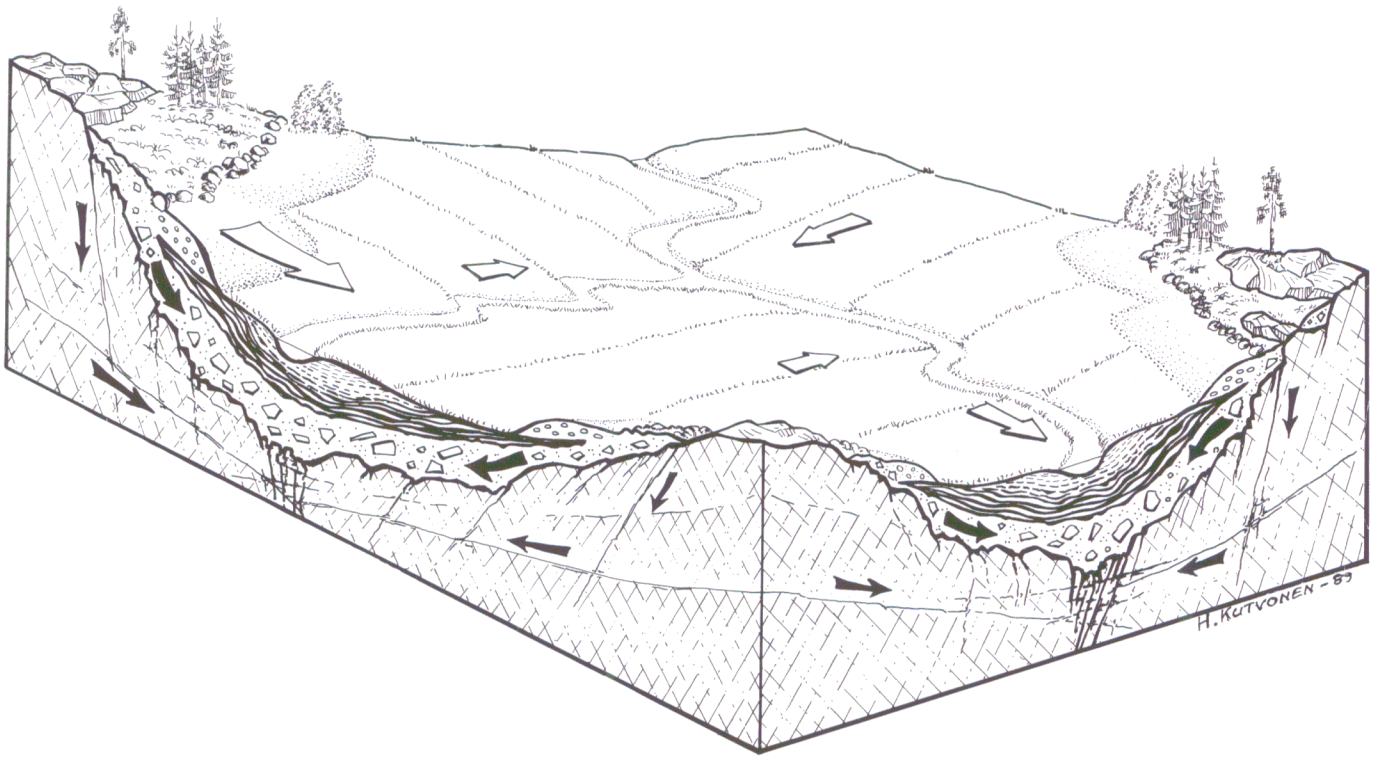


Fig. 3. A schematic block diagram of the hydrogeological conditions in a coastal valley covered with late-and postglacial clay deposits. Topographically elevated areas act as discharge zones while valleys connected with major fracture zones are discharge areas, often featuring confined or artesian conditions (cf. also Fig. 5).

Kuva. 3. Kaavamainen esitys rannikon savipeitteisestä laaksosta. Yläviltä pohjaveden muodostumisvyöhykkeiltä virtaava pohjavesi on usein paineista savikerrosten alaisissa moreeni- tai hiekkakerrostumissa ja kallioperän raoissa. Katso merkkien selitykset kuvasta 5.

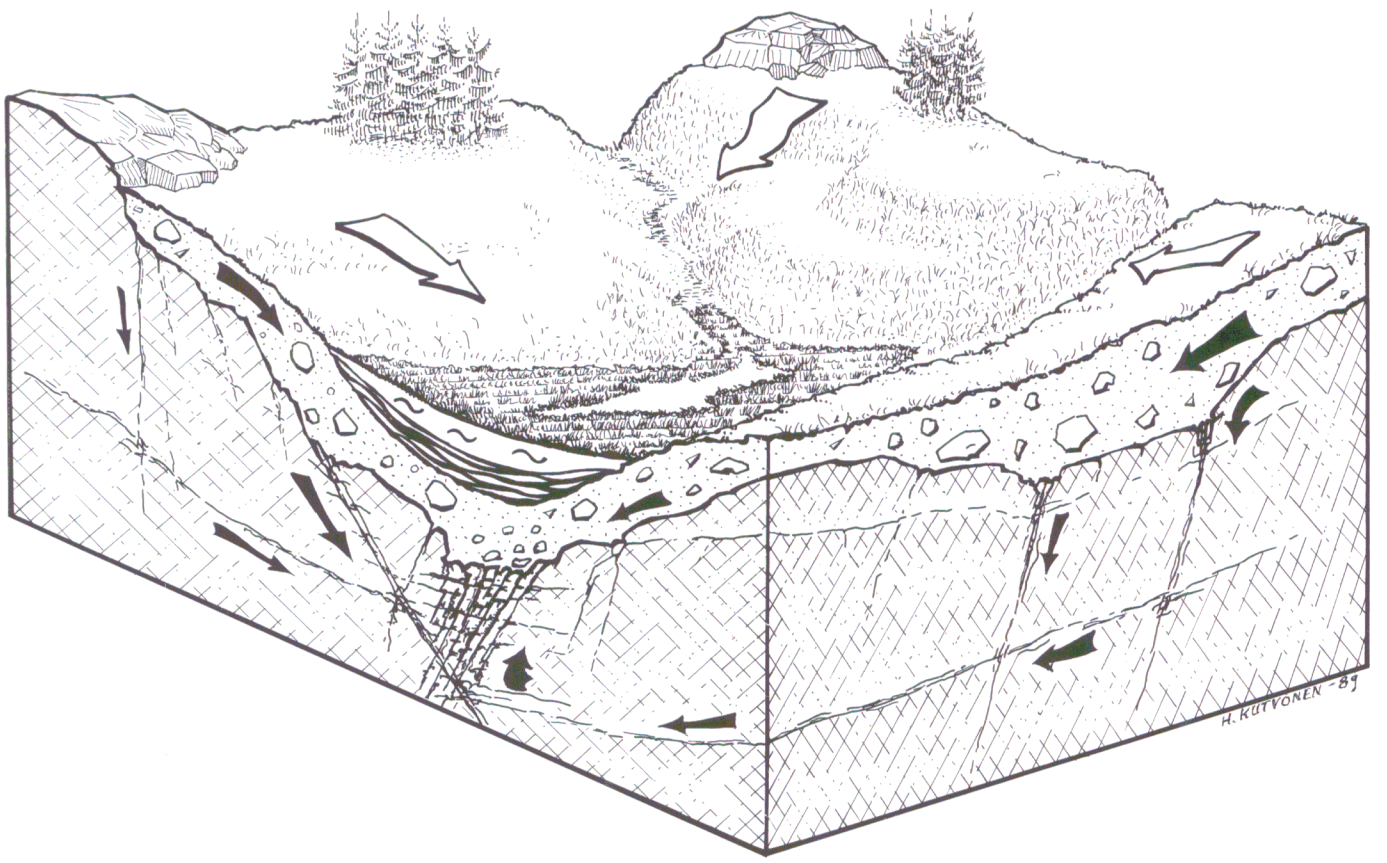


Fig. 4. A schematic block diagram of the hydrogeological conditions in till and bedrock, where a major part of the groundwater occurs in fractures and fissures and flows towards the topographically lowest and most fractured part of the bedrock unit (cf. also Fig. 5).

Kuva 4. Kaavamainen esitys moreenin ja kallioperän pohjavesioloista. Kallioperän ja moreenin pohjavesi ovat läheisessä vuorovaikutuksessa virtauksen suuntautuessa yläviltä muodostumisalueilta murrosvyöhykkeiden luonnehtimiin maaston alaviin laaksokohtiin, jotka ovat usein soiden tai vesistöjen valtaamia. Katso merkkien selitykset kuvasta 5.

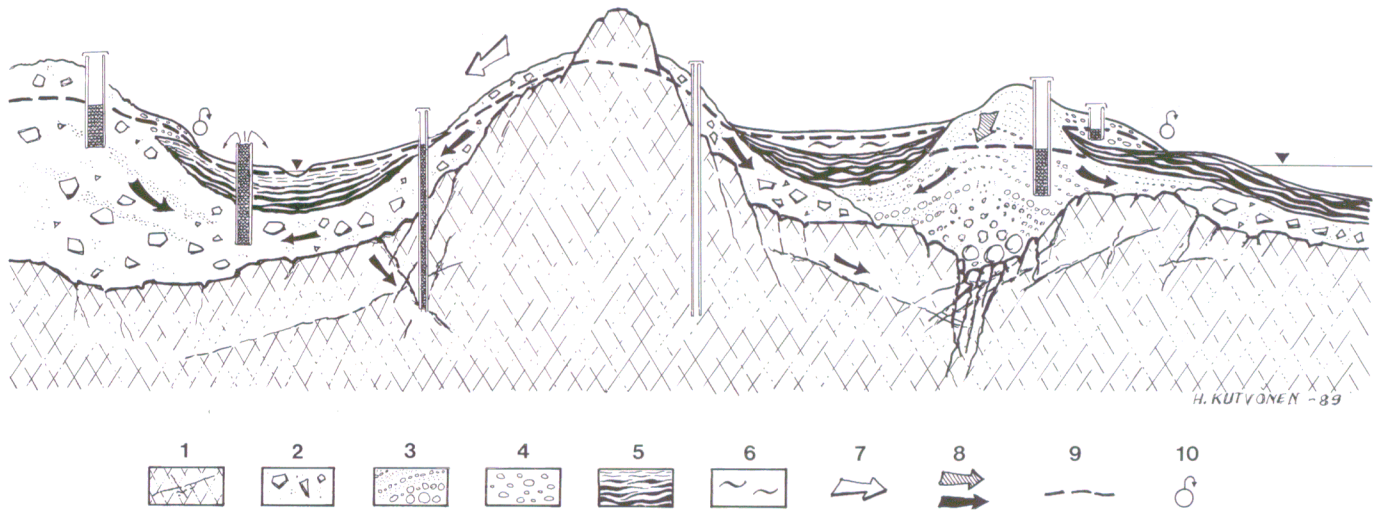


Fig. 5. A schematic cross section through an esker bordered by a peat bog, clay deposits and a lake. 1. Fractured bedrock; 2. Till; 3. Glaciofluvial or littoral sand and gravel; 4. Gravel; 5. Marine or lacustrine clay 6. Peat; 7. Runoff; 8. Vadose water and groundwater flow; 9. Groundwater table; 10. Springs, dug wells and drilled bedrock wells. Figures 2,3,4 and 5 are drawn by Harri Kutvonen.

Kuva 5. Kaavamainen leikkaus harjun ja saven osittain peittämien moreeni- ja hiekkakerrostumien läpi. 1, rakoillut kallioperä; 2, moreenia; 3, hiekkaa ja soraa; 4, soraa; 5, savea ja silttiä; 6, turvetta; 7, pintavaluntaa; 8, vajo- ja pohjavesivaluntaa 9, pohjavedenpinta; 10, lähde ja kuilu- ja kallioporakaivoja. Kuvat 2,3,4 ja 5 on piirtänyt Harri Kutvonen.

CLASSIFICATION OF AQUIFER TYPES

The previous chapter briefly described the surficial (Quaternary) deposits and hard rock formations that contain groundwater. These can be divided into the following aquifer types:

1) Eskers and ice-marginal formations with related deltas and glaciofluvial transverse ridges. In terms of the groundwater regime there are two main types of aquifer: the draining or effluent ("synclinal") type, and the losing or influent ("anticlinal") type, depending on whether the glaciofluvial aquifer drains or loses groundwater from or to the environment. Transitional types exist between these two main types.

2) Small glaciofluvial lee-side formations at the foot of bedrock hills or littoral deposits overlying glaciofluvial or till deposits or other underfined small sand deposits.

3) Partly or wholly clay-covered glaciofluvial or till deposits in valleys. The most extensive and productive confined aquifers are the extensions of glaciofluvial eskers or deltas underneath clay deposits. The composition of an aquifer material below a clay or silt blanket is not generally known.

4) Glacial till deposits occurring as ablation moraine or basal till and as hummocky moraines and drumlines. Till is the most common aquifer material for private wells.

5) Bedrock or "hard rock" aquifers, which in some parts of Finland (partly central Lapland) can be divided into upper weathered mantle or saprolite aquifers and lower fissured and fractured hard rock aquifers.

The above aquifer types are presented in block drawings and a cross section (Figs. 2, 3, 4 and 5) showing the structure of a typical esker formation, and till and clay deposits, and the fracture tectonics of the bedrock.

SAMPLING SITES

The sampling sites fall into three main categories: natural springs and captured springs discharging water mainly from surfical Quaternary deposits, dug wells (or rarely tube wells) in overburden and wells drilled into bedrock. These types of sampling site are schematically presented in Fig. 5.

The springs were either in a natural state or lined with a shallow wooden casing or concrete ring. Some springs were fitted with several rings, and pipes had been installed to conduct water to the household. Since there is some outflow from springs, small scale construction does not generally affect the water quality. The rate of outflow is generally not more than 0.5–1.0 litres per second.

Dug open wells constitute the most common well type. In the old days, wells were often lined with wood or stones, but nowadays concrete rings are used. Private dug wells are generally 3–10 m deep and 80–120 cm in diameter. Many of the old wells are poorly maintained and unprotected, enabling polluted surface runoff to reach the groundwater. Ring wells are more carefully constructed and therefore have better-quality water than the old stone- or wood-lined wells. The amount of pumped water also affects water quality. The greater the amount of pumped water the better the quality of the water correlates with that of the intact groundwater in the feeding aquifer. In densely populated rural areas and in the outskirts of urban areas there are abundant dug wells that have been unused for different periods of time. Although not necessarily representative, they were sometimes the only sampling sites available for this survey. The suction hoses of pumps were below the water level or the water was taken with galvanised metal buckets, thus making dissolved heavy metal contamination possible. If there was no access to the well shaft, the samples were collected by hand pump or from taps through pressurized water storage tanks. Flowing tube wells were sometimes constructed in confined sand and gravel aquifers partly or

wholly covered by clay deposits. In some cases, there are tube wells at the bottom of open dug wells. These are, however, rare in the present material.

The bulk of the wells drilled into bedrock are 40–80 m deep and 110 mm in diameter, and yield 500-2000 litres of water per hour. The water samples were collected or from taps supplied by an electrical pump, often through a pressurized container. There is thus a danger of heavy metal contamination with a hand pump installed at the top of the well or sometimes. However, since the drilled wells are relatively small in diameter, pumped water, if not conducted through and preserved for some time in a pressurized container, comes straight from the fractures and fissures of the bedrock and reflects the true composition of the bedrock groundwater.

ENVIRONMENTAL FACTORS AFFECTING GEOCHEMISTRY OF GROUNDWATER

ATMOSPHERIC FACTORS

Since rainwater is a primary source of groundwater, the rate and composition of precipitation are important for the recharge event and for the initial composition of soil water, perched water and shallow groundwater. The more pervious the aquifer material, the stronger the correlation between rain water and groundwater quality. The infiltration and replenishment of groundwater reserves take place in late spring during the thaw, and in autumn, which is generally wetter than summer with less evapotranspiration. At the height of the summer, evapotranspiration generally exceeds rainfall and no appreciable amounts of vadose water reach the groundwater zone (cf. e.g. Soveri 1985).

Although the exact amounts of material deposited through wet or dry fallout are still poorly known, some quantitative evaluations can be made (cf. Järvinen 1986). Table 1 lists average rainwater compositions. Evapotranspiration has a strong impact on concentrations in summer, most of the deposited salts being concentrated in the top soil as little or no infiltration occurs during dry periods. With the onset of heavy rain, the salts are flushed down to soil water and perched or shallow groundwater. Evapotranspiration may then cause brief chemical fluctuations in water quality, as most of the salts will then be flushed into groundwater. The calculations in Table 1 show that there is a close similarity between the chemical composition of rainwater and of perched and shallow groundwater. Most of the SO_4 and NO_3 contents in shallow groundwater occurring in natural conditions seem to derive from rainwater. These components are partly adsorbed and transformed in the humus-rich soil zone.

GEOLOGICAL FACTORS

The texture and lithological composition of aquifer material has an effect on soil water and groundwater quality. In sand and gravel aquifers, where the material contains only small amounts of fines, the groundwater is slightly more diluted than in more fine-grained or less sorted material, e.g. till deposits. This is partly due to the larger water-rock contact area and the related longer residence time of water in poorly pervious material. The time factor is also clearly visible in groundwater in deeper parts of the overburden and in bedrock, where the abundances of dissolved solids in water are usually higher than in more shallow aquifers (see e.g. Lahermo 1970, 1971).

The mineral composition of soil has a clear impact on water quality. In felsic mineral and rock environments the groundwater statistically contains smaller abundances of dissolved solids than in mafic environments, provided other conditions are comparable (see e.g. Lahermo 1970). This correlation between bedrock composition and groundwater quality is also seen in the findings reported in this paper, although other environmen-

		SO_4 mg/l	NO_3 mg/l	Cl mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l
Fallout ($g/m^2/y$)	South	1.8–3.6	0.2–0.3	0.2–0.6	0.2–0.9	0.05–0.1	0.1–0.3	0.07–0.2
	North	0.6–1.8	0.05–0.1	0.2–0.4	0.1–0.3	0.04–0.07	0.1–0.2	0.05–0.15
Rainwater (mg/l)	South	4–6	0.4–0.5	0.3–1.0	0.3–1.4	0.08–0.15	0.2–0.5	0.1–0.3
	North	1.5–4	0.1–0.3	0.4–0.9	0.2–0.7	0.07–0.15	0.2–0.4	0.1–0.3
Enriched by ET (mg/l)	South	6–10	0.6–0.9	0.5–1.7	0.5–2.4	0.1–0.3	0.3–0.9	0.2–0.5
	North	2–6	0.15–0.5	0.6–1.4	0.3–1.1	0.1–0.2	0.3–0.6	0.1–0.5
Shallow groundwater (mg/l)		4.7–5.2	0.1–0.8	2.5–2.6	5.7–6.6	1.8–2.2	2.5–2.6	1.0
Atmospheric origin (%)		40–(210)	20–(150)	20–70	5–40	5–15	10–40	10–50

Table 1. Rainwater composition compared with the chemistry of shallow groundwater discharged from springs and captured springs in order to evaluate the abundance of material derived from the atmosphere. Rainwater composition was computed from fallout values (Järvinen 1986) using average values for precipitation: 600–650 mm/y in southern Finland and 400–550 mm/y in northern Finland (Anon 1986). Enriched concentrations introduced into soil and shallow groundwater were calculated using the following evapotranspiration values: 300–450 mm/y in southern Finland and 150–300 mm/y in northern Finland. The values in parentheses exceeding 100% indicate that the concentrations of SO_4 and NO_4 in fallout are higher than those measured from shallow groundwater.

Taulukko 1. Laskeuma-arvoista arvioitu sadeveden koostumus (Järvinen 1986) verrattuna lähteistä purkautuvan, nopeasti vaihtuvan pohjaveden koostumukseen. Laskelmissa on käytetty keskimääräisiä sadanta-arvoja 600–650 ja 400–550 mm/y ja haihdunta-arvoja 300–450 ja 150–300 mm/y maan etelä ja pohjoisosissa (Anon 1986). Ilmasta peräisin olevat ainesmäärät on esitetty prosentteina. Jos määrät ylittävät 100%, kyseistä komponenttia tulee ilmatietä enemmän kuin mitä sitä esiintyy matalapohjavedessä.

tal factors often mask the geological ones. In rock aquifers, clay minerals and other secondary alteration products covering the fracture and fault surfaces have a relatively strong impact on water-rock interactions although the reactive surfaces in rock openings are not as large as those in soil.

MARINE FACTORS

During late phases of deglaciation, the Baltic basin was occupied by a much larger water body than the present sea. Owing to eustatic changes in sea level and the concomitant isostatic uplift of the central part of the Baltic Shield, the basin gradually diminished in size until it reached its present areal extent. The most saline seawater phase of the Baltic, the Litorina Sea, started in southern Finland about 7300 to 7400 years BP (Eronen et al. 1979, Hyvärinen et al. 1988). It covered a large coastal area, especially in the low-lying western part of the country, where the rate of isostatic uplift has been the most rapid. The Litorina Sea phase is thought to have been appreciably more saline than the present stage (up to 10 to 11 per mil against the present 6 to 7 per mil in the western part of the Gulf of Finland, and 8 to 9 per mil against the present 3 to 4 per mil in the northern part of the Bothnian Bay, Eronen et al. 1979). After the areal climax of the Litorina Sea, the salinity gradually fell to the present-day level.

The relict seawater trapped in the fissures and fractures of the bedrock and pore water in marine clay and silt sediments may contribute to the electrolyte contents of groundwater in unconsolidated deposit and hard rock aquifers covered by marine sediments in the coastal belt. The strength of the marine effect, which manifests itself as enhanced Na, Cl and SO_4 contents in many of the coastal groundwater occurrences, depends on the proximity of the aquifer to the present-day coast line and on the depth and stagnancy of the groundwater.

Recent observations show that there are also deep-seated saline groundwaters inland far from the present sea coast. Compared with the significance of the water-rock interaction, the old seawater component may play only a minor role in their genesis although it cannot be ruled out altogether. The geochemical evolution processes of deep bedrock groundwater are not yet fully understood. In this material, however, the household drilled wells represent such shallow aquifers that a discussion about the genesis and evolution of deep-seated saline groundwaters is not warranted.

ANTHROPOGENIC FACTORS

The influence of human activities on the chemical quality of shallow groundwater is ubiquitous. In the cases of point-source pollution the changes in groundwater chemistry can be locally large if the soil is pervious. The biologically active surface soil has, however, the ability effectively to oxidize and chemically and bacteriologically to decompose contaminants and pollutants and thereby to scavenge heavy metals. A sort of natural purification is a valuable soil property that protects groundwater. When the soil cover is removed by extraction of sand and gravel, often down to or even below the water table, the groundwater is exposed to rapid pollution. The thicker the soil and intermediate zone above the groundwater table the better the groundwater is protected. The confined groundwater in aquifers covered by clay and silt deposits is affected only by activities in distant recharge areas. The purification processes that occur during the long-lasting residence along the flow paths appreciably improve the quality of the water.

Not even aquifers located in remote, uninhabited areas can escape some anthropogenic effect on the quality of shallow groundwater. Regional acid wet and dry fallout increases the concentrations of pollutants (e.g. SO_4, NO_3, cf. Table 1) and other dissolved components in soil and groundwater not only directly but also indirectly by enhancing the exchange and disintegration processes in soil, thus causing overall diffuse changes in the chemistry of weakly buffered shallow groundwater.

Groundwater occurring in fractures and fissures of the surficial part of the bedrock may be exposed to pollution if the main recharge is through bedrock outcrops. Poorly pervious till and clay deposits may, however, effectively protect bedrock groundwater, even though some anthropogenic influence will still be felt. Only deep-seated brackish or saline bedrock groundwater at a depth of several hundreds of metres may be intact and unaffected by human activities (apart from the effect of drilling fluids or pumping).

Slight contamination and more severe pollution are reflected in a general increase in dissolved components (TDS). The most sensitive indicators of human activities are NO_3, Cl and K (see e.g. Lahermo 1984, 1987, 1988a and 1988b). The elements and compounds introduced depend on the type of pollutant, e.g. communal sewage seeping into the soil and groundwater zone from leaking pipes, septic tanks, storage lagoons and treatment plants, from the fertilizers used in agriculture and forestry, the wastes created by animal husbandry and from various industrial spills.

SEASONAL CHANGES IN GROUNDWATER QUALITY

Hydrometeorological factors, i.e. the rate and quality of precipitation and surface runoff (overland or storm flow and interflow) and the rate of evapotranspiration, have a strong effect on the chemical composition of soil water and shallow groundwater. This is mainly felt in the seasonal fluctuation in groundwater chemistry, which can be divided into three distinct phases. The spring peak of abruptly rising groundwater table and discharge is characterized by dilution of groundwater and a reduction in the abundances of chemical compounds as a result of infiltrating melt water. In summer and autumn the water tables and chemical composition of groundwater fluctuate irregularly, depending on the amount of infiltrated water, which may vary conspicuously from summer to summer. In summer, when evapotranspiration reaches its peak, the amount of water infiltrating into the groundwater zone tends to be small. Later in autumn, the groundwater reserves are again replenished. Summer and autumn can also be considered as two separate phases, each with its own characteristics. In winter, infiltration cease, resulting in a steady lowering of the groundwater table and a related decline in discharge.

The contents of dissolved elements in shallow groundwater are highest in late winter, just before the snow melts. In shallow, pervious sand and gravel aquifers the amplitude of the chemical fluctuations in water is generally smaller than in groundwater occurring in less pervious till or deep in bedrock protected by till or fine-grained bottom sediments. In large sand and gravel aquifers water quality tends to remain fairly stable, whereas in small till aquifers the spatial and chemical changes may be marked. The deeper the groundwater and the less pervious the aquifer material, the smaller are the seasonal fluctuations in water chemistry.

As pointed out above, the variation in the groundwater table and in the related volumes of discharge and amounts of dissolved load in shallow groundwater exhibit reverse patterns. The same trend is found, but even more pronounced, in stream water chemistry. In winter, due to base flow, stream water is primarily groundwater discharged into the stream. This is especially true in drainage basins with either no lakes or only a few. The TDS values decrease abruptly during the spring discharge peak, when streams are in flood. Then the base flow, although somewhat bigger than in winter, accounts for only a fraction of the total discharge of streams. There is some delay in the change in composition of groundwaters and the chemical fluctuations in surface waters, depending on the properties of the aquifers.

GENERAL AND REGIONAL RESULTS

GENERAL GROUNDWATER COMPOSITION

To obtain an overall view of the chemical composition of Finnish groundwater the sampling sites were divided into three main categories, each one representing a distinctly different mode of occurrence and regime of groundwater: 1) springs and captured springs discharging water from surficial parts of the overburden, 2) open dug wells in the overburden, and 3) wells drilled into Precambrian bedrock (Table 2). The statistical data on chemical parameters show differences in distribution between the categories.

Spring water represents perched water or shallow groundwater residing in the upper part of the overburden for only a short time, sometimes no more than a few days or weeks. This is reflected in the chemical resemblance to rain water and the very low concentrations of dissolved solids. Dug wells obtain their water from deeper parts of surficial deposits, which is demonstrated by the 2.3–2.8 times higher concentrations of dissolved electrolytes (calculated on the basis of specific electrical conductivity). The highest concentrations are in bedrock groundwater sampled from drilled wells exhibiting 3.3–3.5 times higher dissolved concentrations than in spring waters.

The distribution of the main components, divided into the three classes mentioned above, is presented in three pairs of triangular diagrams for anions and cations (Fig. 6). Spring waters are composed of 60 equivalent-% HCO_3, 20 equivalent-% SO_4 and 20 equivalent-% Cl. The corresponding cation equivalent percentages are 50, 20 and 30 for Ca, Mg and Na + K, respectively. The arithmetic mean values for dug and drilled well waters are roughly the same. Although there are similarities between the average compositions, there are differences in the shape of the spatial distribution patterns of the large material, as seen from the diagrams.

The distribution pattern of cations is more concise in spring waters than in dug well and bedrock well waters. The last mentioned group shows a pronounced, narrowing lobe towards the Na + K corner owing to the presence of some brackish and saline well waters in coastal areas. The anion distributions are still wider in all three sampling site categories. This is due to the fact that there are a few samples among the large material that are not of the overwhelmingly dominant Ca–HCO_3 type of water. Although small in number, they show quite divergent types of water. In coastal areas the influence of marine relict salts or present seawater intrusion into aquifers is reflected in a shift towards Na-Cl dominant waters. Ca-SO_4 type waters are encountered more seldom in sulphide-mineral potential areas and magnesium-rich waters are very rare.

Histograms and superimposed cumulative curves showing the frequency distribution of most of the measured properties and analysed components are presented in Figs. 7–10. Since in most cases the modes of distribution are roughly the same for waters from springs, dug wells and drilled bedrock wells, the bulk of the material presented is from dug wells with only a few examples from springs and drilled bedrock wells.

The scales of the histograms are logarithmic (with base $\sqrt{2}$), except for pH, dissolved O_2 and SiO_2, which are arithmetic. The mode of distribution of pH, EC and HCO_3 values is symmetrical, or almost symmetrical and normally distributed, while that of dissolved O_2 is fairly uniform without any clear concentration peaks. $KMnO_4$ consumption values and SO_4 concentrations show slight positive and negative skewnesses, respectively. The Cl concentrations represent springs and bedrock groundwater and have positively skewed (22 % of samples have concentrations lower than 1.0 mg/l) and relatively symmetric distributions, respectively. Clear symmetric and positive skewnesses are shown in the SiO_2 distribution of spring and well waters, respectively.

The F distribution is truncated, as most of the concentrations are below the analytical detection level (0.1 mg/l). The NO_3 concentrations refer to a multi-modal distribution, most probably because of the application of two different detection limits (below 0.1 and 1 mg/l). The mode of distribution for the main cations Ca, Mg and K is symmetric. The exception is Na in bedrock groundwater, which has a slightly skewed distribution. The distribution patterns of Fe, Mn, Zn, Cu, Ni, Pb and Cd (the last not presented) are strongly positively skewed, as the analytical detection limits applied are not appropriate for the naturally very low heavy metal contents in water.

Table 2. The properties and chemical contents of groundwater from springs, dug wells and wells drilled into bedrock classified according to aquifer material and structure.

Taulukko 2. Pohjaveden koostumus lähteissä ja katetuissa lähteissä, kuilukaivoissa ja kallioporakaivoissa pohjavettä sisältävän muodostuman maalajin ja rakenteen perusteella luokiteltuna.

Source		Springs						Dug wells						Drilled wells	
Aquifer type		Sand and gravel		Till		Clay covered		Sand and gravel		Till		Clay covered		Bedrock	
Mean/Median		Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median
pH		6.3	6.2	6.2	6.2	6.3	6.2	6.4	6.4	6.4	6.3	6.7	6.6	6.7	6.6
El. conductivity (EC)	mS/m, 25°C	9.0	6.1	9.7	6.7	23.5	17.9	20.6	15.0	23.7	19.5	38.3	32.7	35.0	23.9
Eh	mV	390	390	390	390	390	390	370	370	390	390	370	380	360	370
O_2	%	72	72	73	78	54	55	63	65	61	62	48	45	51	45
CO_2	mg/l	23	20	26	20	43	40	35	30	43	40	44	40	39	30
Colour	mg/l Pt	11	5	12	5	16	10	16	5	19	10	20	20	20	5
$KMnO_4$ consumption	mg/l	8.0	4.9	8.4	4.9	8.3	6.2	11.9	6.5	14.7	9.0	13.6	9.1	10.3	6.0
Total hardness	°dH	1.5	1.0	1.7	1.1	4.0	3.1	3.4	2.5	4.0	3.2	6.8	6.0	5.5	4.1
HCO_3	mg/l	27	21	27	20	64	44	51	35	61	46	123	100	98	74
SO_4	mg/l	8.1	5.0	7.8	5.0	21.1	17.3	17.3	10.6	17.9	13.0	34.0	23.0	18.5	11.3
Cl	mg/l	6.0	2.6	6.2	2.4	15.8	8.7	15.4	7.2	17.1	9.0	25.8	13.4	36.6	12.3
F	mg/l	0.16	0.10	0.15	0.10	0.42	0.17	0.17	0.10	0.16	0.10	0.51	0.25	0.42	0.10
SiO_2	mg/l	10.4	9.9	10.5	10.0	15.2	14.2	11.1	10.3	11.6	10.9	16.5	16.6	14.0	13.0
NO_3	mg/l	3.3	0.7	4.5	1.0	8.2	1.8	13.6	4.0	15.1	6.7	8.4	2.0	11.8	2.4
Ca	mg/l	7.2	4.4	7.8	5.0	18.1	14.2	17.6	12.4	20.6	16.5	30.4	27.0	26.6	19.2
Mg	mg/l	2.2	1.4	2.4	1.5	6.1	4.4	4.2	2.6	5.0	3.5	10.9	8.9	7.8	5.5
Na	mg/l	3.6	2.5	3.6	2.6	10.1	7.0	9.1	5.4	10.1	6.9	22.0	11.7	25.1	8.8
K	mg/l	1.9	1.0	2.1	1.0	5.2	2.6	7.8	3.1	8.7	4.3	8.2	5.1	7.1	3.2
Fe	mg/l	0.33	0.05	0.19	0.05	0.71	0.07	0.53	0.07	0.40	0.07	0.63	0.16	0.92	0.10
Mn	mg/l	0.03	0.02	0.04	0.02	0.20	0.02	0.08	0.02	0.09	0.02	0.19	0.07	0.23	0.05
Zn	µg/l	56	20	75	20	176	30	196	50	175	50	196	60	322	100
Cu	µg/l	9.4	3.0	13.0	4.0	19.0	4.5	11.4	6.0	14.5	7.0	19.0	6.0	25.3	9.0
Ni	µg/l	3.7	2.0	4.4	2.0	3.8	2.0	8.6	3.0	14.8	3.0	8.0	2.0	4.6	2.0
Pb	µg/l	1.2	1.0	1.3	1.0	1.2	1.0	2.3	1.0	1.8	1.0	1.1	1.0	1.2	1.0
Cd	µg/l	0.5	0.5	0.5	0.5	0.6	0.5	0.6	0.5	0.6	0.5	0.6	0.5	0.5	0.5
U	µg/l	1.4	1.0	1.4	1.0	1.7	1.0	1.7	1.0	1.4	1.0	3.1	1.0	21.2	1.0
No. of samples (No. of U samples)		229 (109)		997 (575)		88 (72)		663 (373)		2600 (1602)		290 (232)		1027 (991)	

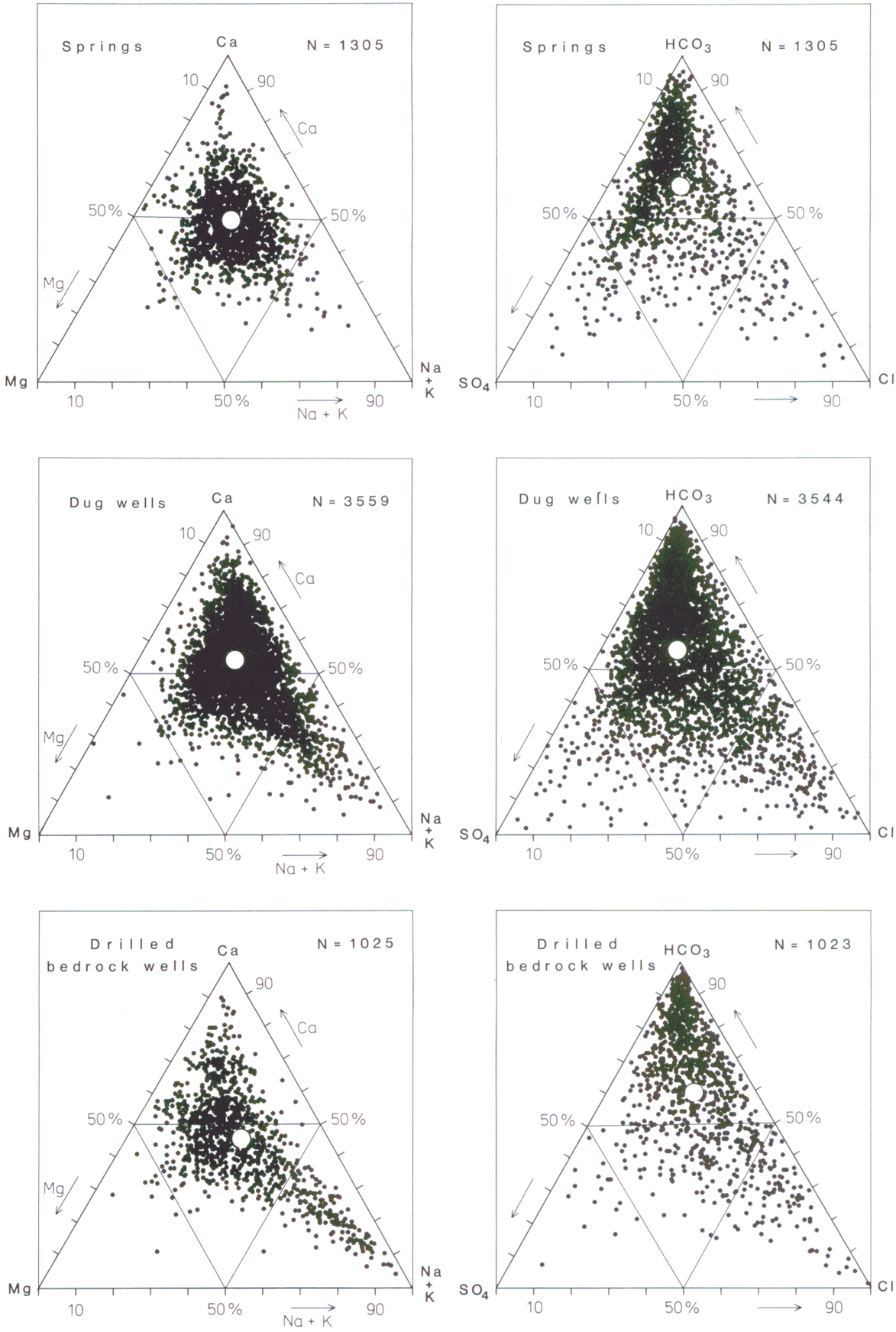


Fig. 6. Triangular diagrams showing the equivalent percentages of the main anions (HCO_3, SO_4, Cl) and cations (Ca, Mg, Na+K) in water from springs, dug wells and wells drilled into bedrock. Since the distribution and arithmetic means of the particular chemical parameters in water from sand and gravel, till and clay-covered aquifers do not differ conspicuously from each other, they are not presented separately. The arithmetic means are shown by large open circles.

Kuva 6. Pääanionien (HCO_3, SO_4, Cl) ja -kationien (Ca, Mg, Na+K) prosentuaaliset ekvivalenttijakautumat kolmiodiagrammeina esitettyinä. Kuviot on laadittu erikseen lähde-, kuilukaivo- ja porakaivovesistä. Koska hiekan ja soran, moreenin sekä savenalaisten kerrostumien veden laatuominaisuuksien jakautumat ovat erilaisista ainesmääristä huolimatta keskenään samankaltaisia, niitä ei ole esitetty erikseen. Havaintojoukon aritmeettiset likimääräiset keskiarvot on esitetty valkeina palloina.

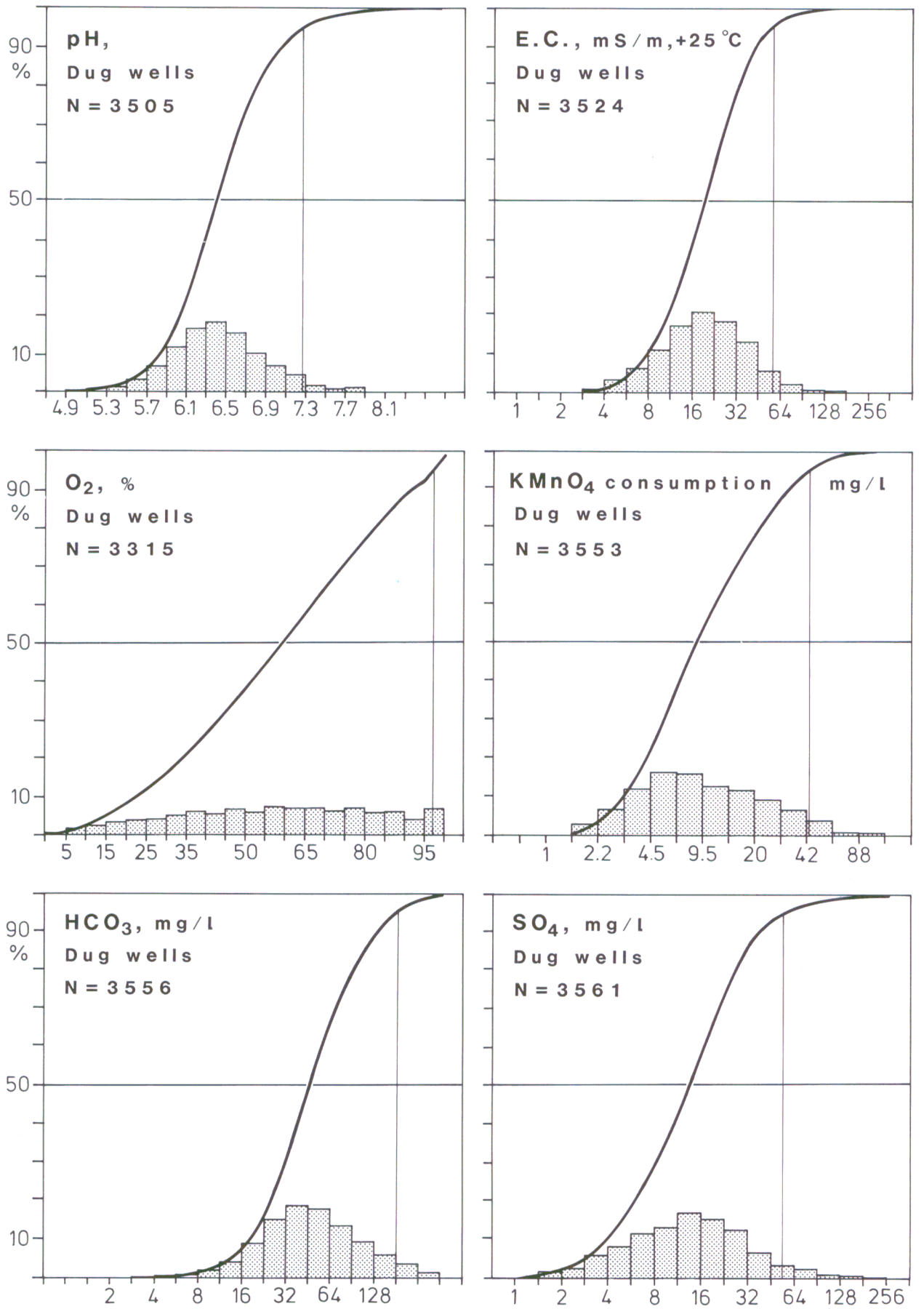


Fig. 7. The frequency distribution of some main properties and concentrations in groundwater sampled from dug wells presented as histograms and cumulative curves. Also 95 % percentiles are marked. The pH and O_2 scales are arithmetic; all the others are logarithmic (with base $\sqrt{2}$).

Kuva 7. Pohjaveden pääominaisuuksien ja komponenttien jakautumat histogrammeina ja summakäyrinä esitettyinä. Kuviot on laadittu vain kuilukaivojen vesistä. pH:n ja liuenneen O_2:n asteikot ovat aritmeettisia, muiden logaritmisia (kantaluku $\sqrt{2}$).

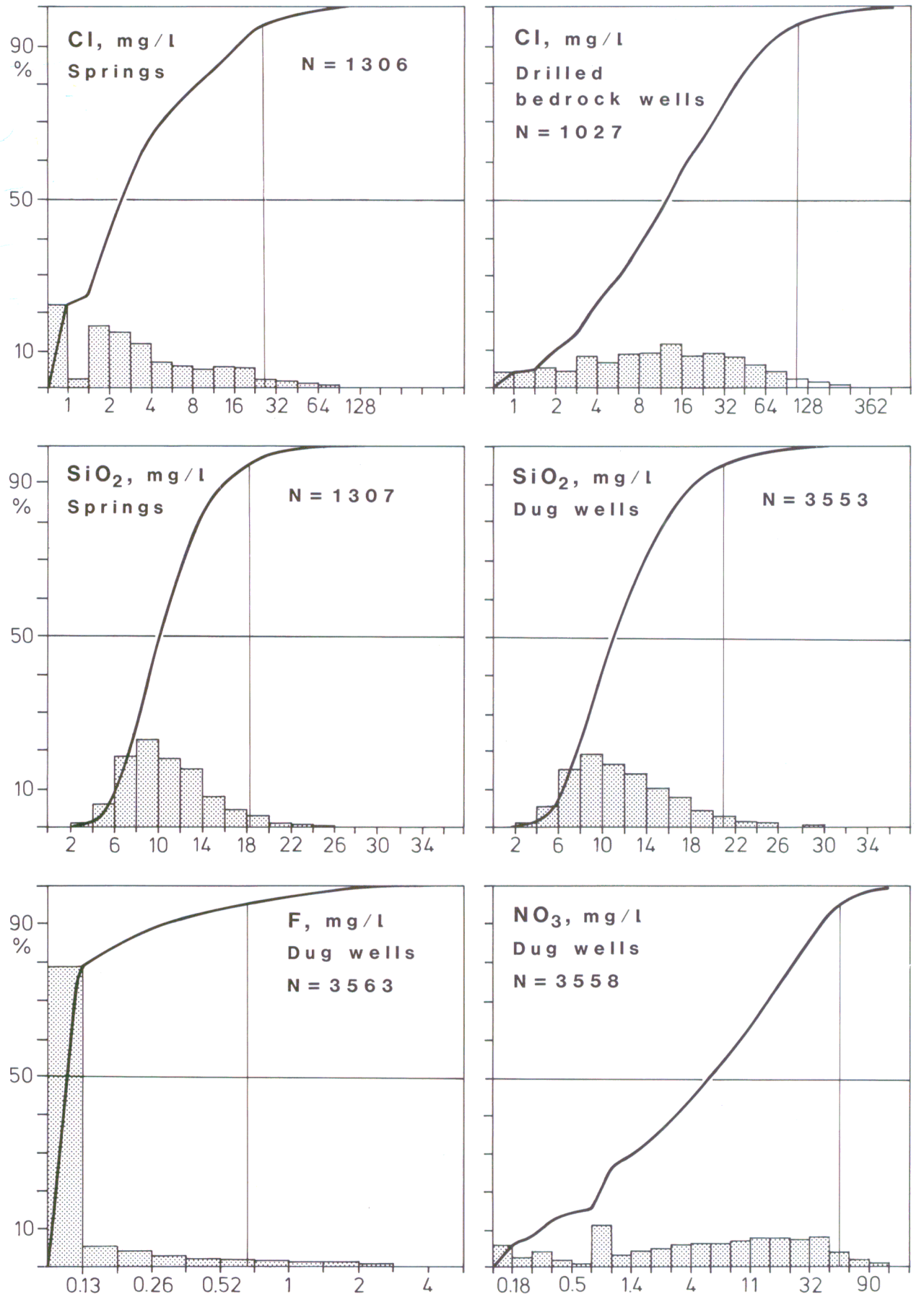


Fig. 8. The fequency distribution of Cl, SiO_2, F and NO_3 in groundwater sampled from springs,dug wells and bedrock wells (Cl) presented as histograms and cumulative curves. The SiO_2 scale is arithmetic; the others are logarithmic (with base $\sqrt{2}$).

Kuva 8. Pohjaveden eräiden pääkomponenttien jakautumat histogrammeina ja summakäyrinä esitettyinä. Kloridin lähde- ja porakaivovesille, piihapon kuviot on laadittu lähde- ja kuilukaivovesille ja fluoridin ja nitraatin kuviot kuilukaivovesille. SiO_2:n asteikko on aritmeettinen, muiden logaritmisia (kantaluku $\sqrt{2}$).

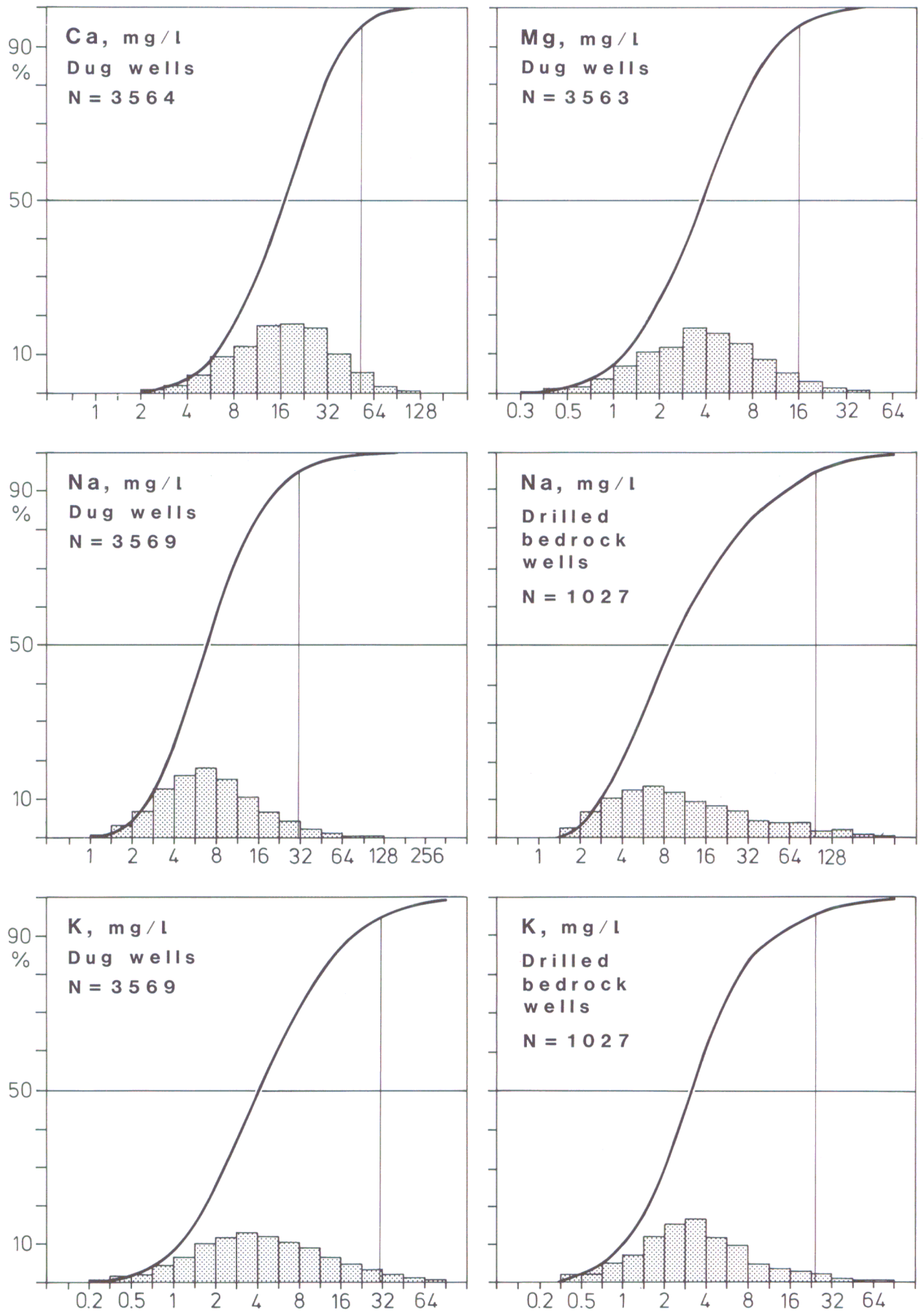


Fig. 9. The frequency distribution of the main cations in groundwater sampled from dug and drilled bedrock wells presented as histograms and cumulative curves. All scales are logarithmic (with base $\sqrt{2}$).

Kuva 9. Pohjaveden pääkationien jakautumat histogrammeina ja summakäyrinä esitettyinä. Kalsiumin ja magnesiumin kuviot on laadittu kuilukaivovesille ja natriumin ja kaliumin kuviot kuilu- ja porakaivovesille. Asteikot ovat logaritmisia (kantaluku $\sqrt{2}$).

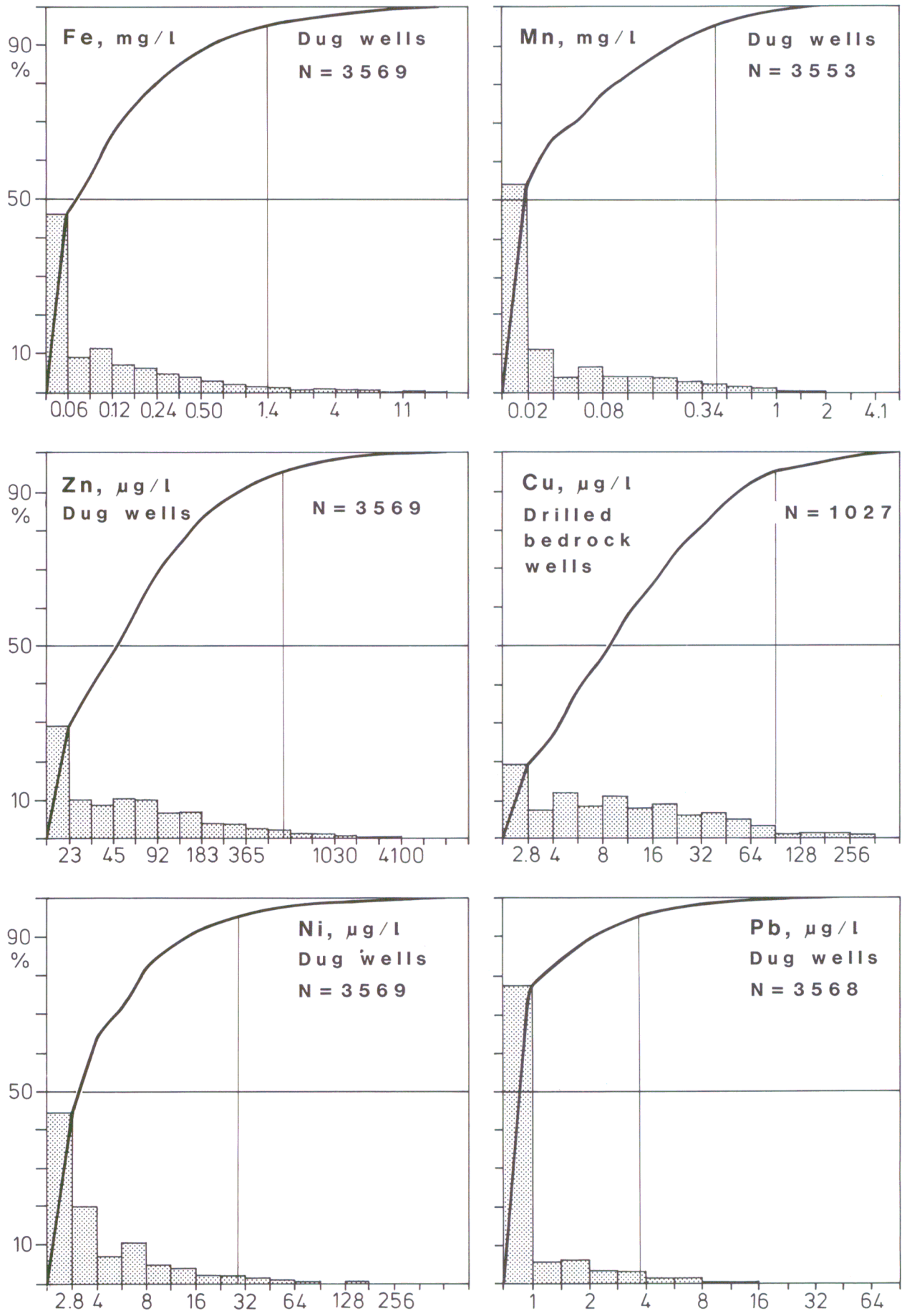


Fig. 10. The frequency distribution of the trace metals in groundwater sampled from dug wells (except for Cu, which was sampled from bedrock wells) presented as histograms and cumulative curves. The scales are logarithmic (with base $\sqrt{2}$).

Kuva 10. Pohjaveden raskasmetallien jakautumat histogrammeina ja summakäyrinä esitettyinä. Kuviot on laadittu kuilukaivovesistä (paitsi Cu porakaivovesistä). Asteikot ovat logaritmisia (kantaluku $\sqrt{2}$).

REGIONAL GROUNDWATER COMPOSITION WITH SPECIAL REFERENCE TO GEOLOGICAL ENVIRONMENT

Computerized maps of most of the physical and chemical parameters were processed for groundwater representing springs, dug wells in overburden and wells drilled into bedrock. The most informative black-and-white dot maps and coloured surface maps, are given in this report (Figs. 11–35). In the following, the regional distribution of water quality parameters and the environmental factors affecting them are discussed in the order presented in Table 2.

The distribution of pH values measured in the field is presented in Fig. 11. Finnish groundwater is slightly acidic on the whole (see also Table 2), and the distribution pattern of the pH is partly the same as that of EC (cf. Fig. 12). The wedge-shaped Peräpohja schist area, to the north of the Bothnian Bay, emerges strongly from the background (cf. Fig. 42). Parts of the west coast show up as low pH areas although the abundances of dissolved electrolytes are comparatively high. This is mainly a result of the high concentrations of sulphates derived from marine sulphides and sulphates in soil and the fairly high dissolved CO_2 and humus in water (cf. Figs. 14, 15 and 16). In parts of the west coast (Vaasa area), southwest coast and archipelago the pH values are higher, roughly coinciding with those of the areas of elevated EC values. The Archaean basement in eastern Finland appears as a uniformly low pH region as do the large granitic plutons in central Finland and Lapland (cf Fig. 36). The Pori–Vammala–Tampere sulphide mineral potential belt is likewise an area of low groundwater pH (cf. Fig. 42).

Specific electrial conductivity (EC) measured in the field gives useful information on abundances of dissolved electrolytes. Conductivity values are elevated in the southwestern and western coastal belt and in the archipelago (Fig. 12), mainly owing to relict sea salts in confined aquifers partly covered with clay and silt deposits and in fractures of bedrock, and to anthropogenic contamination in intensively cultivated agricultural areas. Values are also elevated in the Peräpohja schist area (cf. Fig. 42). As part of the Karelidic schist belt, the Peräpohja schist area is mainly composed of mica schists, leptites, quartzites, amphibolites and gabbros. Small occurrences of ultramafites, limestones and dolomites and sulphide mineralizations are also common in the area, causing widespread elevated EC values in the water. A part of the schist belt in central Lapland, stretching from Kittilä via Sodankylä and Salla to Kuusamo (Lapland–Kuhmo–Suomussalmi greenstone belt, see Saverikko, 1988) and composed largely of mafic and ultramafic volcanics and plutonics, is also shown as elevated EC values. Other large anomalous areas occur in eastern and southeastern parts of the country in the sulphide mineral potential "Ladoga-Bothnian Bay or Raahe zone" (cf. Fig. 42). The large Archaean basement area in eastern Finland, which is mainly composed of granite gneisses, and the granitoid areas in central Finland and southern Lapland are shown as areas of low electrolyte concentrations in groundwater.

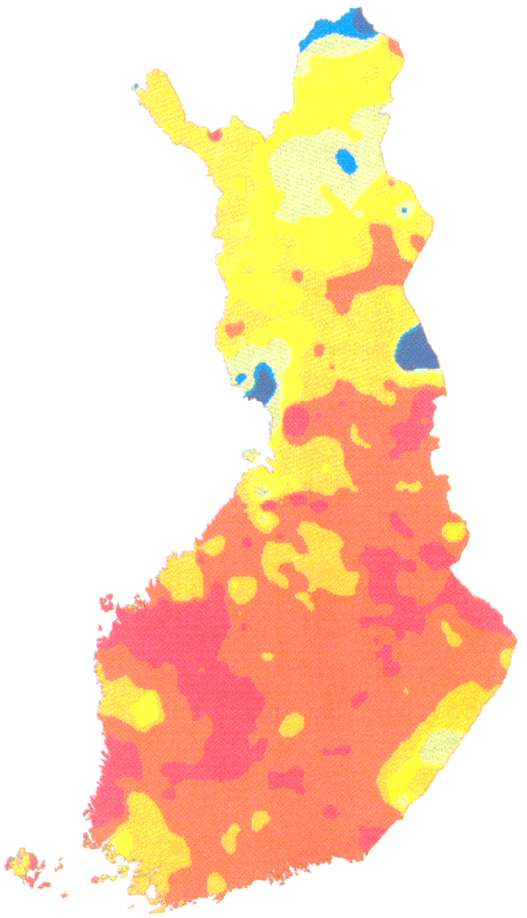
The distribution of redox potential (Eh) shows that the values are lowest in the western coastal belt, where groundwaters tend to contain more dissolved humic material (viz. higher colour and $KMnO_4$ consumption values) and less dissolved O_2. Likewise a slight depletion of dissolved oxygen in groundwater is found in the western and southern coastal belts (Fig. 13). The main reasons for the reduced O_2 concentrations are the oxidation of natural humus and organic anthropogenic pollutants, which can enter aquifers through recharge areas or poorly protected wells as overland flow. The O_2 depletion is exacerbated by the confined conditions in aquifers partly or wholly covered with clay and silt or peat deposits. Consequently, the distributions of Eh, dissolved CO_2, colour and $KMnO_4$ consumption values (Figs. 14, 15 and 16) are compatible with that of dissolved oxygen. The described trends are most marked in the dug well and bedrock well categories but less so in spring waters. Since total hardness (Fig. 17) is governed by the Ca and Mg contents, it will be discussed in connection with those cations (p. 31).

The distribution pattern of bicarbonates (alkalinity) is compatible with that of EC and partly with that of the pH values (Fig. 18). The strong positive correlation between EC and HCO_3 suggests that the geological factors contributing to the chemical composition of water are the same for both parameters. Thus, as to HCO_3 concentrations the Peräpohja schist area manifests itself clearly in spring, dug well and drilled bedrock well categories. The easternmost part of the Karelidic schist belt in southern Lapland, i.e. the Kuusamo schist area, composed of mafic amphibolites and metabasalts shows up as higher concentrations in HCO_3 distribution. The water from drilled wells has elevated HCO_3 values in the coastal belt and in the western and central part of the Ladoga-Bothnian Bay sulphide mineral potential belt. There are small areas of elevated HCO_3 values in the water on the western side of the Kymi rapakivi batholith and also on the southwest coast and in the archipelago. It is likely that seawater has affected water quality in the last mentioned areas, although, in places, small occurrences of limestone in bedrock or Palaeozoic limestone material transported and mixed with overburden by the continental ice sheet from the bottom of the Bothnian Sea, also may contribute to elevated HCO_3 concentrations.

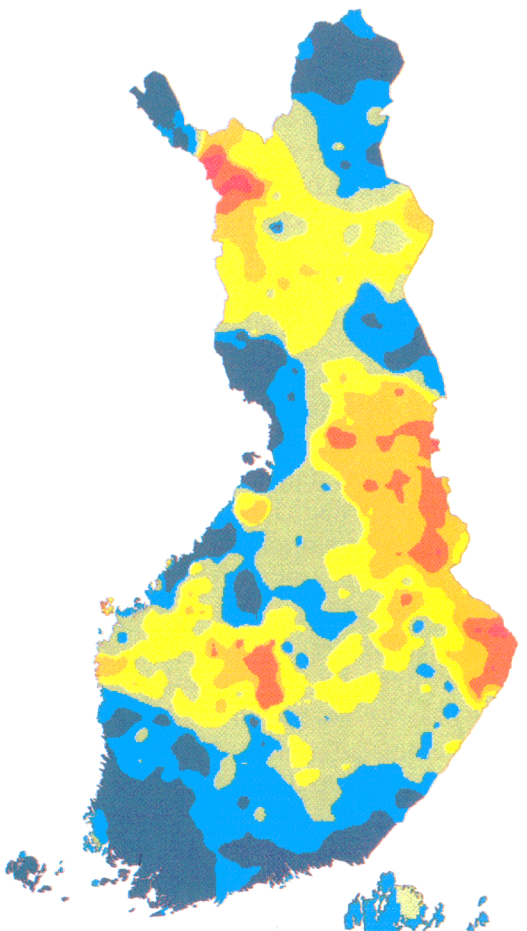
The distribution of sulphates is a striking demonstration of the effect seawater has on groundwater quality, as the contents of the analysed compounds are highest along the coast (Fig. 19). Sulphates may be released to water from marine sulphide-sulphate-rich clay and silt deposits bordering or covering the aquifers or from relict seawater trapped in fine-grained sediments or fractures and fissures in bedrock. The effect of bedrock composition is seen in the Peräpohja schist area, and in the southeastern part of the Ladoga-Bothnian Bay sulphide mineral potential belt and in the nearby Outokumpu sulphide mineral district. The Pori-Vammala-Tampere sulphide mineral potential belt is also characterized by comparatively high SO_4 concentrations in groundwater. These geological features are reflected in spring and drilled bedrock well categories as well. The southward increasing background concentrations in spring waters suggest an anthropogenic impact on near-surface groundwaters.

Geological Survey of Finland

Hydrogeochemical map



Springs
Lähteet



Bedrock wells
Porakaivot

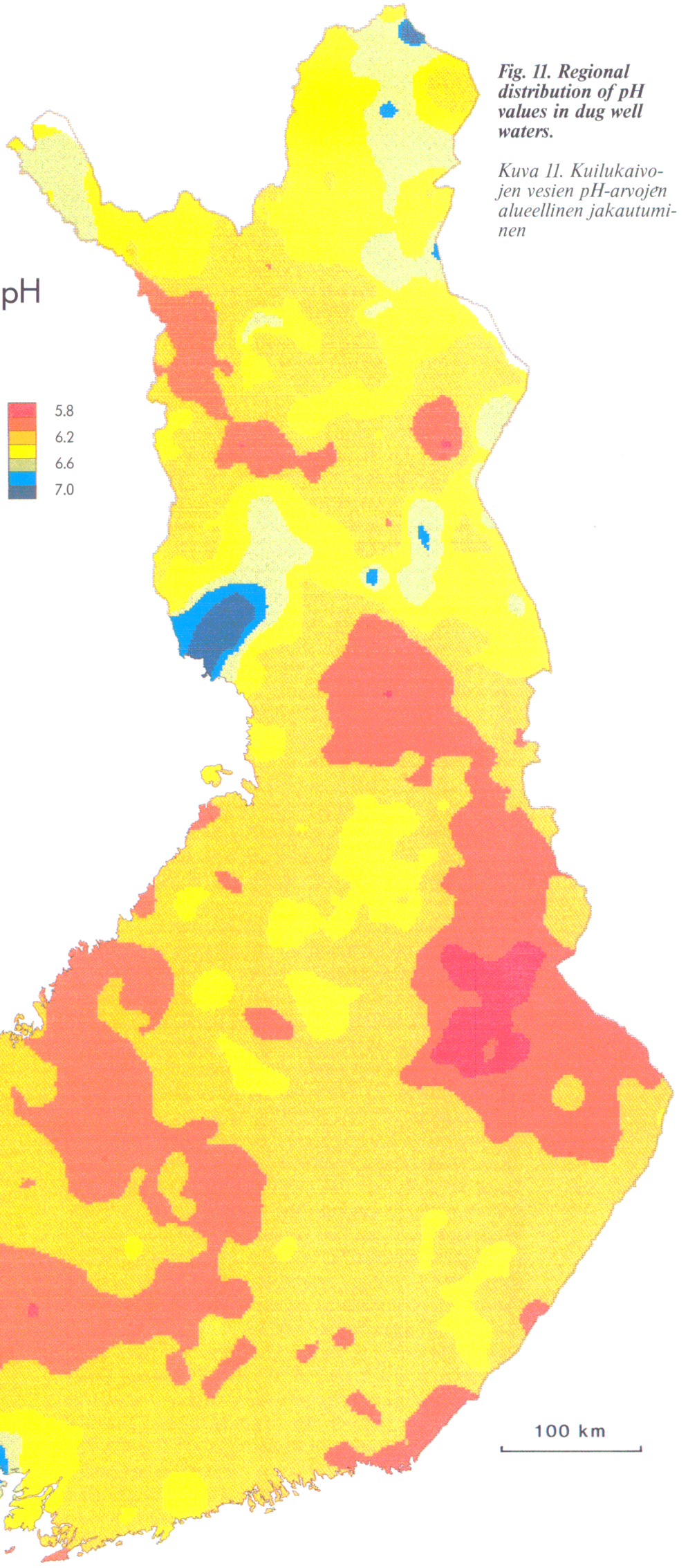


Fig. 11. Regional distribution of pH values in dug well waters.

Kuva 11. Kuilukaivojen vesien pH-arvojen alueellinen jakautuminen

Geological Survey of Finland

Hydrogeochemical map

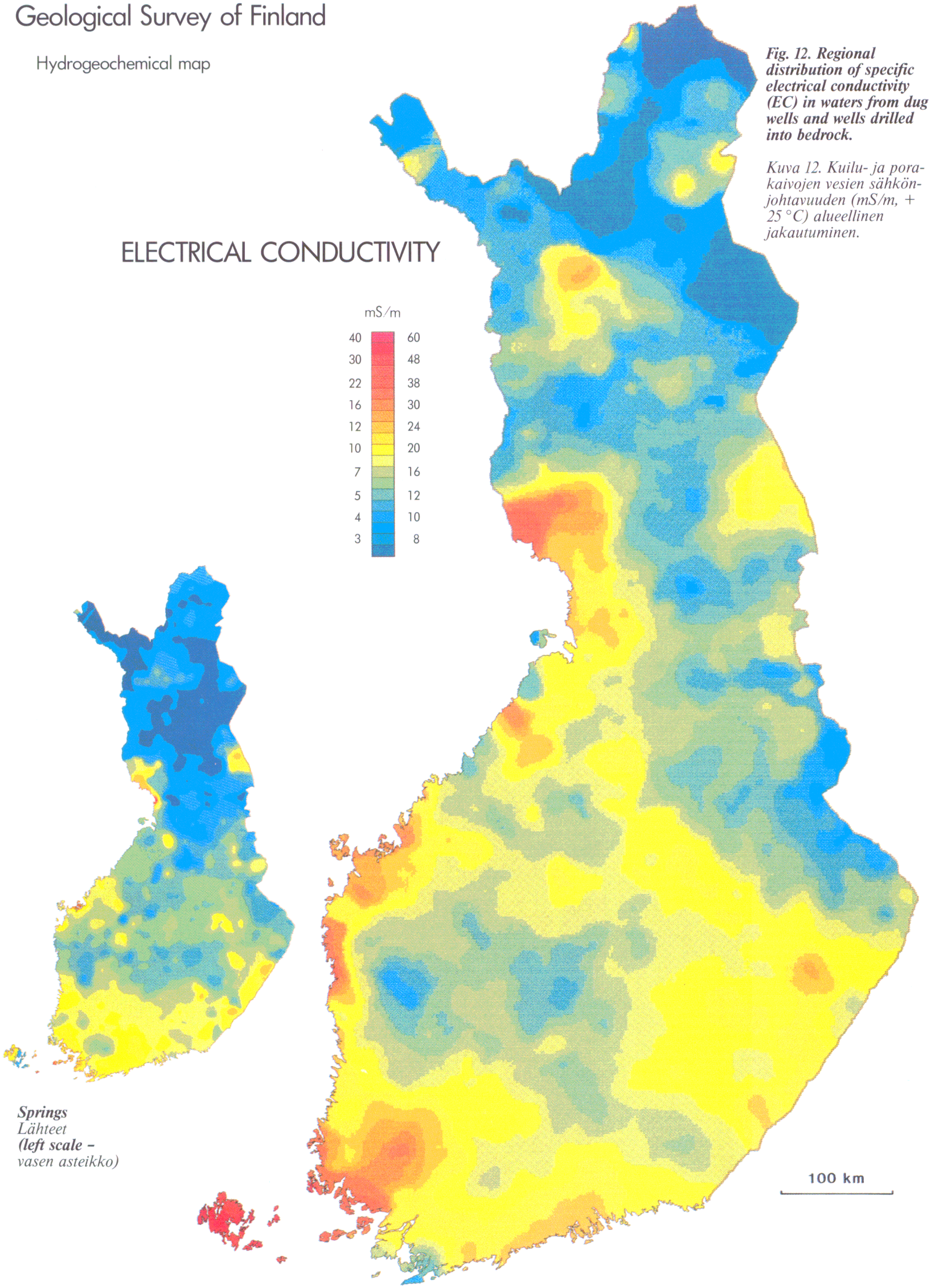


Fig. 12. Regional distribution of specific electrical conductivity (EC) in waters from dug wells and wells drilled into bedrock.

Kuva 12. Kuilu- ja porakaivojen vesien sähkönjohtavuuden (mS/m, + 25 °C) alueellinen jakautuminen.

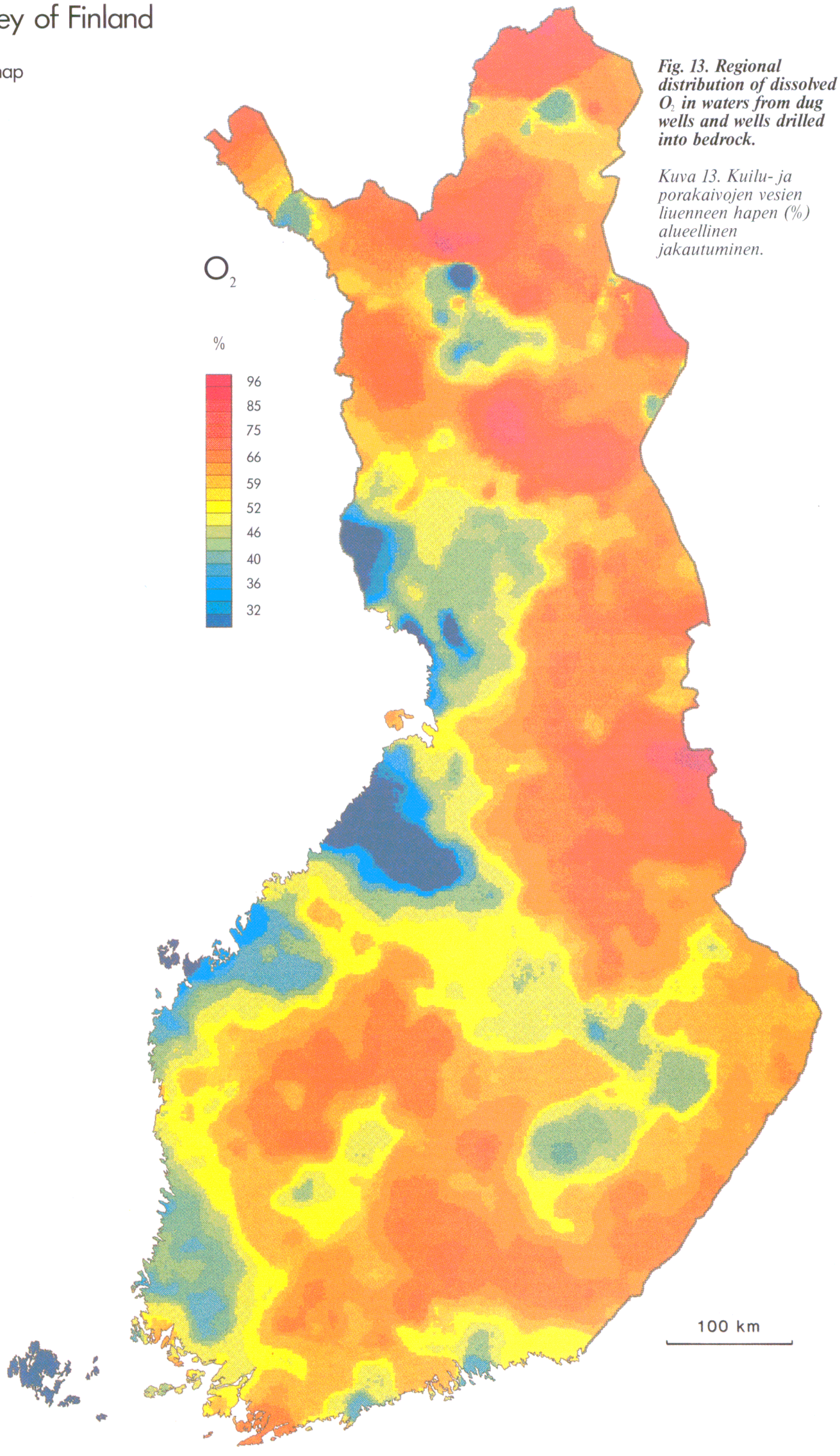


Fig. 13. Regional distribution of dissolved O_2 in waters from dug wells and wells drilled into bedrock.

Kuva 13. Kuilu- ja porakaivojen vesien liuenneen hapen (%) alueellinen jakautuminen.

Geological Survey of Finland

Hydrogeochemical map

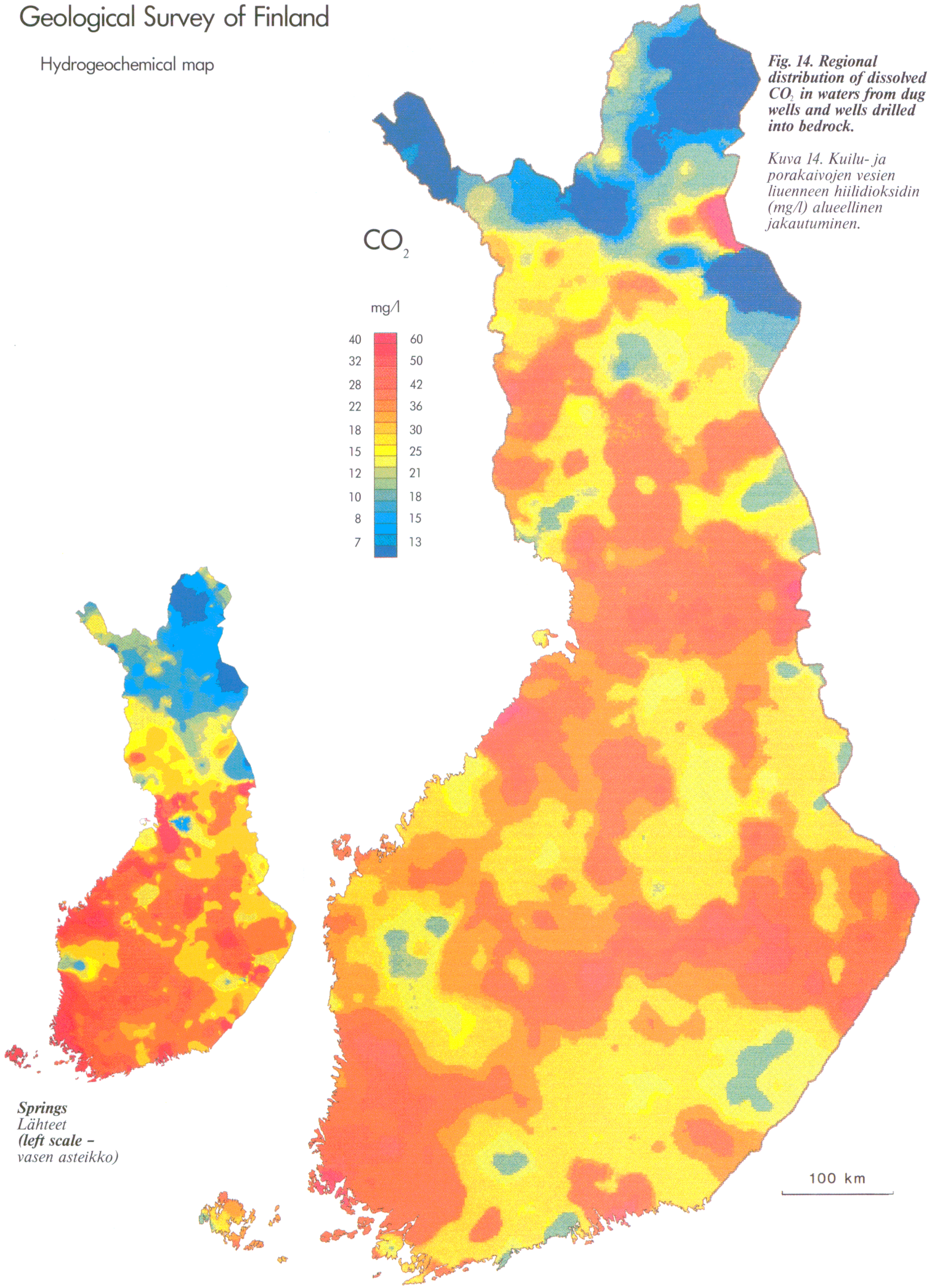


Fig. 14. Regional distribution of dissolved CO_2 in waters from dug wells and wells drilled into bedrock.

Kuva 14. Kuilu- ja porakaivojen vesien liuenneen hiilidioksidin (mg/l) alueellinen jakautuminen.

Springs
Lähteet
(left scale –
vasen asteikko)

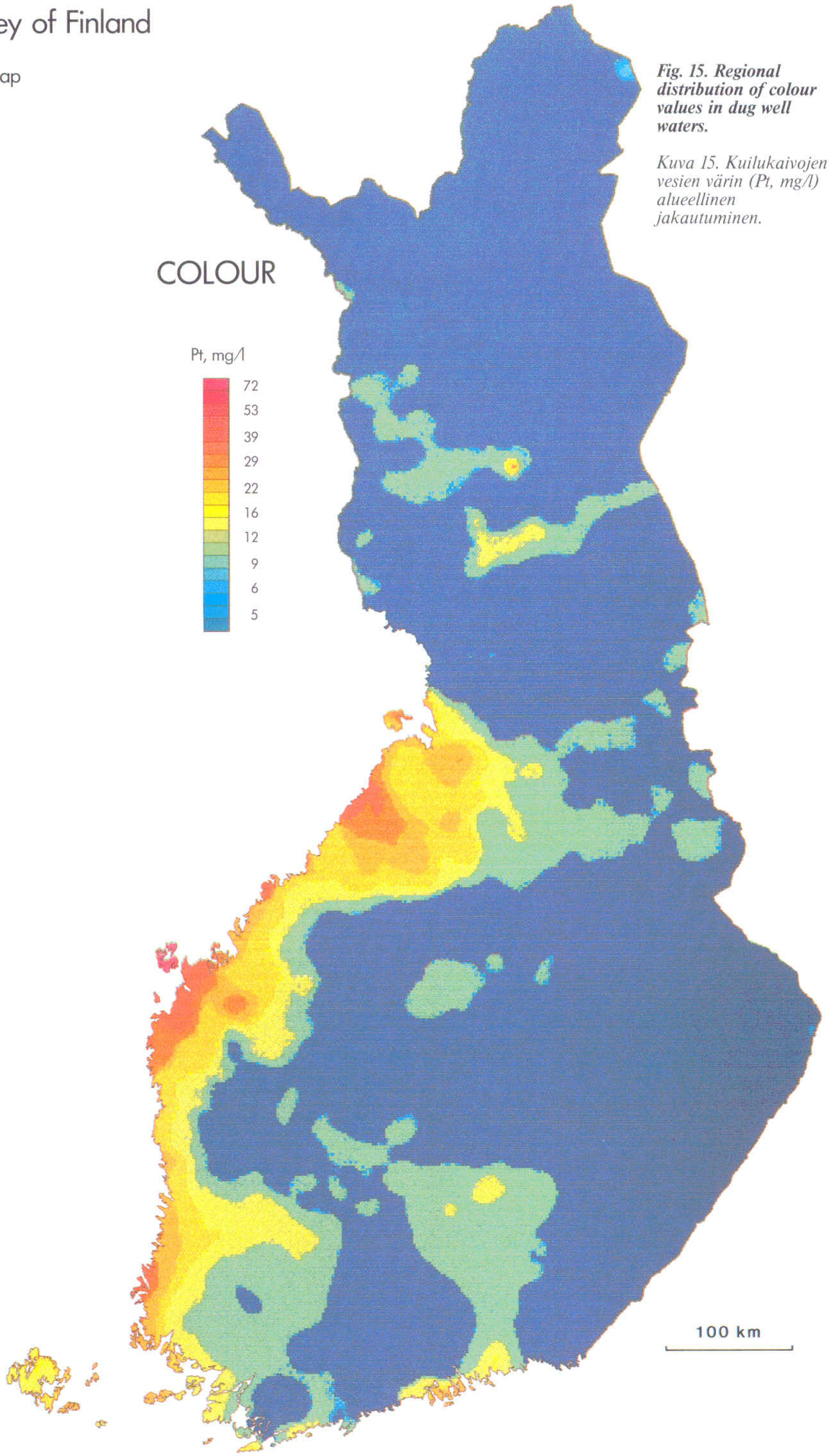


Fig. 15. Regional distribution of colour values in dug well waters.

Kuva 15. Kuilukaivojen vesien värin (Pt, mg/l) alueellinen jakautuminen.

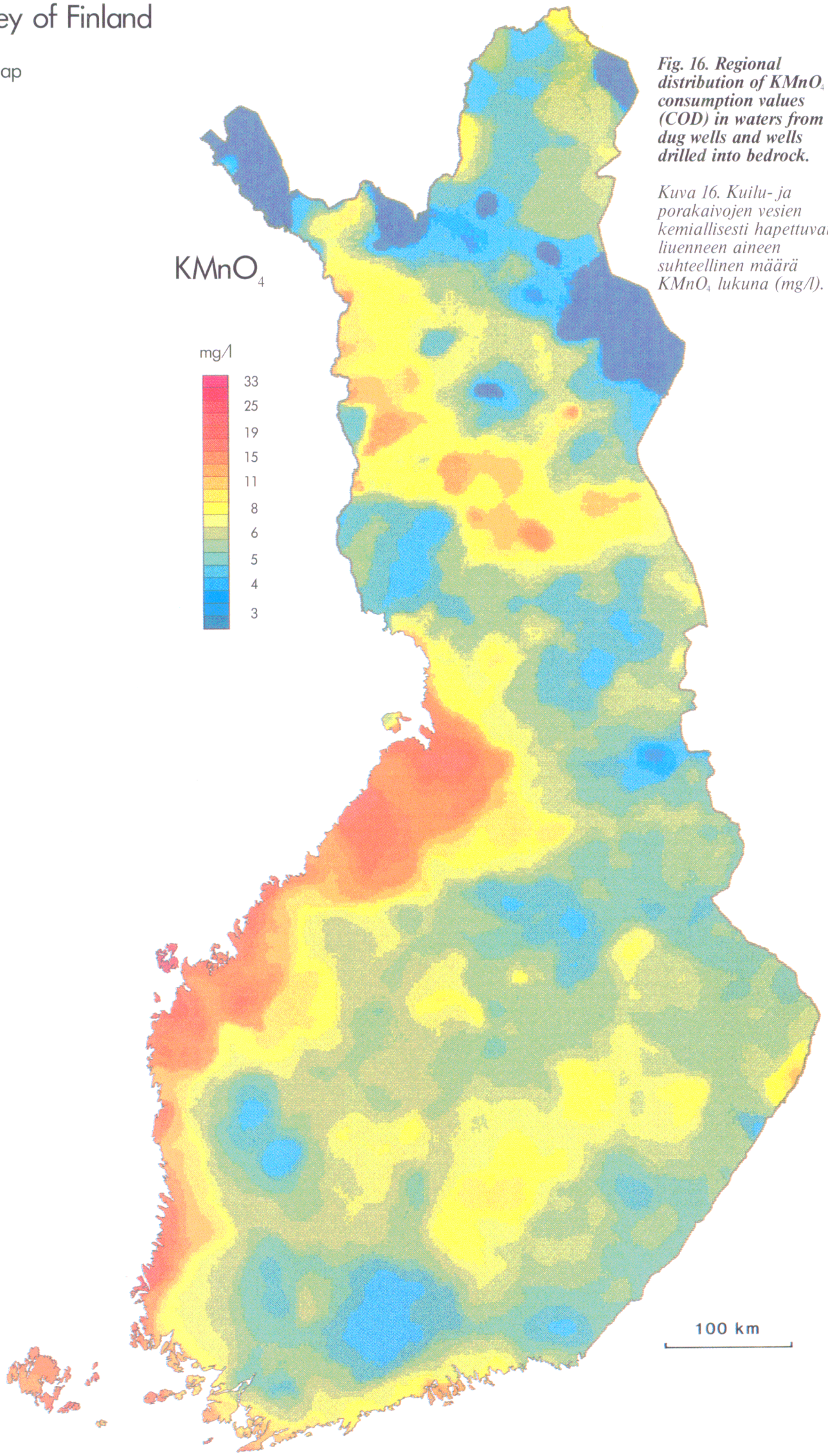


Fig. 16. Regional distribution of $KMnO_4$ consumption values (COD) in waters from dug wells and wells drilled into bedrock.

Kuva 16. Kuilu- ja porakaivojen vesien kemiallisesti hapettuvan liuenneen aineen suhteellinen määrä $KMnO_4$ lukuna (mg/l).

Geological Survey of Finland

Hydrogeochemical map

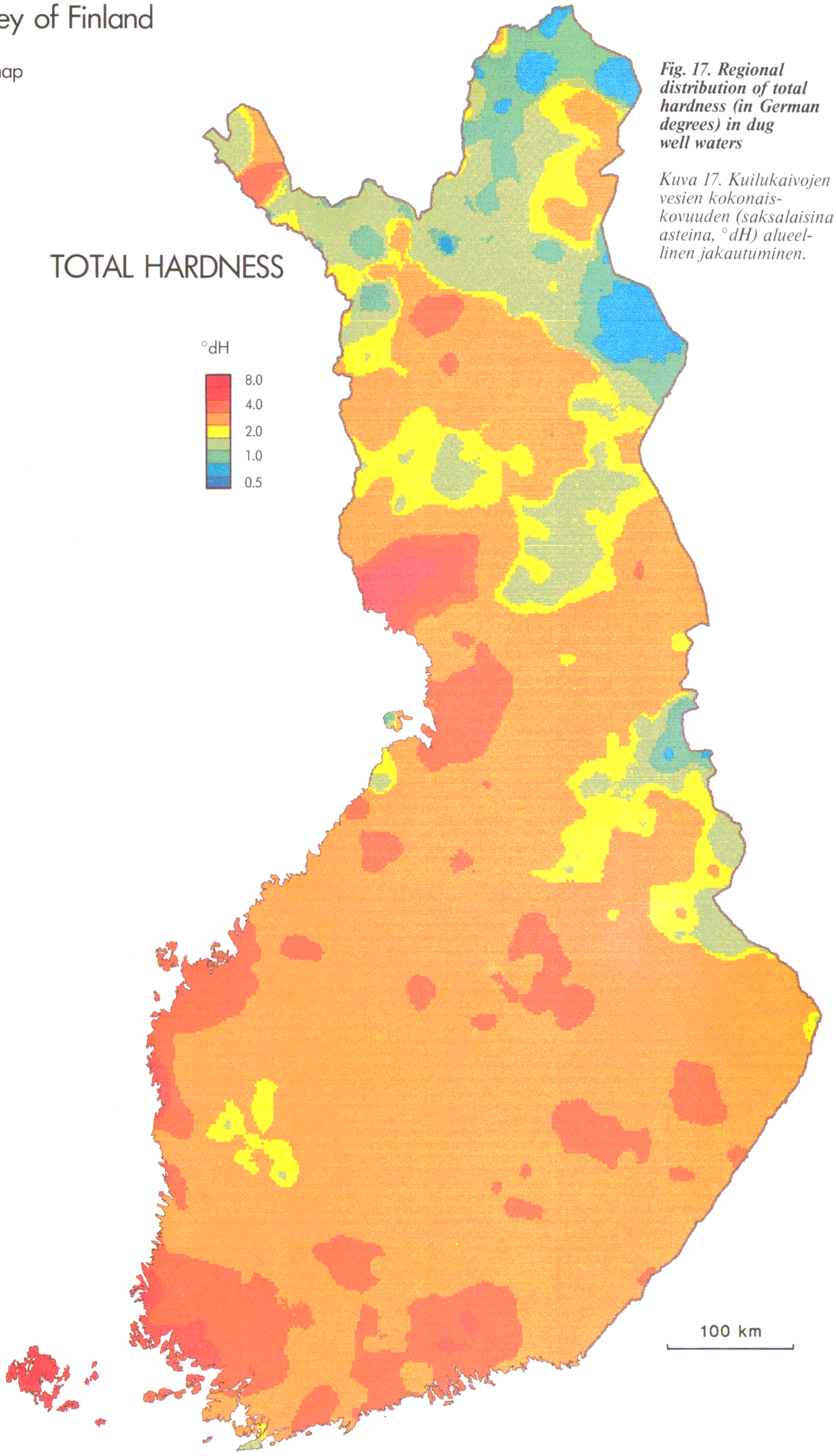


Fig. 17. Regional distribution of total hardness (in German degrees) in dug well waters

Kuva 17. Kuilukaivojen vesien kokonaiskovuuden (saksalaisina asteina, °dH) alueellinen jakautuminen.

Geological Survey of Finland

Hydrogeochemical map

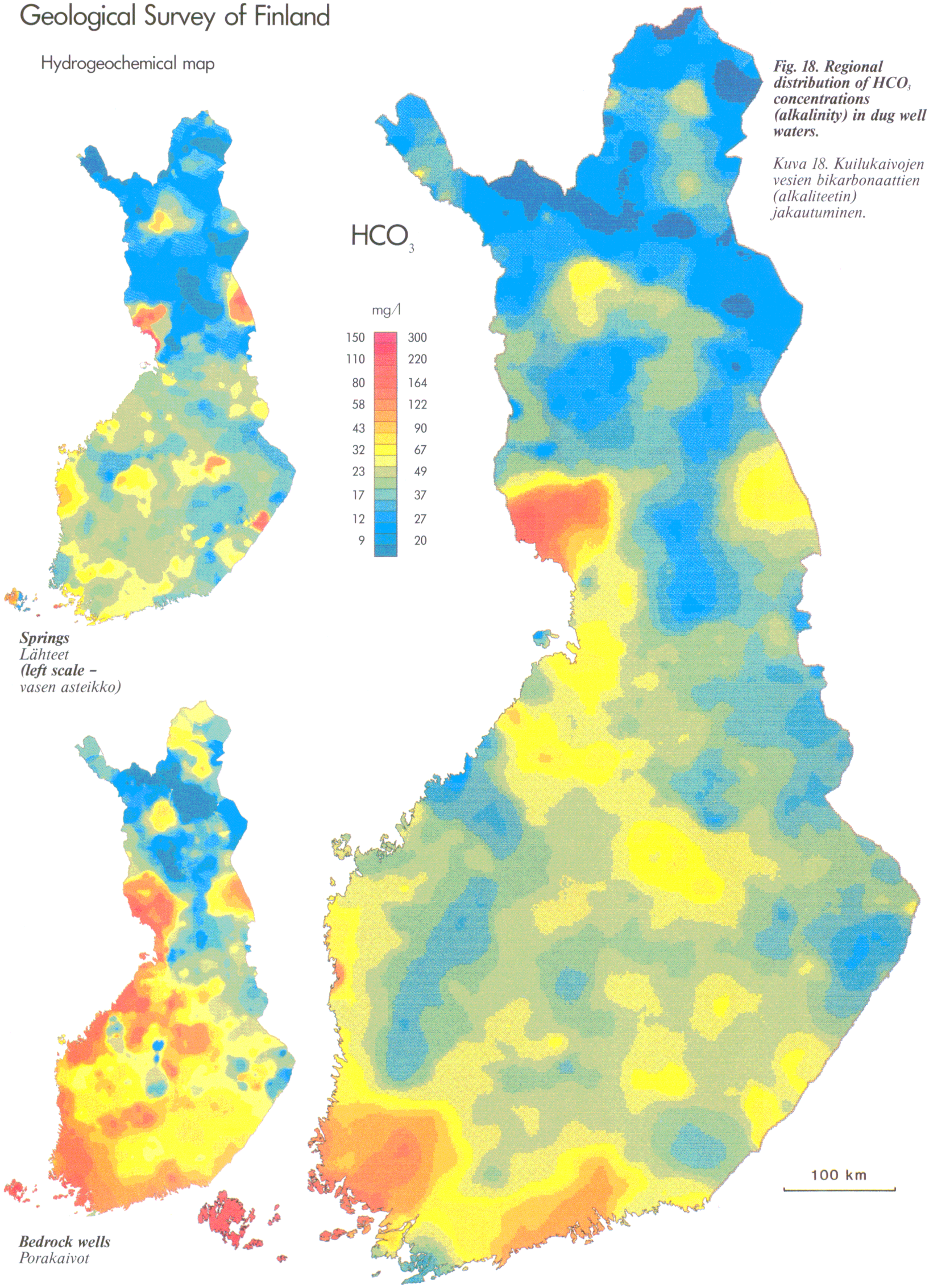


Fig. 18. Regional distribution of HCO_3 concentrations (alkalinity) in dug well waters.

Kuva 18. Kuilukaivojen vesien bikarbonaattien (alkaliteetin) jakautuminen.

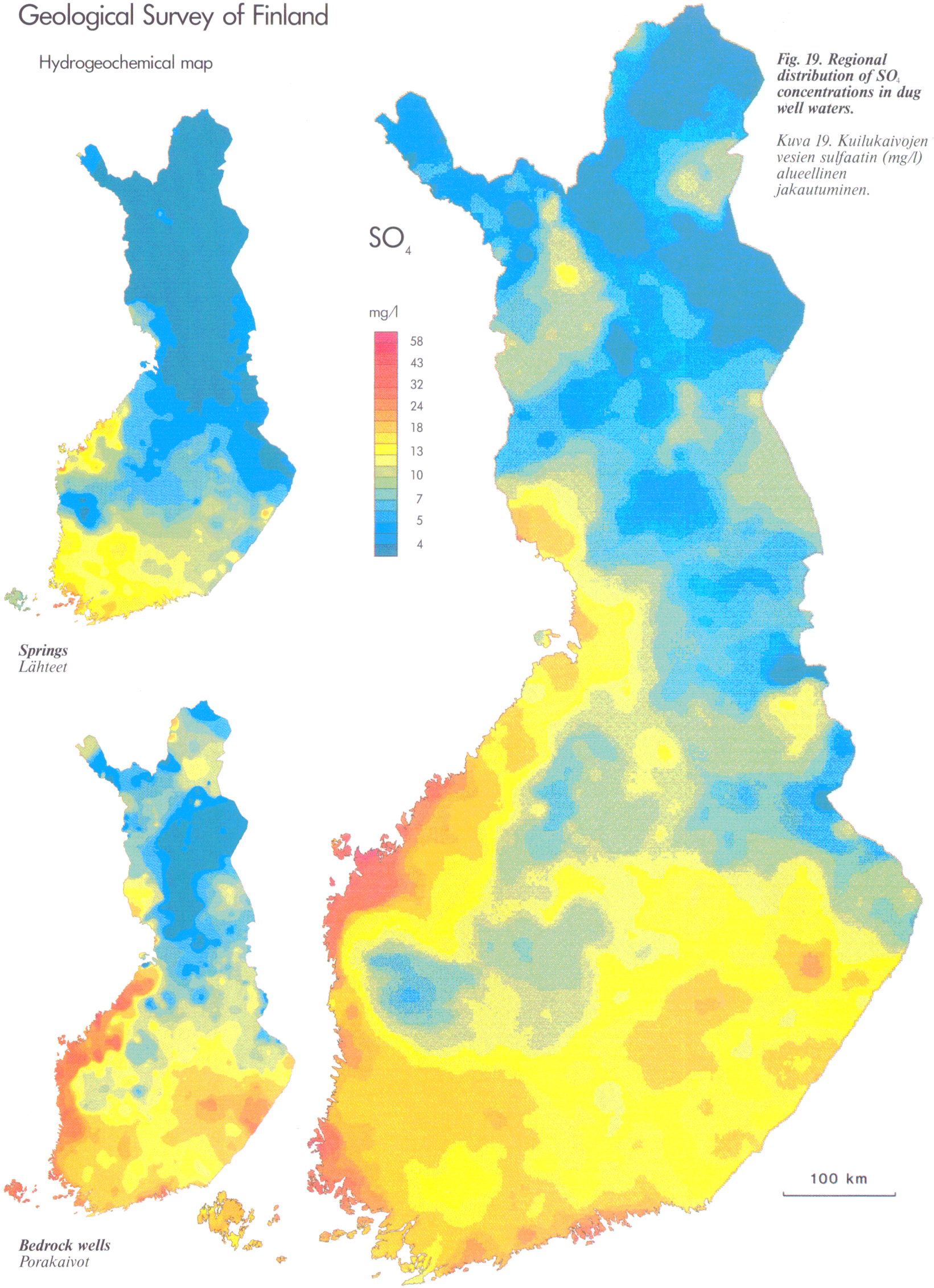


Fig. 19. Regional distribution of SO_4 concentrations in dug well waters.

Kuva 19. Kuilukaivojen vesien sulfaatin (mg/l) alueellinen jakautuminen.

The regional distibution of chlorides in water from dug wells does not indicate any clear correlation with bedrock composition (Fig. 20). This is fully understandable as minerogenic Cl sources are meagre. The effect of present or relict seawater is notably strong in drilled bedrock wells in some parts of the west coast and in the archipelago, where Cl concentrations are elevated. The marine effect seems not to be as conspicuous in dug well waters. Marine chlorides are transported by air to the level of 0.5 to 1.7 mg/l in groundwater throughout the country (cf. Table 1), while the concentrations above that level in the shallow groundwater of inland areas derive solely from anthropogenic pollution. Since lithologic sources of chlorides are very scant for shallow groundwater, chlorides are good indicators of pollution if only the marine sources can be excluded. In the spring category there are sporadically higher Cl concentrations but there is a general decrease in concentrations northwards. In the northernmost tip of the country Cl concentrations increase again due to airborne aerosols from the Arctic Ocean. In the drilled bedrock wells the effect of sea water is clearly seen as higher Cl contents along the coast.

The regional distribution of fluorides is closely related to the geological environment (Figs. 21 and 22). The F concentrations in groundwater are 10–15 times higher in the areas of rapakivi granite and related anorogenic coarse-grained K-rich granites than in other rock type areas.

The F concentrations are highest in the western part of the southeastern Wiborg rapakivi area, slightly lower in the southwestern rapakivi area in Laitila and Vehmaa and lowest in the rapakivi area of the archipelago of Åland (cf. Fig. 36 and 42). Many high F concentrations in groundwater are also found on the west coast, around the town of Vaasa, in an area composed of granodiorites. Southwards, sporadically high concentrations are encountered in a broad coastal zone that extends down to Pori and joins the Laitila rapakivi pluton. The bedrock is composed of granodiorites, mica gneisses and mica schists intermingled with granitic veins. The small Isojoki granite pluton in the same area is distinctly revealed by a few higher F concentrations. Distinct F anomalies in groundwater, are also encountered, for example, in the large granite pluton in western Lapland, and in the Pomovaara and Nattanen area more to the north and in the small Onas and Obbnäs areas on the south coast, which are composed of anorogenic rapakivi-type granites or other coarse-grained, K-rich granites. There are also a few sporadically high F values in the large central Finnish granitoid pluton, which is composed of acid plutonic rocks and granodiorites, and in the schist belt of the Tampere region to the south of it, where frequent granitic intrusions are intermingled with mica schists, gneisses and amphibolites.

The high F concentrations in the groundwater of the Laitila rapakivi pluton continue southwards and southeastwards beyond the limits of the batholith. Since this is also the direction in which the continental ice sheet moved, the elevated concentrations are presumably partly due to transported rapakivi material mixed with till. Some of the anomalous concentrations undoubtedly derive from the local bedrock, which is composed of Svecokarelidic schists and granites. Limestone may also contain F-rich minerals as is suggested by a detailed study of fluorides in groundwater in the environment of the Parainen limestone quarry. All the regional hydrogeochemical features discussed above are also present in the spring, dug well and drilled bedrock well categories, although the water from bedrock wells shows sporadically high F concentrations all over the country (Fig. 22).

Silica concentrations vary rather little regardless of the type of groundwater and aquifer. Consequently, the concentrations are only slightly lower in spring water than in water from bedrock wells (Fig. 23). No clear correlation seems to exist between the SiO_2 concentrations in water and the bedrock composition. A faint anomalous zone can, however, be detected in some parts of the Ladoga-Bothnian Bay sulphide mineral potential belt.

Nitrate concentrations are not related to the geological composition of the bedrock or soil. The sources of the elevated nitrate concentrations are solely of anthropogenic origin (Fig. 24). The type of aquifer may, however, play a role, for example, sandy aquifers are more apt to become contaminated than confined aquifers covered with clay. On the other hand, water in wells dug into till deposits seems to be slightly more contaminated in terms of NO_3 than the water in sand or gravel aquifers (Lahermo 1987). In the category of spring waters, NO_3 values are elevated in the southwestern part of the First Salpausselkä ice marginal formation, which is mainly composed of pervious glaciofluvial material. In the dug well category there is a large area of higher NO_3 concentrations in the central and southeastern part of the country (Karelia and Savo) presumably mainly due to the poor condition of private wells on farms. In the old days wells were often dug near barns, dung heaps and waste tips without careful protection of the well against polluted overland flow. There are still many old stone- or wood-lined wells in which the quality of the water is deficient (Table 3).

The regional distribution of total hardness is compatible with that of calcium and magnesium (Figs. 17, 25 and 26). Therefore only the latter elements are discussed here. The distribution of Ca shows the same trends as that of the pH and EC values and HCO_3 concentrations. The Peräpohja schist belt, the western and southwestern coastal areas and the archipelago show up as distinctive features, as does the boundary between the central Lapland schist belt and the granulite complex. Magnesium has a roughly similar distribution although with some differences (Fig. 26). The schist belt in central Lapland emerges faintly as elevated Mg concentrations, while the Mg distribution brings out the Ladoga-Bothnian Bay sulphide mineral potential belt more clearly than calcium.

The regional distribution pattern of sodium is closely correlated with that of Cl, and of the major cations (Ca, Mg) and the anion (HCO_3) (Fig. 27, cf. also Fig. 20). The schist belt in central Lapland and the Ladoga-Bothnian Bay belt are only faintly seen on the map. Relict sea salts are an important source of sodium on the coast and in the archipelago although anthropogenic sources can never be ruled out in well waters. The distribution of potassium is totally different from that of sodium (Fig. 27) and the coastal areas are not so pronounced. Anomalously high concentrations are encountered in different parts of the

		Dug wells with					
		concrete			stone or wooden linings		
		a.m.	m.	n.	a.m.	m.	n.
pH		6.4	6.3	594	6.2	6.2	234
El. conductivity (EC)	mS/m	22.6	19.3	599	19.0	15.8	235
HCO_3	mg/l	60	50	530	50	40	173
$KMnO_4$ consumption	mg/l	10.8	7.4	530	13.5	9.8	173
NO_3	mg/l	16.5	10.0	530	21.7	15.2	173
Cl	mg/l	16.0	9.0	529	15.7	9.6	173
SO_4	mg/l	19.3	14.7	529	18.7	16.0	173
Total hardness	°dH	4.1	3.4	530	3.5	3.0	173
Na	mg/l	9.5	6.5	529	7.8	6.5	173
K	mg/l	9.2	4.6	529	12.8	6.0	173

Table 3. Comparision of some chemical characteristics of water from dug wells provided with concrete rings and stone or wood linings in eastern and southeastern Finland (provinces of Mikkeli, Kuopio and North Karelia). a.m., arihmetic mean; m., median; n, number of wells.

Taulukko 3. Veden laatu betonirenkailla ja kivi- tai puukehyksillä varustetuissa kuilukaivoissa Itä- ja Kaakkois-Suomessa (Mikkelin, Kuopion ja Pohjois-Karjalan lääneissä). a.m., aritmeettinen keskiarvo; m., mediaani; n., näytteiden lukumäärä.

country without any clear correlation with the bedrock composition. However, it seems plausible that many elevated K concentrations emerge from areas composed of mica schists. Potassium also derives from a large range of human activities and is thus one of the most sensitive indicators of contamination (Lahermo 1987).

Iron and manganese are the most abundant of the heavy metals. The highest concentrations are found in the western and southwestern coastal areas (Figs. 29 and 30), where confining aquifer conditions and dissolved organic material in water cause oxygen depletion (cf. Figs. 14–16). Consequently, the aquifer type, e.g. the occurrence of peat and fine-grained sediments, the condition of the well and pollution are more pronounced contributors to the Fe and Mn concentrations than the lithological environment.

The zinc, copper and nickel values are distributed without any distinct systematic relation to geological or any other environmental factors (Figs. 31, 32 and 33). The occasionally slightly elevated concentrations may also be due to contamination caused by the mains and pipes, pumps and containers in the wells underground and in houses, or by the Ruttner type sampler used. For example, the regional distribution patterns of Cu concentrations in spring, dug well and drilled bedrock well categories do not show any similarity with each other. Nor do the anomalously high concentrations correlate systematically with the known mineralizations and ore potential belts, except for some separate groups of higher Zn and Cu values. The most conspicuous anomalous areas are located in a large belt between the mines of Orijärvi and Eräjärvi in southern Finland and between the mines of Lahnaslampi and Mustavaara in northeastern Finland (Figs. 31–32).

A few slightly elevated concentrations of lead and cadmium, considered to be environmentally toxic elements, are distributed irregularly over the whole country (Fig. 34). Although mainly attributed to anthropogenic contamination at the site of sampling, there is one small anomalous area of higher Cd concentrations at Pihtipudas, to the north of Kolimajärvi, central Finland, that seems to refer to mineralizations around the Pyhäsalmi Zn-Cu mining area. Cadmium anomalous areas do not, however, correlate with Zn anomalies although these elements correlate with each other in water as shown in the calculated correlation matrices (cf. Table 4).

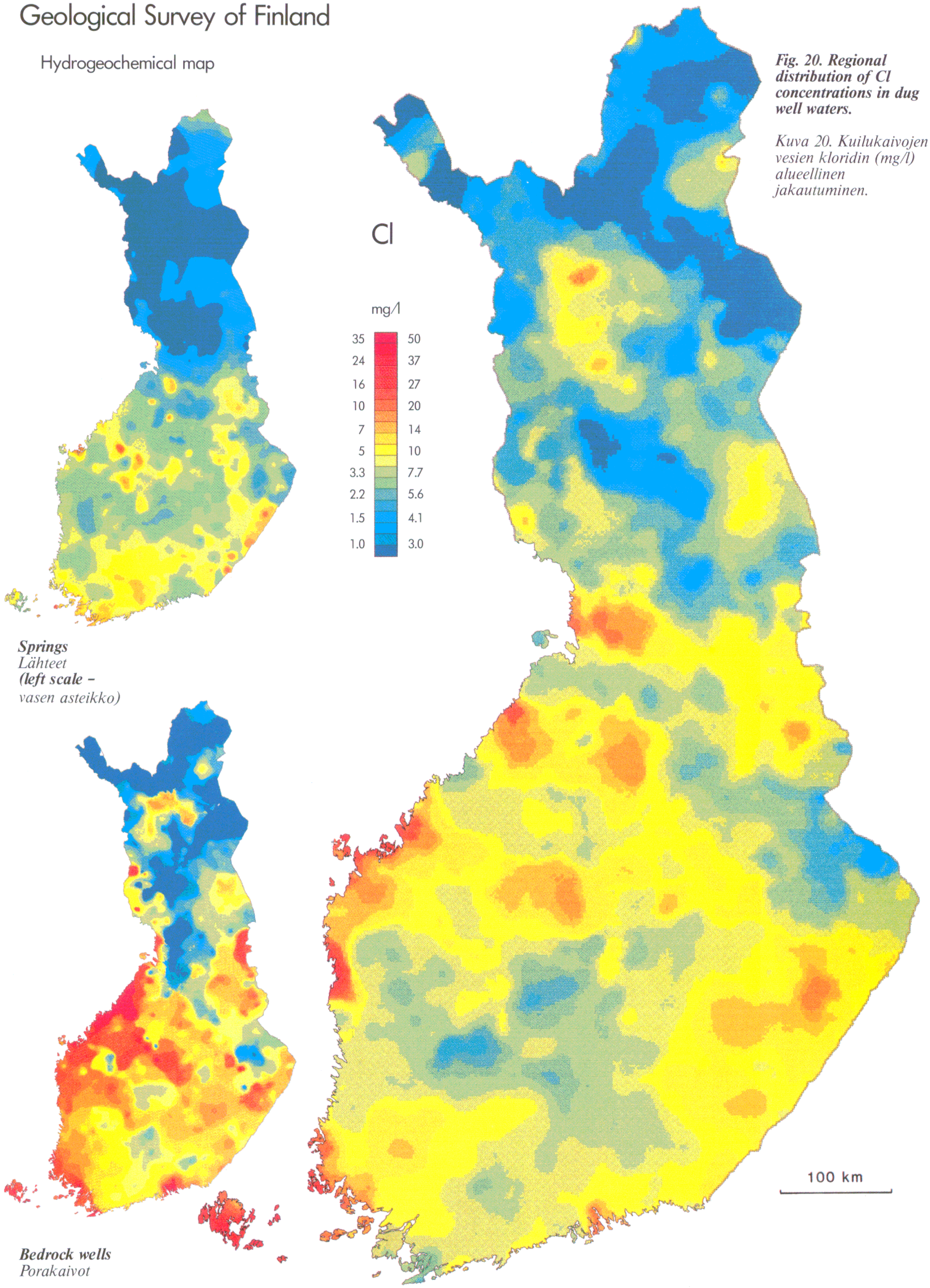
In spring and dug well waters uranium is nearly always below analytical detection limits, but in water from drilled wells conspicuous concentrations are found. The concentrations are highest in the southern part of the country in granitic bedrock areas and sometimes in areas composed of migmatitic gneisses intercalated with granite veins (Fig. 35). Somewhat higher concentrations are found in the granitic area to the north of the Tampere schist belt. Note that, in general, U concentrations are not high in rapakivi granite areas.

The few elevated U concentrations in spring and dug well waters from overburden are similarly concentrated in the southern part of the country.

The small anomaly in the unmetamorphosed Jotnian sandstones of Satakunta in western Finland is not a true one, since an analytical detection limit of 12 μg/l was accidentally applied to the samples from this particular area instead of 1–4 μg/l as used for the rest of the material.

Geological Survey of Finland

Hydrogeochemical map



Springs
Lähteet
(left scale –
vasen asteikko)

Bedrock wells
Porakaivot

Fig. 20. Regional distribution of Cl concentrations in dug well waters.

Kuva 20. Kuilukaivojen vesien kloridin (mg/l) alueellinen jakautuminen.

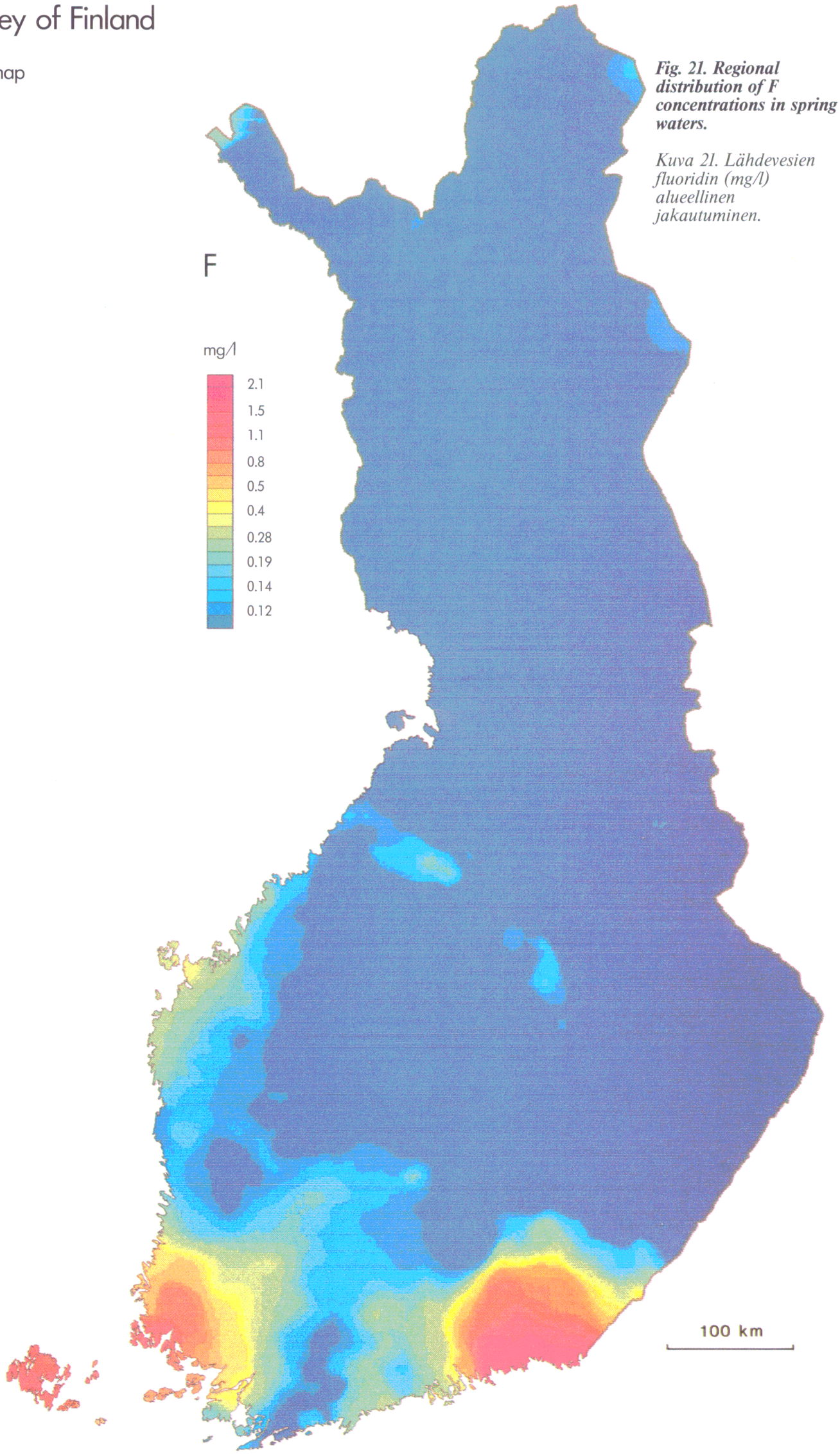


Fig. 21. Regional distribution of F concentrations in spring waters.

Kuva 21. Lähdevesien fluoridin (mg/l) alueellinen jakautuminen.

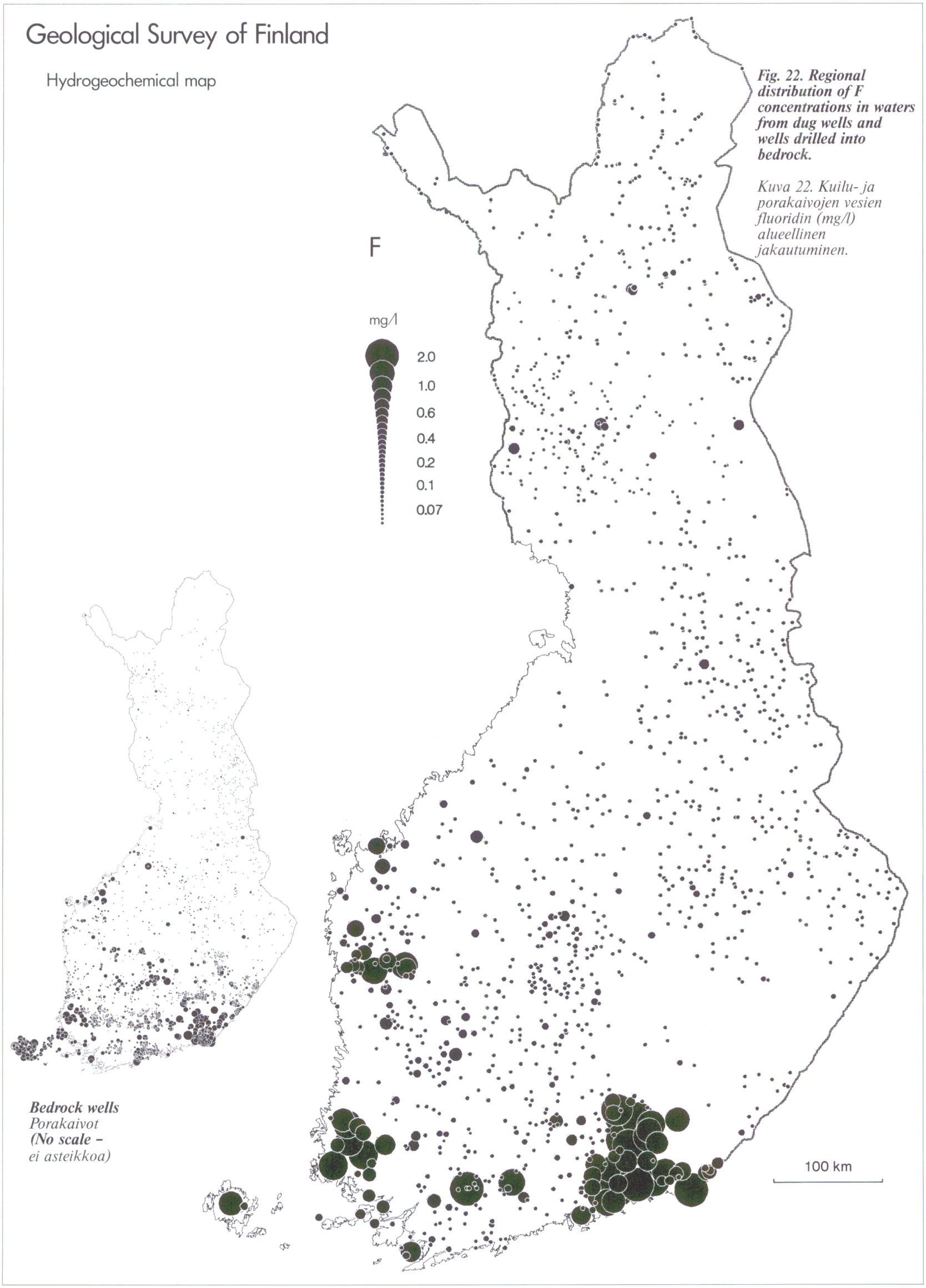
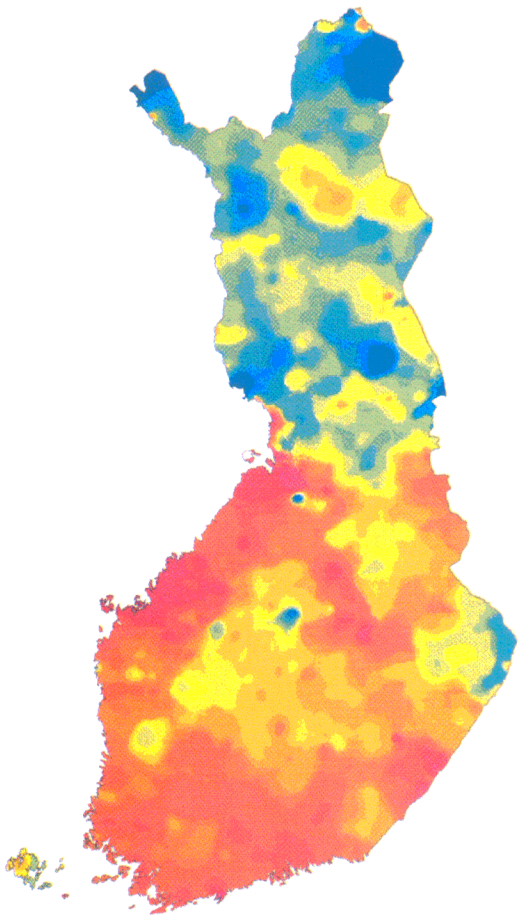


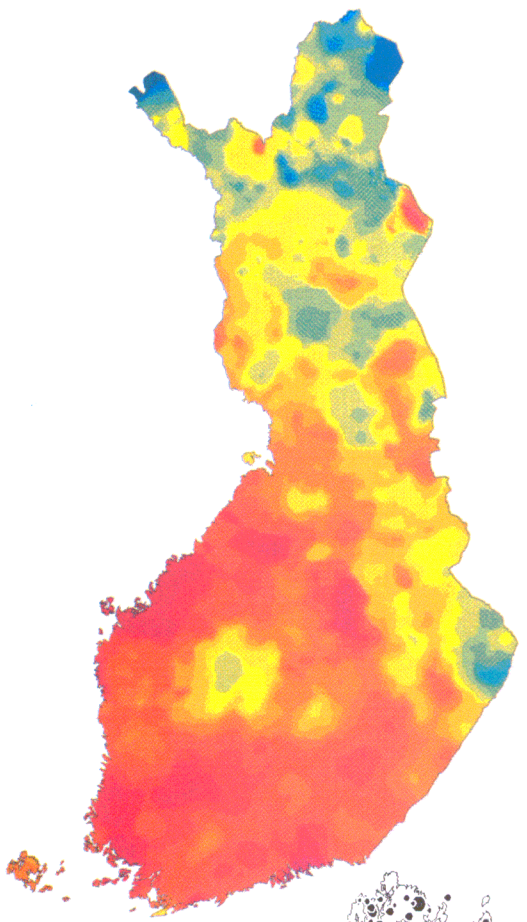
Fig. 22. Regional distribution of F concentrations in waters from dug wells and wells drilled into bedrock.

Kuva 22. Kuilu- ja porakaivojen vesien fluoridin (mg/l) alueellinen jakautuminen.

Bedrock wells
Porakaivot
(No scale –
ei asteikkoa)



Springs
Lähteet



Dug and bedrock wells
Kuilu- ja porakaivot

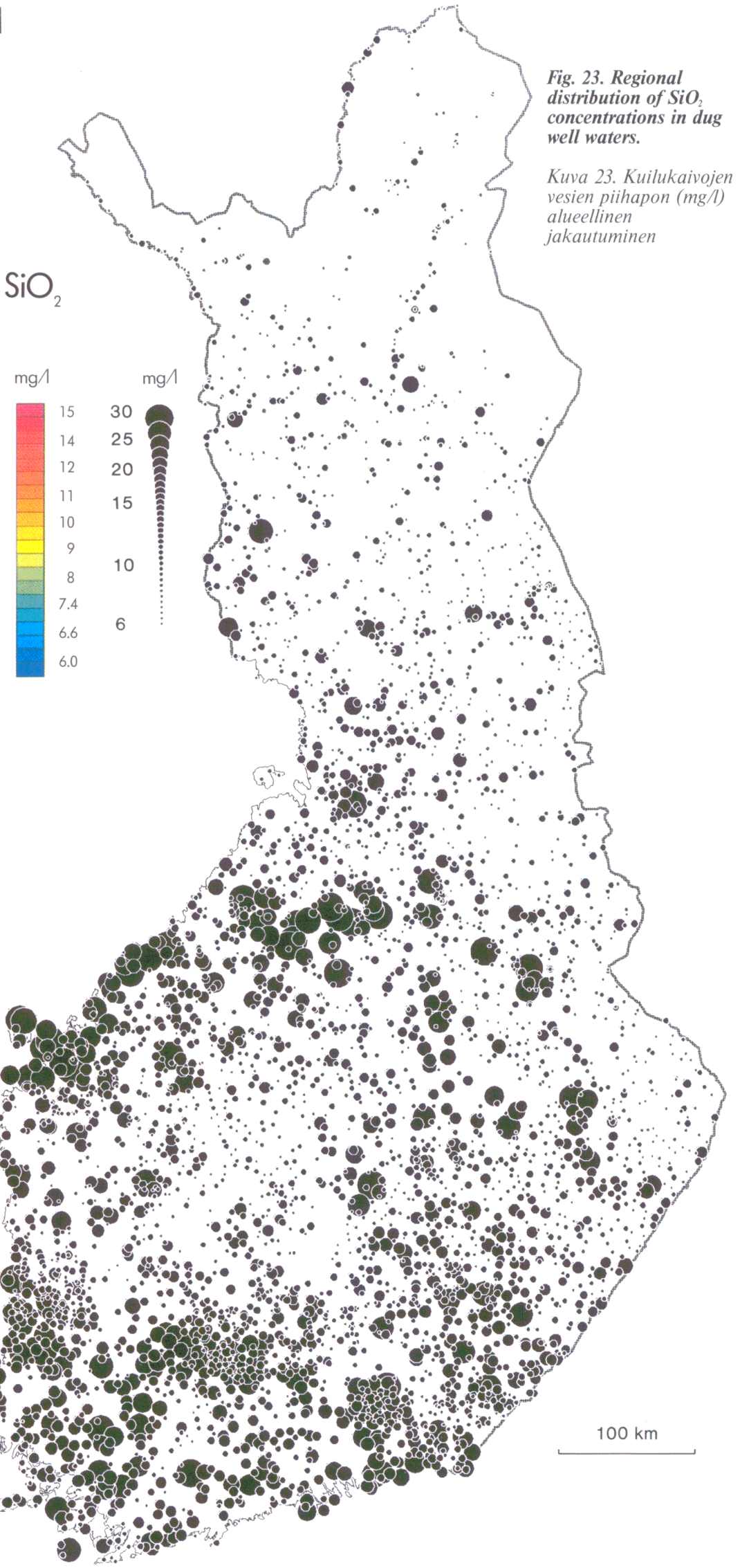


Fig. 23. Regional distribution of SiO_2 concentrations in dug well waters.

Kuva 23. Kuilukaivojen vesien piihapon (mg/l) alueellinen jakautuminen

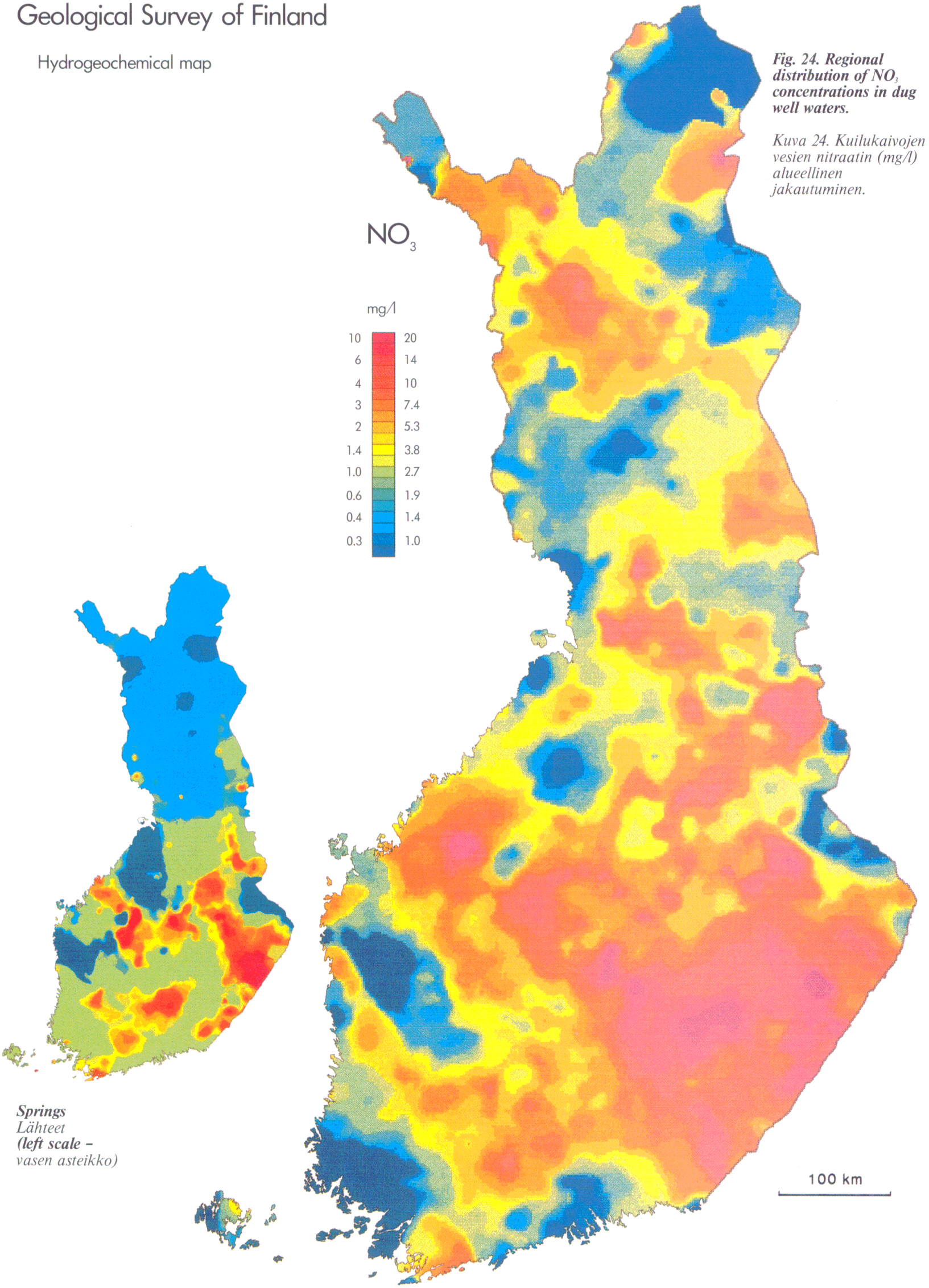


Fig. 24. Regional distribution of NO_3 concentrations in dug well waters.

Kuva 24. Kuilukaivojen vesien nitraatin (mg/l) alueellinen jakautuminen.

Springs
Lähteet
(left scale –
vasen asteikko)

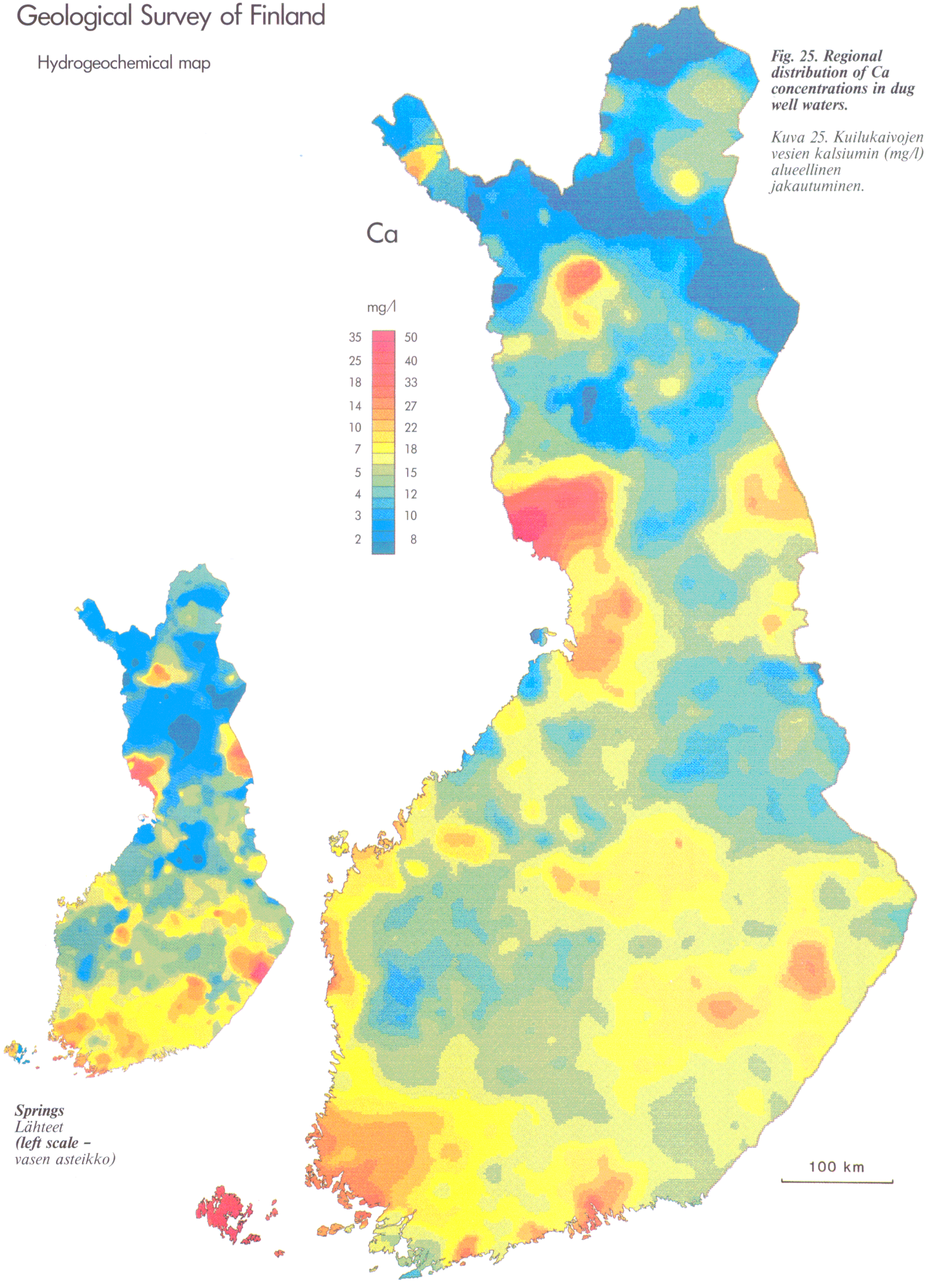


Fig. 25. Regional distribution of Ca concentrations in dug well waters.

Kuva 25. Kuilukaivojen vesien kalsiumin (mg/l) alueellinen jakautuminen.

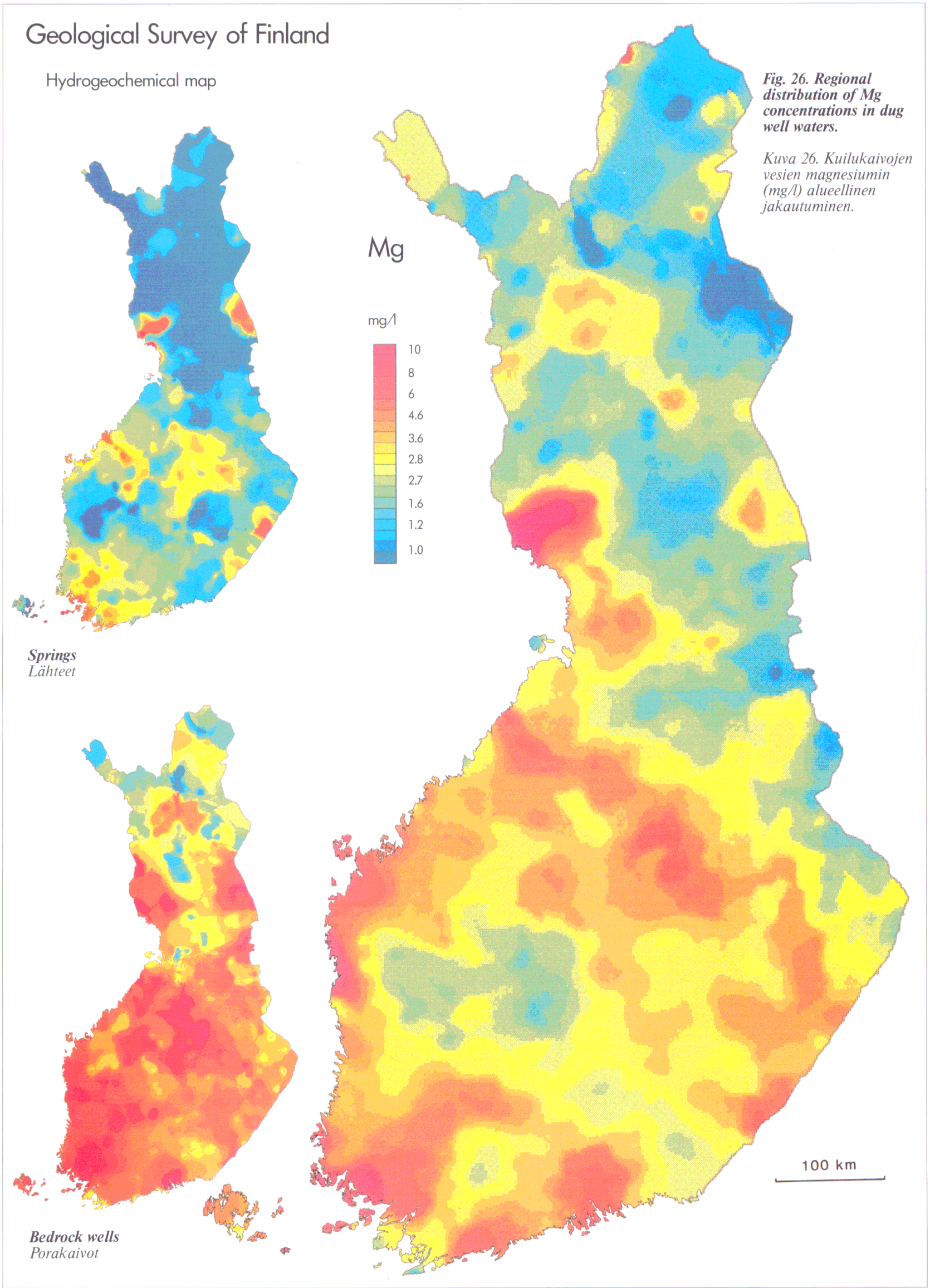
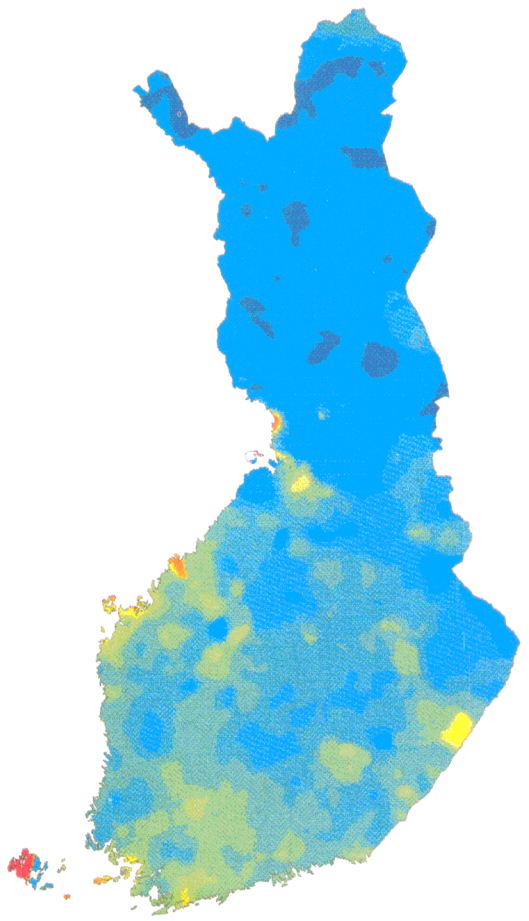


Fig. 26. Regional distribution of Mg concentrations in dug well waters.

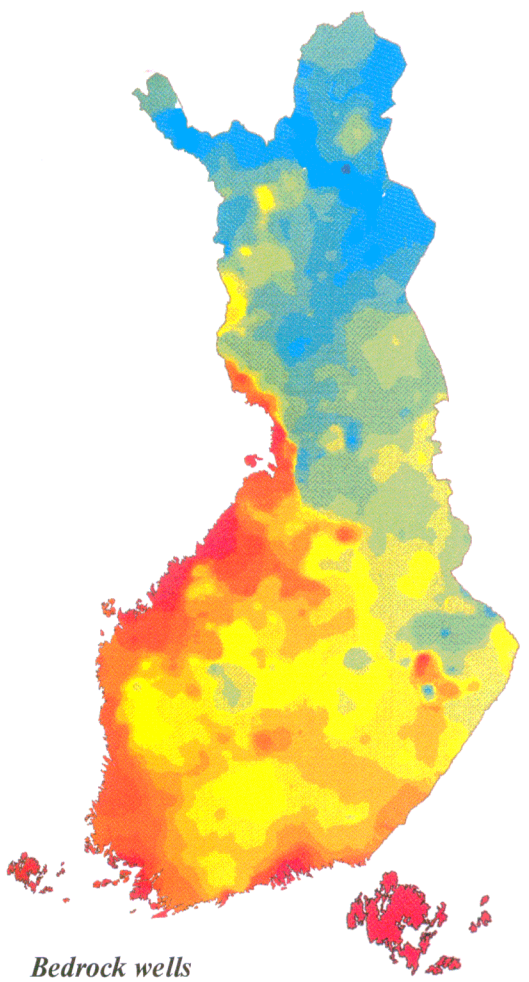
Kuva 26. Kuilukaivojen vesien magnesiumin (mg/l) alueellinen jakautuminen.

Geological Survey of Finland

Hydrogeochemical map



Springs
Lähteet



Bedrock wells
Porakaivot

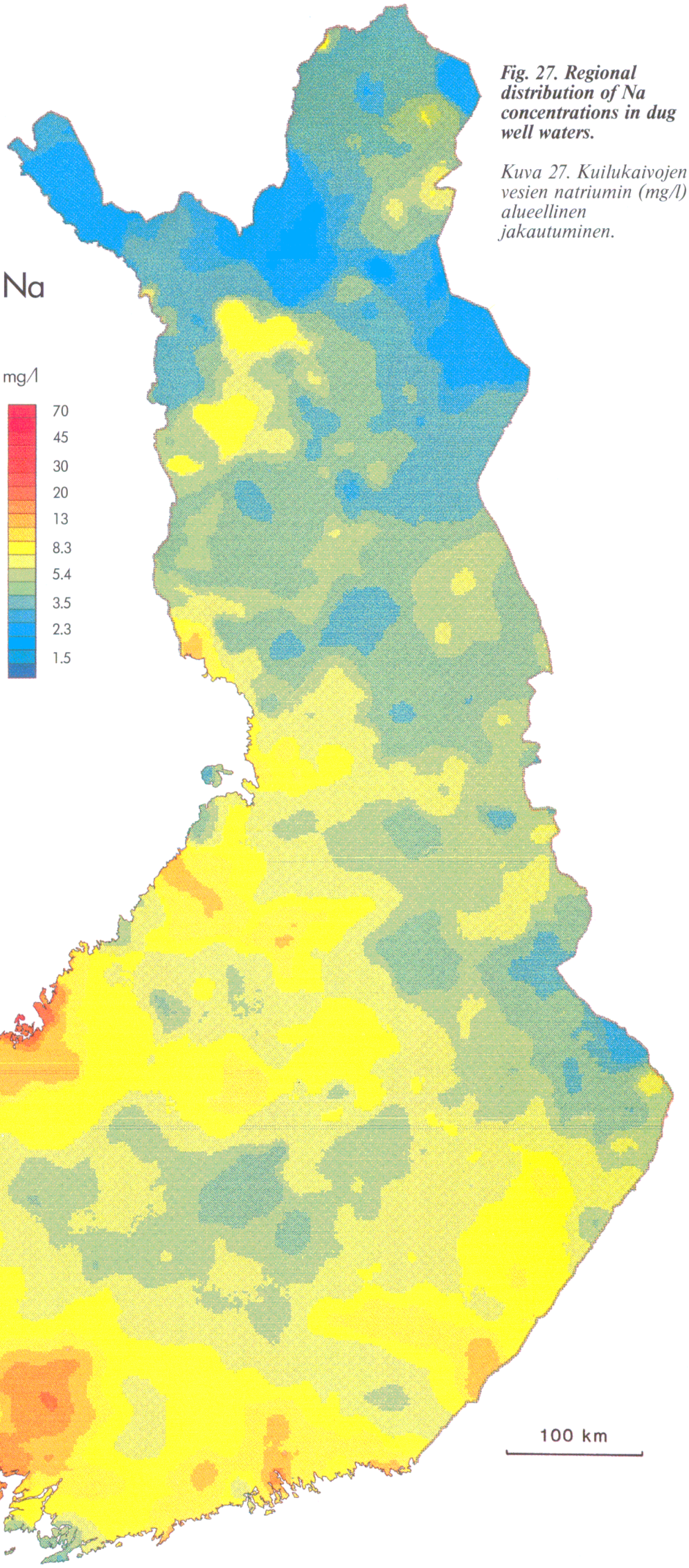


Fig. 27. Regional distribution of Na concentrations in dug well waters.

Kuva 27. Kuilukaivojen vesien natriumin (mg/l) alueellinen jakautuminen.

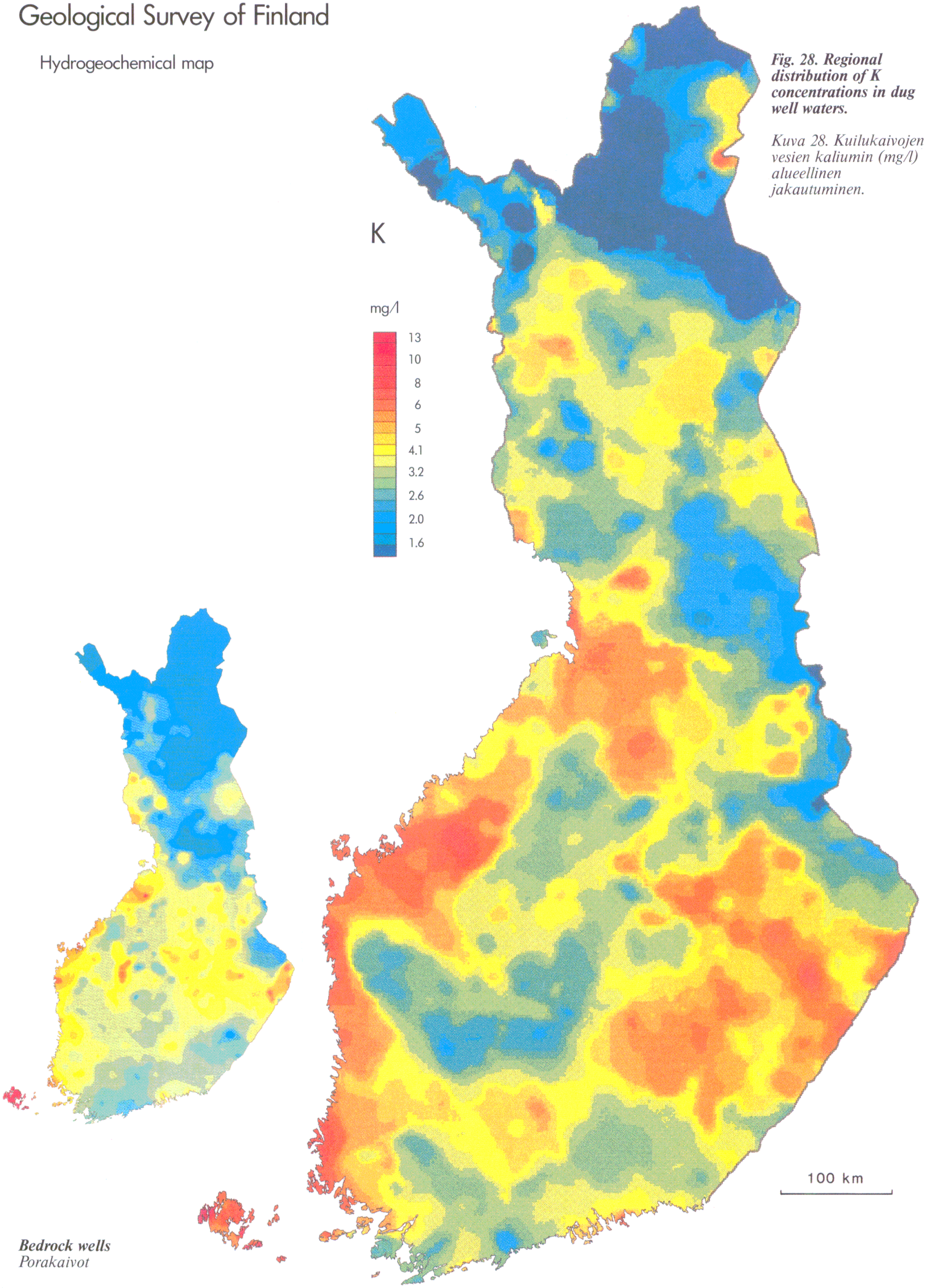


Fig. 28. Regional distribution of K concentrations in dug well waters.

Kuva 28. Kuilukaivojen vesien kaliumin (mg/l) alueellinen jakautuminen.

Bedrock wells
Porakaivot

Geological Survey of Finland

Hydrogeochemical map

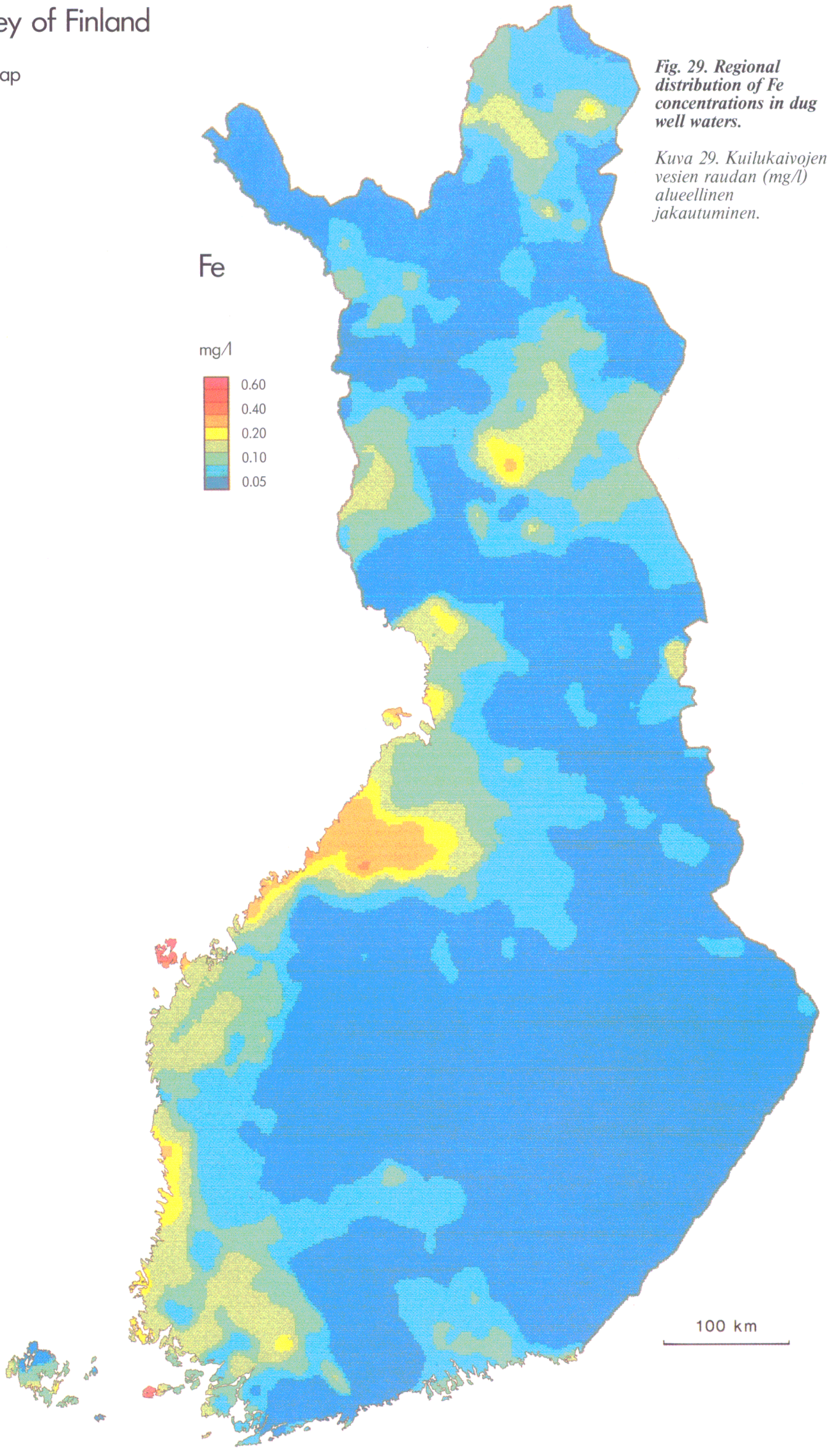


Fig. 29. Regional distribution of Fe concentrations in dug well waters.

Kuva 29. Kuilukaivojen vesien raudan (mg/l) alueellinen jakautuminen.

Geological Survey of Finland

Hydrogeochemical map

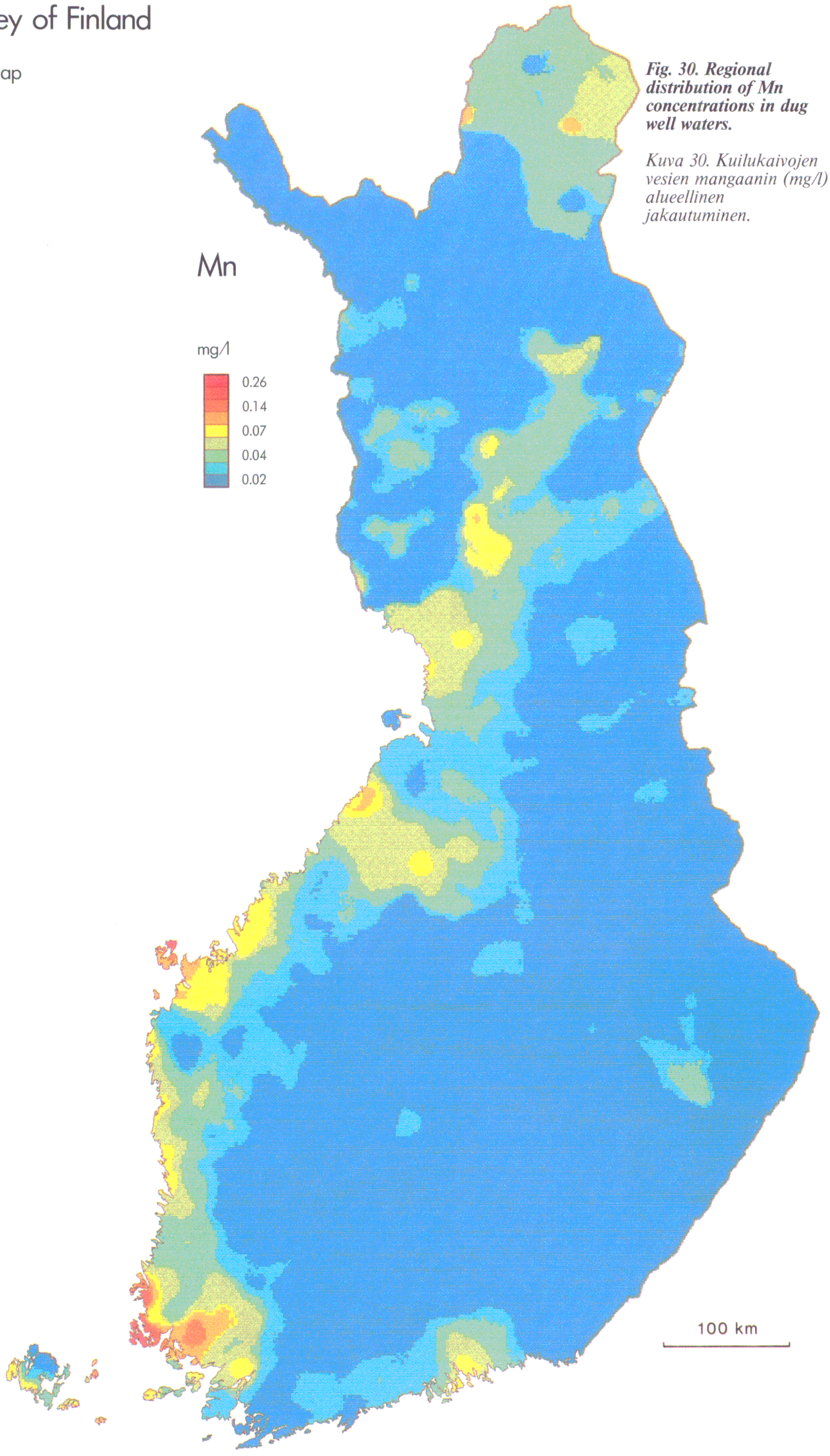


Fig. 30. Regional distribution of Mn concentrations in dug well waters.

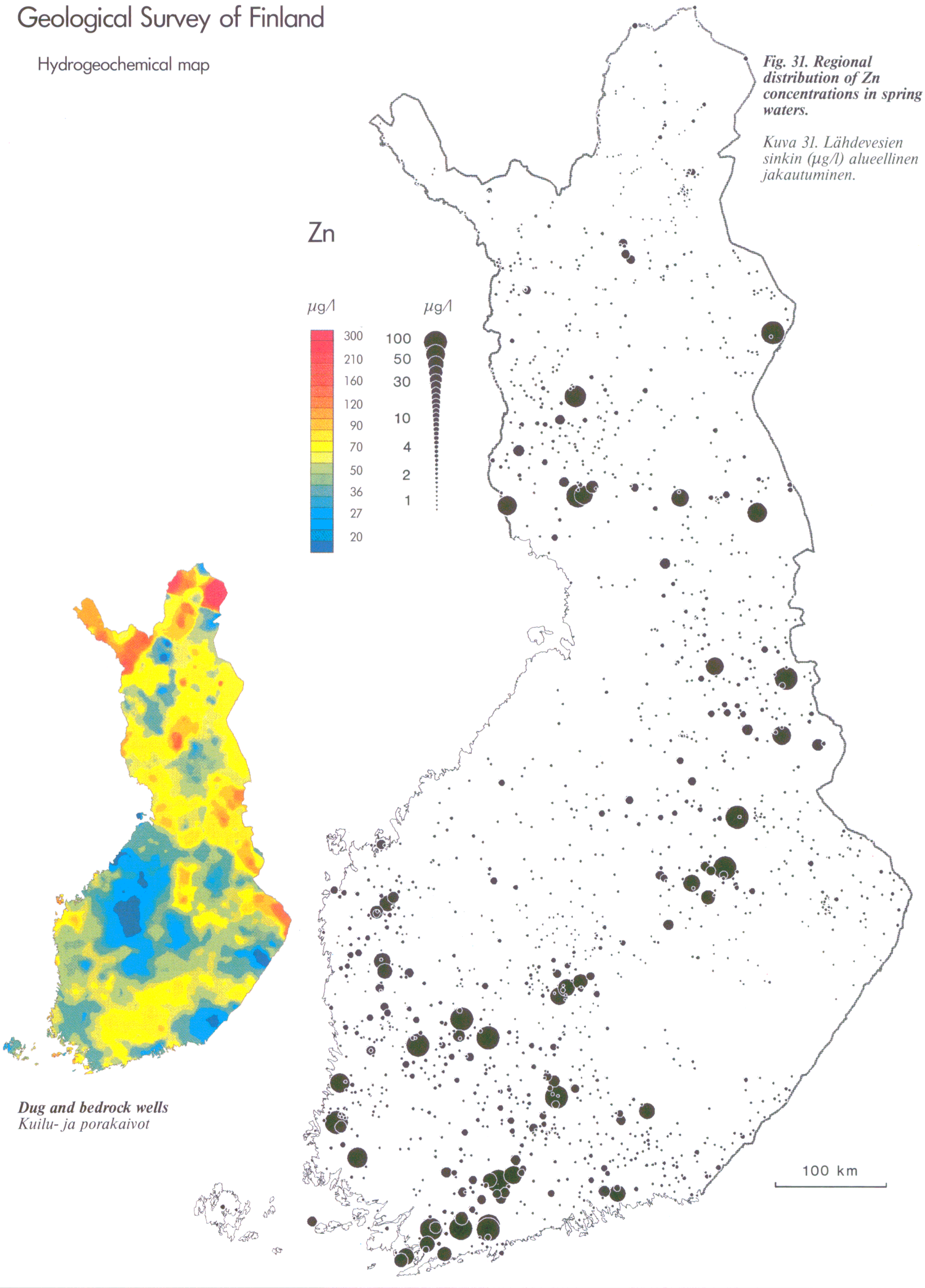
Kuva 30. Kuilukaivojen vesien mangaanin (mg/l) alueellinen jakautuminen.

Geological Survey of Finland

Hydrogeochemical map

Fig. 31. Regional distribution of Zn concentrations in spring waters.

Kuva 31. Lähdevesien sinkin (µg/l) alueellinen jakautuminen.



Dug and bedrock wells
Kuilu- ja porakaivot

Geological Survey of Finland

Hydrogeochemical map

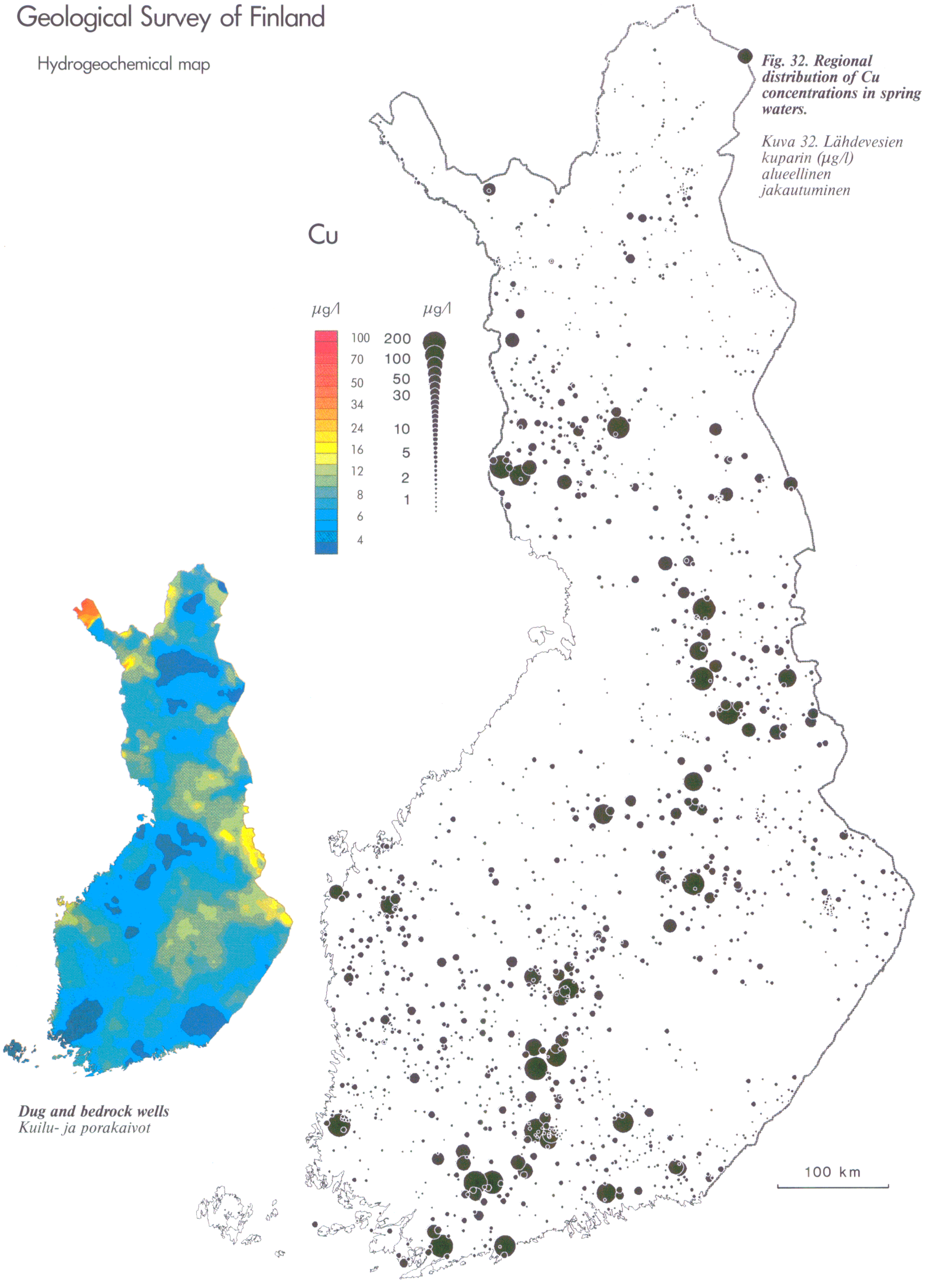


Fig. 32. Regional distribution of Cu concentrations in spring waters.

Kuva 32. Lähdevesien kuparin (µg/l) alueellinen jakautuminen

Dug and bedrock wells
Kuilu- ja porakaivot

Fig. 33. Regional distribution of Ni concentrations in spring waters.

Kuva 33. Lähdevesien nikkelin (µg/l) alueellinen jakautuminen

Fig. 34. Regional distribution of Pb concentrations in spring waters.

Kuva 34. Lähdevesien lyijyn (µg/l) alueellinen jakautuminen.

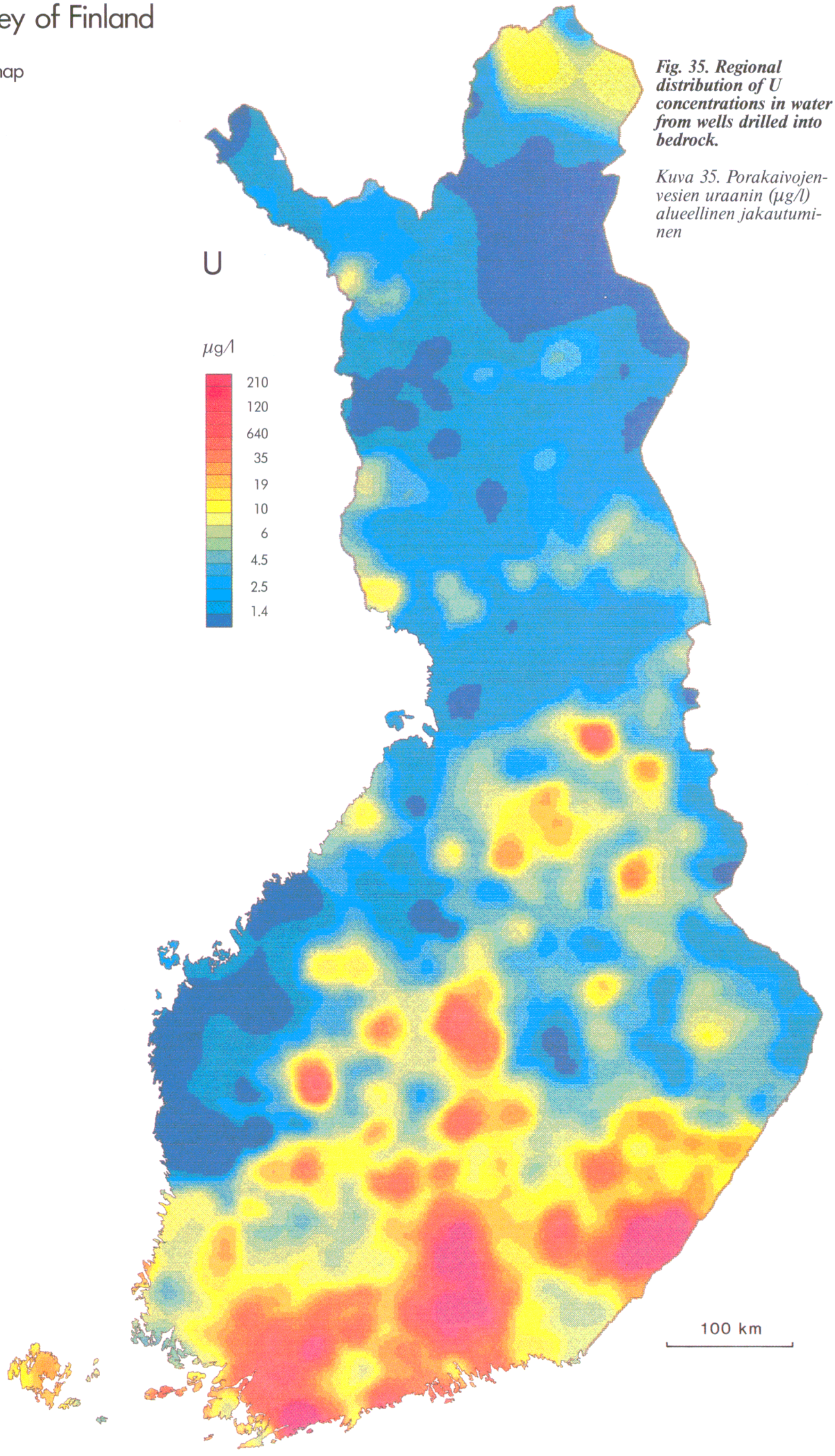


Fig. 35. Regional distribution of U concentrations in water from wells drilled into bedrock.

Kuva 35. Porakaivojen-vesien uraanin (µg/l) alueellinen jakautumi-nen

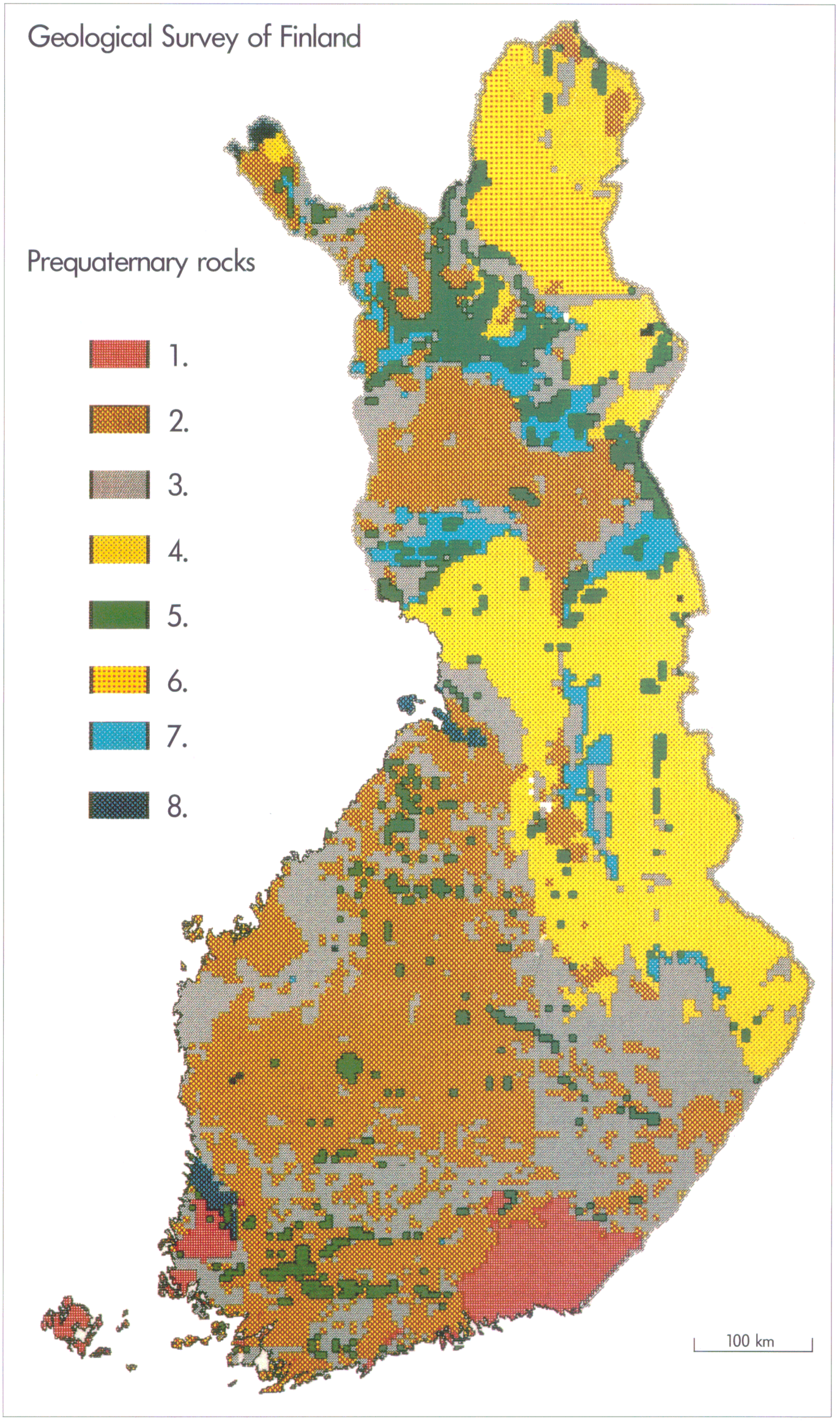


Fig. 36. A simplified computer-processed map of Prequaternary rocks of Finland (after Simonen 1980). 1. Rapakivi granites; 2. Granitoids; 3. Mica schists and gneisses; 4. Archaean basement, mainly gneisses; 5 Mafic volcanics and plutonics; 6. Granulite complex; 7. Quartzites; 8. Sandstones.

Kuva 36. Tietokoneella Simosen (1980) mukaan laadittu yksinkertaistettu Suomen kallioperäkartta. 1. rapakivigraniitteja; 2. muita granitoideja; 3. kiilleliuskeita ja -gneissejä; 4. vanha arkeeinen pohja, etupäässä gneissejä; 5. emäksisiä vulkaniitteja ja syväkiviä; 6. granuliitteja; 7. kvartsiitteja; 8. hiekkakiviä.

THE HYDROGEOCHEMICAL CORRELATIONS BETWEEN CHEMICAL PARAMETERS

CORRELATION ANALYSIS

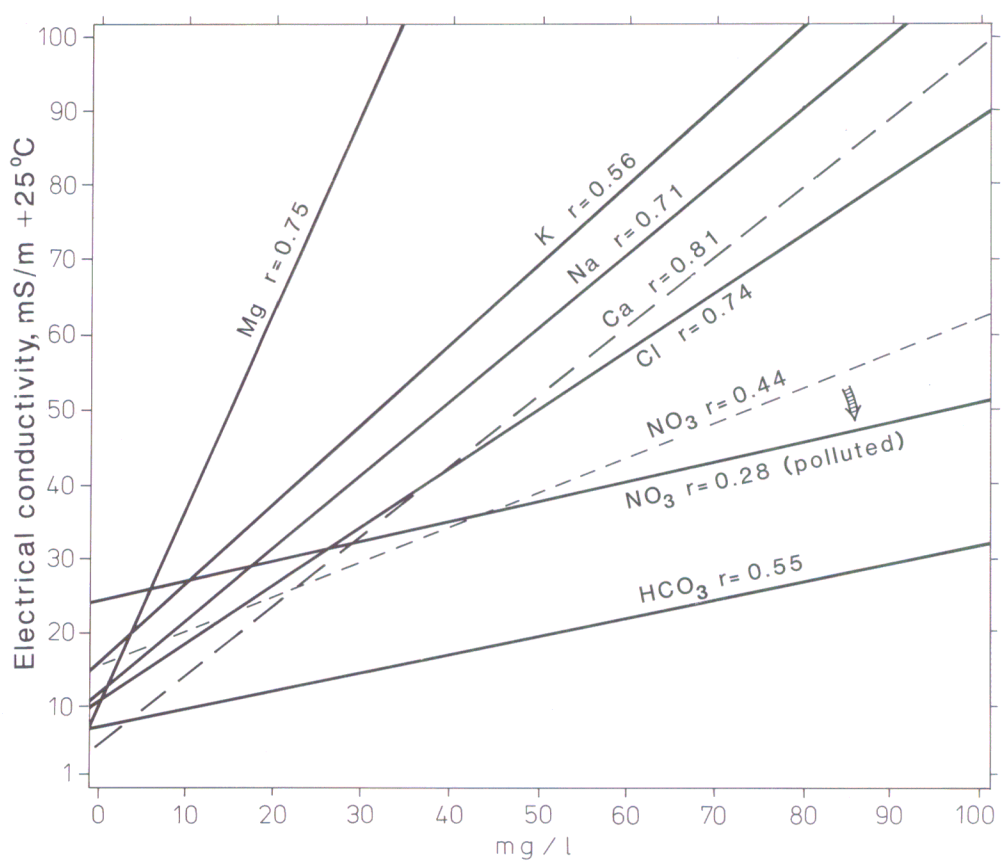
The correlation matrix was computed for all the hydrogeochemical parameters determined in this study. Since the most important correlations between the parameters are in dependent of the type of aquifer and sampling site and related changes in water quality, the matrix is presented for springs and captured springs, bedrock well waters, which represent extreme ranges of concentrations, and the whole material, but not separately for dug well waters (Table 4). The geochemically most important correlations are also presented as a correlation diagram (Fig. 37). Based on the correlation matrix the data were submitted to factor analysis using the SPSS-X program. But first, the Pearson correlation matrix is interpreted.

The elevation (z, metres above sea level) of the sampling site correlates negatively with HCO_3, SO_4, SiO_2, F and Na concentrations. The correlation is highest in the drilled bedrock well group. These correlations are compatible with the anomalous occurrence of SO_4, HCO_3 and Na in low-lying coastal areas, mainly due to marine influence. Furthermore, F-rich rapakivi areas are coastbound.

The pH values have a weak positive correlation with HCO_3 concentrations and a negative one with CO_2 concentrations. The covariation of the presented parameters shows that the pH values of the surficial groundwaters are mainly governed by CO_2–HCO_3 equilibrium, while the acid rain or oxidation of sulphides does not seem to have any significant effect (cf. SO_4 values). The computed data also show that pH values measured in the field

Fig. 37. Correlation between specific conductivity and major anion and cation concentrations. Mg concentrations contribute relatively strongly to EC; NO_3 and HCO_3 concentrations less so. The correlation with NO_3 decreases with increasing pollution (arrow). The number of samples varies from 5908 to 6145 except for polluted groundwater (1939 samples).

Kuva 37. Sähkönjohtavuuden ja pääkationien ja -anionien välinen korrelaatio. Lisääntyvät Mg-määrät vaikuttavat suhteellisesti voimakkaammin sähkönjohtavuuteen kuin esim. NO_3 ja HCO_3 (kts. myös korrelaatiokertoimia). Likaantuneiden kaivovesien NO_3-määrät (polluted) korreloivat heikommin sähkönjohtvuuteen kuin puhtaammiksi luokitelluissa vesissä. Näytteiden määrä vaihtelee 1939 ja 6145 välillä.



	z	EC	pH	Redox	O_2	CO_2	Colour	$KMnO_4$	HCO_3	SO_4	Cl	F	SiO_2	NO_3	Ca	Mg	Na	K	Fe	Mn	Zn	Cd	U
EC	−0.31																						
	− 0.25																						
	− 0.30																						
pH	0.11																						
		0.19																					
	− 0.30	0.15																					
Redox		− 0.2																					
	0.11		− 0.26																				
	0.27	− 0.21	− 0.35																				
O_2	0.29	− 0.35	0.11	0.13																			
	0.26			0.19																			
	0.38	− 0.22	− 0.31	0.34																			
CO_2	− 0.27	0.49	− 0.40		− 0.46																		
	− 0.11	0.27	− 0.36		− 0.36																		
		0.15			− 0.11																		
Colour			− 0.12	− 0.13	− 0.23	0.15																	
	− 0.16			− 0.15	− 0.31	0.21																	
	− 0.21	0.10		− 0.30	− 0.27	0.26																	
$KMnO_4$			− 0.22		− 0.18	0.18	0.80																
		0.18			− 0.24	0.27	0.69																
	− 0.26	0.32			− 0.18	0.39	0.52																
HCO_3	− 0.26	0.73	0.31	− 0.18	− 0.35	0.22																	
	− 0.30	0.54	0.47	− 0.19	− 0.38	0.20	0.22	0.21															
	− 0.51	0.41	0.50	− 0.26	− 0.43		0.20	0.34															
SO_4	− 0.39	0.64			− 0.29	0.38		0.12	0.38														
	− 0.36	0.50			− 0.22			0.17	0.36														
	− 0.43	0.52		− 0.14	− 0.20	0.22	0.15	0.35	0.44														
Cl	− 0.20	0.80			− 0.25	0.48			0.39	0.38													
	− 0.10	0.86				0.12			0.19	0.21													
	− 0.15	0.93		− 0.15	− 0.11			0.20	0.15	0.30													
F	− 0.29	0.15			− 0.14				0.16	0.19													
	− 0.32	0.22	0.19	− 0.15	− 0.19				0.29	0.18													
	− 0.47	0.21	0.33	− 0.21	− 0.28	− 0.12			0.37	0.20													
SiO_2	− 0.39	0.40		− 0.13	− 0.34	0.28		− 0.12	0.42	0.34	0.22	0.29											
	− 0.34	0.23	0.13	− 0.16	− 0.32	0.15	0.14		0.32	0.27		0.25											
	− 0.29	0.10	0.22	− 0.30	− 0.37		0.24		0.24			0.12											
NO_3		0.59	− 0.16		0.10	0.45			0.19	0.37	0.53		0.14										
		0.34	− 0.13			0.31				0.21	0.20												
	0.21	0.15	− 0.28	0.14		0.36		0.20	− 0.13	0.14		− 0.16											
Ca	− 0.25	0.90	0.14	− 0.32	− 0.32	0.37			0.74	0.61	0.71	0.15	− 0.32	0.53									
	− 0.17	0.84	0.17		− 0.21	0.19		0.14	0.44	0.36	0.84	0.12	0.16	0.53									
	− 0.14	0.85		− 0.13	− 0.14			0.20	0.22	0.24	0.93			0.32									
Mg	− 0.28	0.84			− 0.33	0.42			0.74	055	065		0.39	0.52	0.78								
	−0.22	0.66	0.17	− 0.12	− 0.27	0.29			0.61	0.50	0.41	0.14	0.32	0.52	0.79								
	− 0.21	0.68	0.11	− 0.17	− 0.28	0.33	0.11	0.23	0.51	0.50	0.51		0.20	0.20	0.49								
Na	− 0.30	0.75	− 0.15	− 0.35	0.38	0.38			0.63	0.48	0.66	0.18	0.46	0.37	0.60	0.46							
	− 0.22	0.87	0.20	− 0.16	− 0.20			0.13	0.42	0.37	0.83	0.28	0.46		0.60	0.61							
	− 0.38	0.92	0.22	− 0.23	− 0.21			0.28	0.43	0.55	0.85	0.31	0.14		0.63	0.44							
K	− 0.12	0.61		− 0.25		0.44	0.15	0.23	0.38	0.36	0.55		0.11	0.51	0.47	0.43	0.46						
		0.40			− 0.19	0.38	0.14	0.29	0.29	0.34	0.18			0.55	0.47	0.44	0.46						
		0.27			− 0.11	0.43	0.15	0.43	0.20	0.30	0.13			0.55	0.22	0.31	0.18						
Fe		0.22		− 0.26	− 0.26	0.22	0.50	0.17	0.23		0.17		0.26		0.11	0.13	0.29						
		013		− 0.26	− 0.22	0.25	0.51	0.14	0.14				0.16			0.11							
	− 0.10			− 0.33	− 0.23	0.33	0.62	0.23	0.11				0.20	− 0.11		0.14							
Mn		0.39		− 0.10	− 0.19	0.17	0.15	0.26	0.29		0.32			0.11	0.35	0.24	0.26	0.33	0.17				
		0.26		− 0.13	− 0.23	0.30	0.20	0.17	0.25	0.19	0.14			0.12	0.35	0.24	0.26		0.17				
		0.17		− 0.17	− 0.18	0.41	0.25	0.36	0.20	0.11			0.14		0.13	0.26		0.26	0.28				
Zn		0.13							0.14	0.12					0.15	0.14							
Cd		0.17							0.17	0.17	0.11				0.22	0.18					0.41		
																					0.28		
														0.10				0.11			0.23		
U		0.16							0.13	0.11	0.10			0.15	0.15	0.17							

Top: Springs and captured springs
Middle: All material
Bottom: Drilled bedrock wells

Table 4. The Pearson correlation matrix for the properties and concentrations of dissolved constituents computed for springs and captured springs and for all material (springs, dug wells and drilled bedrock wells combined) and bedrock well water. Only hydrogeochemically significant correlation coefficients are presented. z. Geographic elevation of the sampling site; EC. Specific electrical conductivity (mS/m, +25 °C).

Taulukko 4. Vesien ominaisuuksien ja ainespitoisuuksien Pearsonin korrelaatiomatriisi lähdevesille (ylin), porakaivovesille (alin) ja koko aineistolle (keskimmäinen) laskettuna. Vain hydrogeokemiallisesti merkittävät korrelaatiot on merkitty. z, näytepaikan korkeus merenpinnasta, EC, veden sähkönjohtavuus (mS/m, +25 °C).

and laboratory correlate only moderately (0.53–0.60). Hence the field measurements made immediately after sampling are to be preferred to the measurements made later in the laboratory.

Electrical conductivity (EC) correlates strongly with the concentrations of the main anions and cations, i.e. HCO_3, Cl, SO_4, Ca, Mg, Na and K. The correlations are especially strong with Cl and Na in the drilled bedrock well group due to the occurrence of relict sea salts in the coastal bedrock aquifers. The correlation between EC values and NO_3 concentrations in weakly mineralized spring waters indicates that anthropogenic contamination strongly increases the amounts of dissolved electrolytes. The strong correlation between the EC values measured in the field and the laboratory (0.93–0.96) indicates the reliablity of the method, irrespective of whether the values are measured in the field immediately after sampling or later in the laboratory.

Redox-potential (Eh) is causally linked with the pH level, and the dissolved O_2 and Fe concentrations, although the correlation coefficients seem to be very low mainly because of the instability of the soft, weakly buffered waters. The positive correlation with O_2 and the negative one with pH and Fe are slightly higher in drilled bedrock wells than in the other categories.

Dissolved O_2 has a weak negative correlation with CO_2, colour, $KMnO_4$ consumption and the main anions and cations. The concentrations of dissolved O_2 are lower in aquifers covered with clay or silt deposits, where conditions favour higher CO_2 and main anion and cation concentrations in water. Dissolved CO_2 shows a weak negative correlation with pH, and dissolved O_2 a slight positive correlation with the main anions and cations. This covariation is most conspicuous in diluted spring water, indicating a causal relationship with CO_2 as a factor promoting silicate weathering. The correlation is not systematic in more concentrated well waters.

Colour and chemical oxygen demand (COD) or $KMnO_4$ consumption, are closely correlated since dissolved humus is the main contributor to the chemically consumable material in water and to colour. Both parameters show a marked correlation with Fe, which occurs, at least partly, as complexes with humus. A slight negative correlation with pH values indicates the effect humus material has on the pH level of water.

Alkalinity, or the concentrations of HCO_3, the most common anion in fresh groundwaters, correlates strongly with EC and the main cations, i.e. Mg, Ca and Na, the magnitude of the coefficient decreasing in this order. In the drilled bedrock well group, however, the correlation is stronger with Na than with Ca owing to relict Na-dominant salts in coastal areas. In the same group the moderate negative correlation with O_2 concentrations refers to bedrock groundwater from deep drilled wells partly depleted in oxygen.

Sulphates correlate moderately with EC, Ca, Na and K, the correlation decreasing in this order in spring and dug well waters. In drilled wells the correlation is stronger with Na than with Ca owing to the occasional occurrence of relict seabound Na. A slight negative correlation with the elevation of the sampling site was noted.

Chlorides correlate strongly with EC, Ca, Na and Mg. The higher the Cl concentrations in water, i.e. the salinity in coastal aquifers containing relict seawater, the stronger the correlation with EC and Na (cf. Lahermo et al. 1987). In diluted spring waters chlorides also correlate markedly with NO_3 as a result of anthropogenic pollution.

Fluoride concentrations are relatively independent of the other water-soluble components. Newertheless, a slight correlation exists with SiO_2 in diluted spring waters and with Na in more concentrated bedrock well waters.

Silica behaves fairly independently of the other components. A moderate correlation, however, exists with Mg, Na and HCO_3 concentrations in diluted spring waters, while there is a slight negative correlation with dissolved O_2 in more concentrated bedrock groundwater. This is because SiO_2 value tend to decrease with increasing depth and salinity, and with decreasing O_2 concentration in water in deep drilled bedrock wells (cf. Nurmi et al. 1985, 1988, Blomqvist et al. 1987). The correlation coefficients decrease systematically from diluted spring waters to dug well and drilled bedrock well waters, i.e. with increasing salinity.

Nitrates correlate strongly in the diluted spring water category with EC, Cl, CO_2 and SO_4 suggesting a causative relationship with anthropogenic sources, which seem to have the least effect on bedrock groundwater. On the other hand, NO_3 is not stable in deep, oxygen-free groundwater.

Calcium and magnesium, the main cations in fresh groundwater, correlate fairly strongly with EC and HCO_3 especially in spring and dug well waters. In bedrock groundwater there is also a strong correlation of Ca with Cl and Na concentrations. The two alkali earths also correlate moderately with SO_4 and somewhat less with K. The mutual covariation between Ca and Mg diminishes from diluted spring waters towards more concentrated drilled bedrock well waters, indicating more complicated hydrogeochemical pathways and sources of various dissolved constituents in bedrock water.

Sodium correlates very strongly with EC and Cl, especially in bedrock groundwater. There are moderate correlations with sulphates and the main alkali earths. In spring waters, Ca correlates moderately with NO_3, indicating the presence of anthropogenic organic pollutants in some places in shallow aquifers.

Potassium, like sodium, correlates fairly strongly with EC in spring and dug well waters but somewhat more weakly with the main dissolved components. The moderate correlation with dissolved CO_2 is worth noting. It may be due to enhanced mineral weathering, but also partly connected with NO_3 and related anthropogenic pollution.

The heavy metals show only a few moderate correlations. As discussed earlier, iron seems to be connected with humic material as indicated by its correlation with colour, but surprisingly not with the $KMnO_4$ consumption values. A weak positive correlation with CO_2 and

negative correlations with redox potential and O_2 are conceivable, as the highest Fe concentrations are in CO_2-rich deep groundwater under reducing conditions. There is a moderate correlation between Fe and NH_4 in spring waters (0.45, the latter component not being reported in this paper). The covariation between Fe and Mn is fairly weak.

Manganese does not correlate with any component except NH_4 in spring and bedrock well waters (0.49–0.54). Other trace elements show very low correlations with other components. Only in spring waters there are moderate correlations between Zn, Cd and Pb, the latter correlation possibly being due to technoqenic contamination during sampling.

Uranium correlates moderately with HCO_3 in water from drilled bedrock wells. Otherwise it seems to be independent of water chemistry.

The correlations between electrical conductivity values and major anions and cations are presented as a diagram (Fig. 37). The Mg concentrations have by far the strongest negative impact on specific conductivity while HCO_3 and NO_3 have the least effect on it. Ca, Na and K are very similar in this respect. With increasing pollution, reflected in the growing NO_3 concentrations, the correlation with electrical conductivity decreases.

FACTOR ANALYSIS

To reveal hidden relationships between various properties and abundances of dissolved components in water which are not revealed by simple correlation analyses, R-mode Varimax-rotated factor loading matrix was computed for the whole combined material (springs, dug wells and drilled bedrock wells) and, for comparison, for spring waters separately (Tables 5 and 6).

Six factors were extracted and interpreted from the combined data (Table 5). In the first, or "contamination factor", NO_3 and K have the strongest positive loadings. The moderate positive loadings on EC, Ca, Mg, CO_2 and SO_4 support the interpretation since these properties or components are elevated by anthropogenic contamination of groundwater.

In the second factor there is a strong covariance between EC, Na and Cl, and a weaker one with Ca and Mg. This "salinity factor" refers to the salinity or marine effect in coastal areas and to airborne marine salts in diluted spring waters.

The third factor is defined as the "elevation factor", since there is a reverse covariation between geographic elevation (z) and F, SiO_2 and SO_4. This factor is attributed to

Table 5. R-mode Varimax-rotated factor loadings of the whole groundwater data (springs, dug wells and drilled bedrock wells combined).

Taulukko 5. Faktori-analyysi suorakulmaisella Varimax-rotaatiolla yhdistetylle lähde-, kuilukaivo- ja kallioporakaivo-aineistolle laskettuna.

Variable	Factor 1	2	3	4	5	6	Communality
Geographic elevation (z)	0.03	– 0.13	– 0.77	– 0.17	0.14	0.04	0.66
pH	– 0.06	0.09	0.05	0.00	0.08	0.90	0.83
Elect. conductivity (EC)	0.55	0.75	0.26	0.07	0.12	0.19	0.98
Redox (Eh)	0.20	– 0.16	– 0.00	– 0.01	– 0.56	– 0.29	0.46
O_2	– 0.21	– 0.02	– 0.46	– 0.22	– 0.40	– 0.01	0.46
CO_2	0.56	0.04	0.19	0.17	0.27	– 0.49	0.69
Colour	– 0.03	0.01	0.13	0.85	0.35	0.01	0.85
$KMnO_4$ consumption	0.21	0.04	0.01	0.89	– 0.03	0.01	0.85
HCO_3	0.37	0.24	0.41	0.15	0.18	0.59	0.77
SO_4	0.46	0.28	0.48	0.08	– 0.08	0.05	0.54
Cl	0.26	0.92	0.03	– 0.03	0.11	– 0.03	0.93
F	– 0.18	0.27	0.57	0.01	0.01	0.15	0.45
SiO_2	0.11	0.05	0.68	– 0.14	0.31	0.04	0.60
NO_3	0.73	0.10	– 0.18	– 0.03	– 0.12	– 0.14	0.61
Ca	0.63	0.40	0.27	0.02	0.14	0.34	0.77
Mg	0.60	0.36	0.34	– 0.12	0.23	0.21	0.72
Na	0.10	0.90	0.21	0.07	0.05	0.14	0.89
K	0.70	0.17	– 0.07	– 0.27	– 0.04	– 0.03	0.60
Fe	– 0.12	0.04	0.04	0.35	0.70	– 0.07	0.63
Mn	0.38	0.06	0.04	– 0.04	0.61	0.00	0.52
Eigenvalue	5.82	2.20	2.11	1.38	1.21	1.07	
Percentage of variance explained by factor	29.1	11.0	10.6	6.9	6.0	5.3	
Cumulative percentage of variance	29.1	40.1	50.7	57.6	63.6	68.9	

Variance	Factor 1	2	3	4	Communality
Geographic elevation (z)	– 0.12	0.01	– 0.73	0.19	0.59
pH	0.06	– 0.16	– 0.06	0.81	0.67
Elect. conductivity (EC)	0.94	0.09	0.24	0.06	0.94
Redox (Eh)	– 0.01	– 0.25	– 0.05	– 0.55	0.37
O_2	– 0.24	– 0.36	– 0.48	0.10	0.43
CO_2	0.47	0.25	0.28	– 0.51	0.63
Colour	– 0.05	0.89	0.07	– 0.01	0.81
$KMnO_4$ consumption	0.05	0.82	– 0.11	– 0.19	0.72
HCO_3	0.65	0.12	0.35	0.44	0.76
SO_4	0.52	– 0.01	0.46	– 0.21	0.53
Cl	0.84	0.07	0.01	– 0.09	0.71
F	– 0.04	– 0.04	0.63	0.08	0.41
SiO_2	0.25	– 0.00	0.71	0.15	0.59
NO_3	0.73	– 0.13	– 0.12	– 0.34	0.68
Ca	0.88	0.00	0.20	0.11	0.82
Mg	0.84	0.00	0.27	0.05	0.79
Na	0.77	0.11	0.34	0.12	0.73
K	0.71	0.35	– 0.06	– 0.04	0.63
Fe	0.13	0.63	0.12	0.27	0.50
Mn	0.41	0.37	– 0.12	0.13	0.33
Eigenvalue	6.82	2.27	1.81	1.75	
Percentage of variance explained by factor	34.1	11.3	9.1	8.7	
Cumulative percentage of variance	34.1	45.4	54.5	63.2	

Table 6. R-mode Varimax-rotated factor loadings of spring water data.

Taulukko 6. Faktori-analyysi suorakulmaisella Varimax-rotaatiolla lähdevesiaineostolle laskettuna.

the F-rich rapakivi granite areas and sulphate-rich marine sediments in low-lying coastal areas. Also the SiO_2 concentrations in groundwater are somewhat elevated along the west and southwest coast. The moderate negative loading on dissolved O_2 is ascribed to the coastal O_2-depleted aquifers partly covered with clay silt or peat deposits.

The fourth, or "humus factor", is due to the strong covariance between colour and $KMnO_4$ consumption. The moderate loading on iron supports the definition since part of the iron is transported as complexes with dissolved humic matter. Introduction of humic matter into groundwater tends to consume some of the dissolved O_2, as is also indicated here by the weak negative loading on oxygen.

The fifth factor is interpreted as the "redox factor", where iron, manganese and colour values correlate with each other, while redox potential and dissolved O_2 have marked negative loadings. This accounts for the occurrence of these metals in humic and O_2-depleted waters.

The sixth factor is called the "pH factor" because of its strong loading on and positive covariance with HCO_3 and the loading opposite in sign to that of dissolved CO_2. The pH of water seems to be determined mainly by the interaction of water between silicate and carbonate minerals: the higher the pH the higher the concentrations of reaction products, i.e. the HCO_3 and Ca released into water.

The negative loading on CO_2 shows that the increase in CO_2 concentrations dissolved in water results in lower pH values.

The percentages of variance show that the contamination factor explains nearly one third of the variance, the salinity and elevation factors explain more than 10 per cent each, and the redox and pH factors only 6 per cent of the computed variance. Note that water-rock reactions contribute only slightly to the geochemical evolution of surficial groundwater. Roughly one third of the variance of the whole model remains unexplained.

For comparison, a factor loading matrix was computed for spring waters, which account for the most diluted and swiftly exchanging surficial groundwaters (Table 6). Only four factors have meaningful eigenvalues, as the composition variations are smaller than in the whole combined data. The first factor seems to be a combined contamination and salinity factor, the second a humus factor, the third an elevation factor and the fourth a pH factor. The latter may also include the redox factor, which was more prominent in the combined material. The explainability of the whole factor model is slightly poorer in spring waters than in the combined material. The relative importance of the "salinity factor" may be partly due to airborne marine salts, which are significant sources of electrolytes in the most diluted perched and shallow groundwaters.

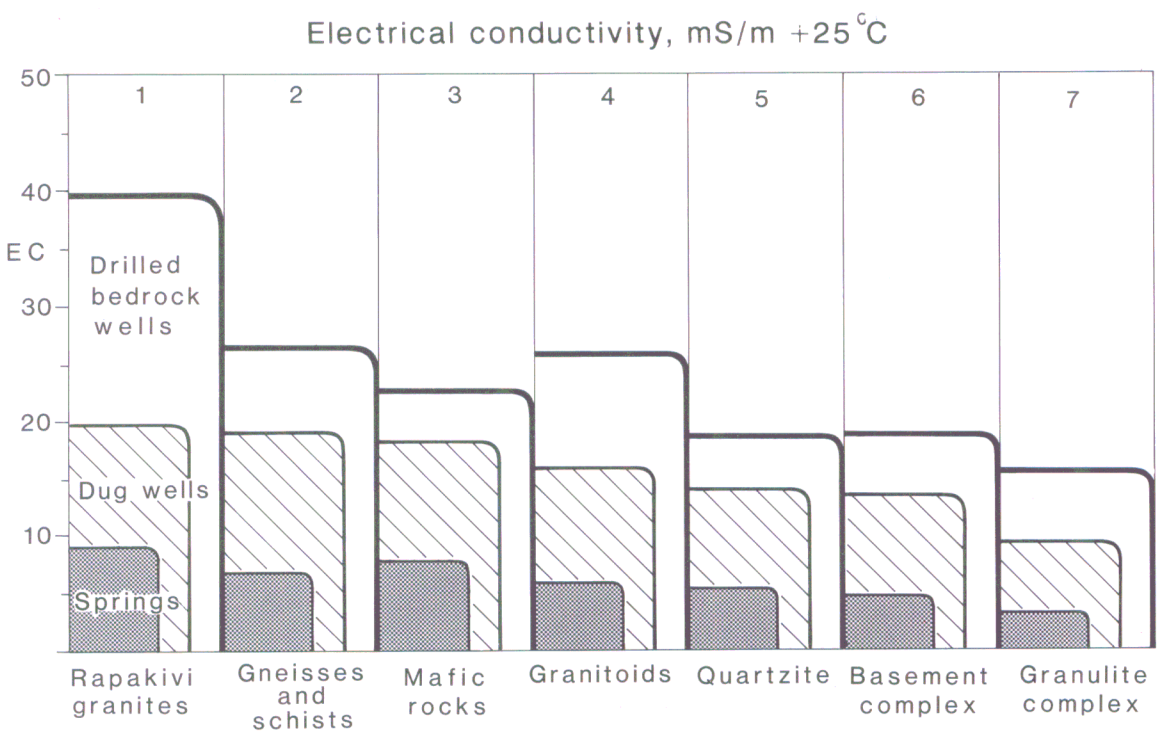
SUMMARY OF THE EFFECT OF ENVIRONMENTAL FACTORS ON GROUNDWATER QUALITY

The effect of bedrock composition on the chemistry of shallow groundwater in the overburden is mediated through the composition of the soil, which in turn reflects the composition of underlying or nearby bedrock. This is because till was not transported far from its source by the continental ice sheet, generally only a few kilometres or even less. The provenance of glaciofluvial rock material may, however, be different from the local bedrock since the material transported by glacial melt water streams was mixed more effectively than the local till.

The effect of the lithological composition of soil and bedrock on groundwater quality is often complicated and masked by other factors, which in many cases have a stronger impact on groundwater quality than the geological environment. Especially marine factors in coastal areas and anthropogenic factors in densely populated areas, or in some cases deficiently protected private wells, mask the water-rock interaction processes in terms of material input into groundwater. As discussed earlier, however, the computer-processed hydrogeochemical maps reveal many correlations with the bedrock composition. The Peräpohja schist area with some mafic and ultramafic rocks and dolomites is reflected as an anomalous province of specific conductivity, HCO_3, Ca and Mg (total hardness). Also parts of the central Lapland schist belt from Kittilä via Sodankylä to Salla, which are largely composed of mafic and ultramafic rocks and greenstones, manifest themselves in elevated concentrations in spring and well water. The old Archaean basement in

Fig. 38. Block diagram showing the median values (as height of columns) of specific conductivity for various rock groups in spring, dug well and drilled bedrock well categories, arranged in order of decreasing EC values of dug well waters.

Kuva 38. Lähdevesien ja kuilu- ja porakaivojen vesien sähkönjohtavuuden mediaaniarvot eri kivilajiryhmissä (vrt. kuva 36). Kivilajiryhmät on järjestetty kuilukaivojen mediaaniarvojen mukaan pienenevässä järjestyksessä. 1. Rapakivigraniitteja; 2. Gneissejä ja liuskeita, mm. kiilleliuskeita; 3. Mafisia eli emäksisiä ja ultraemäksisiä kiviä, mm. metabasaltteja, vihreäkiviä, amfiboliitteja ja gabroja; 4. Granitoideja; 5. Kvartsiitteja; 6. Pohjakompleksiin kuuluvia gneissejä, joissa on usein graniittijuonia; 7. Granuliitteja.



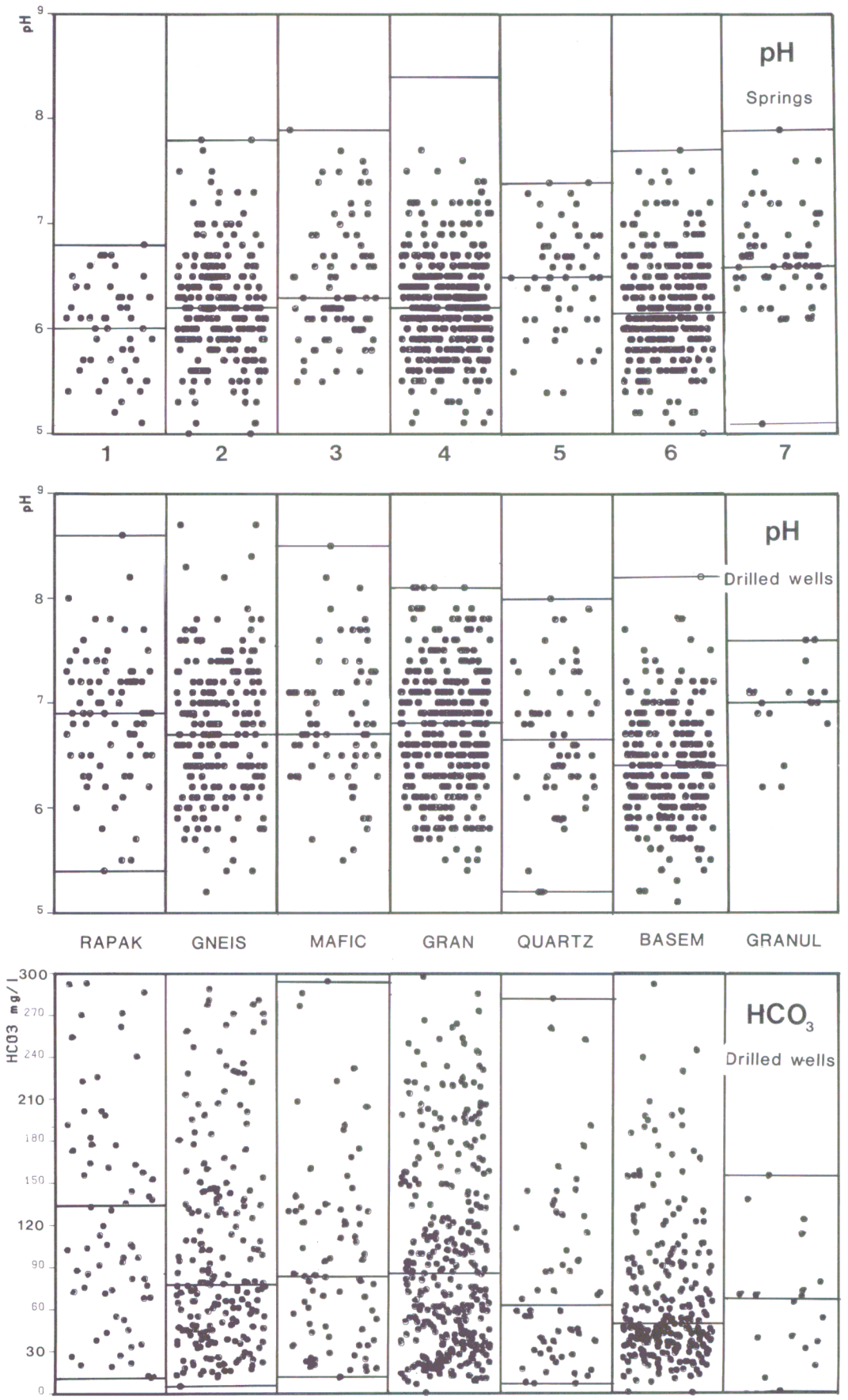


Fig. 39. Scatter diagrams of pH values in spring and drilled bedrock well categories and of HCO_3 concentrations in the drilled bedrock well category grouped according to lithologies. The lower and upper vertical lines (not always marked) are minimum and maximum values; the thickest line refers to the median values of the populations. 1. RAPAK, rapakivi granites; 2. GNEIS, mica schists and gneisses, phyllites, granite veins in migmatites; 3. MAFIC, peridotites, gabbros, serpentinites, metabasalts and amphibolites; 4. GRAN, granites, granodiorites and quartz diorites; 5. QUARTZ, quartzites; 6. BASEM, granitic and granodioritic basement gneisses, sometimes intermingled with granitic veins; 7. GRANUL, granulites. See also Fig. 42.

Kuva 39. Lähteiden ja porakaivojen vesien pH-avojen ja porakaivojen vesien bikarbonaatin jakautuminen eri kivilajiryhmissä (vrt. kuva 36). 1, RAPAK, rapakivigraniitteja; 2, GNEIS, kiilleliuskeita ja -gneissejä, fylliittejä, graniittijuonia migmatiiteissa; 3, MAFIC, peridotiitteja, gabroja, serpentiniittejä, metabasaltteja ja amfiboliitteja; 4, GRAN, graniitteja, granodioriitteja ja kvartsidioriitteja; 5, QUARTZ, kvartsiitteja; 6, BASEM, pohjagneissejä ja -graniitteja, usein graniittijuonia; 7, GRANUL, granuliitteja.

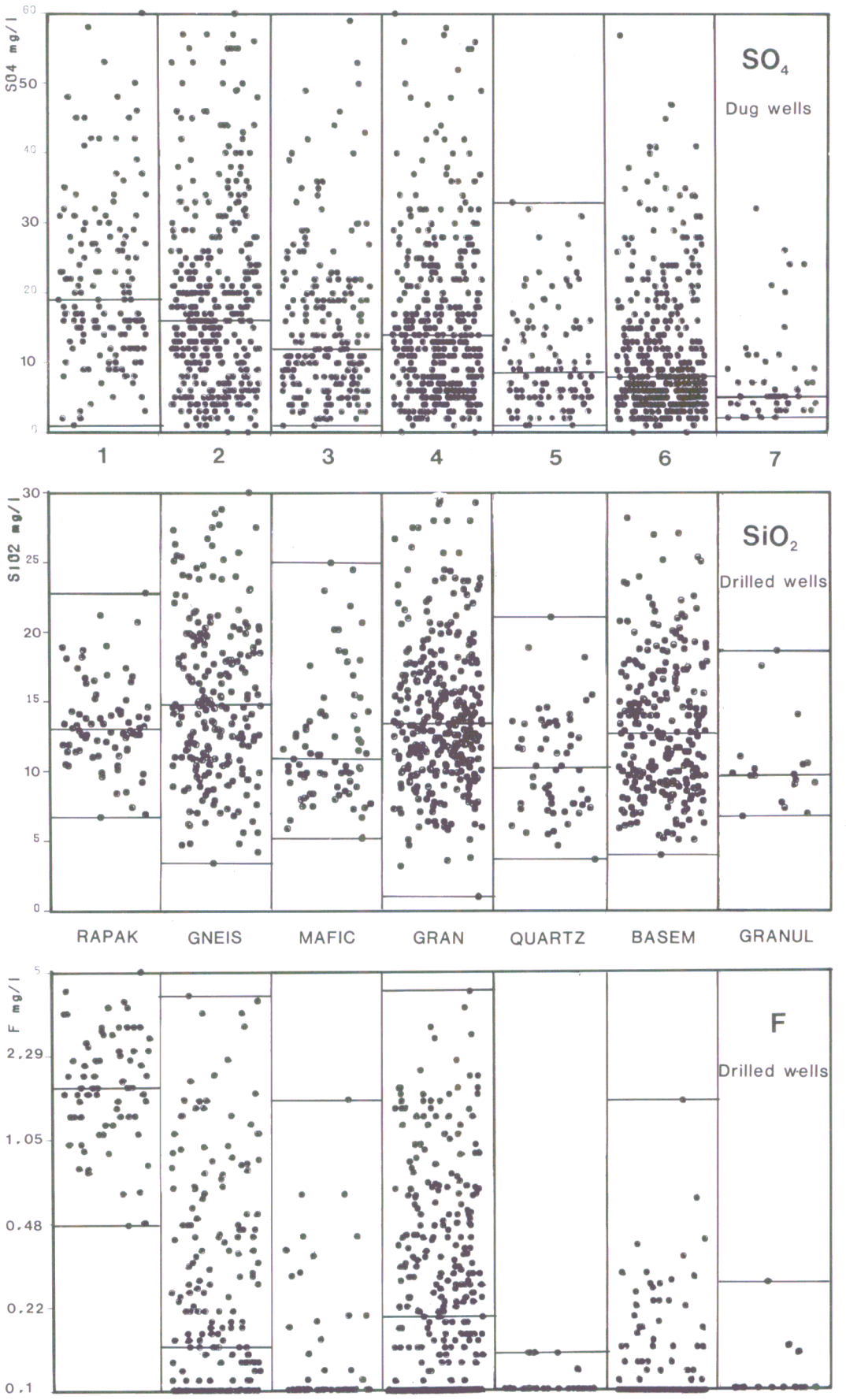


Fig. 40. Scatter diagram of SO_4 concentrations in dug well and SiO_2 and F concentrations in drilled bedrock well categories according to lithologies. For further explanation see Fig. 39.

Kuva 40. Kuilukaivojen vesien sulfaatin ja porakaivojen vesien piihapon ja fluoridin jakautumat eri kivilajiryhmissä (vrt. kuva 39).

eastern and northern Finland, which is mainly composed of granite gneisses, shows up as the provinces with the lowest concentrations of dissolved components. There are other low concentration areas in the large granitoid areas of northern and central Finland, but some of them exhibit higher concentrations of material dissolved in water (e.g. the northern part of the large granitoid pluton in central Finland). Pollution mainly caused by the poor structure and condition of a well is an important local source of material in groundwater (cf. NO_3, Cl and K concentrations), and explains some hydrogeochemically anomalous regions, such as the eastern and southeastern lake regions (cf. Fig. 20, 24 and 28).

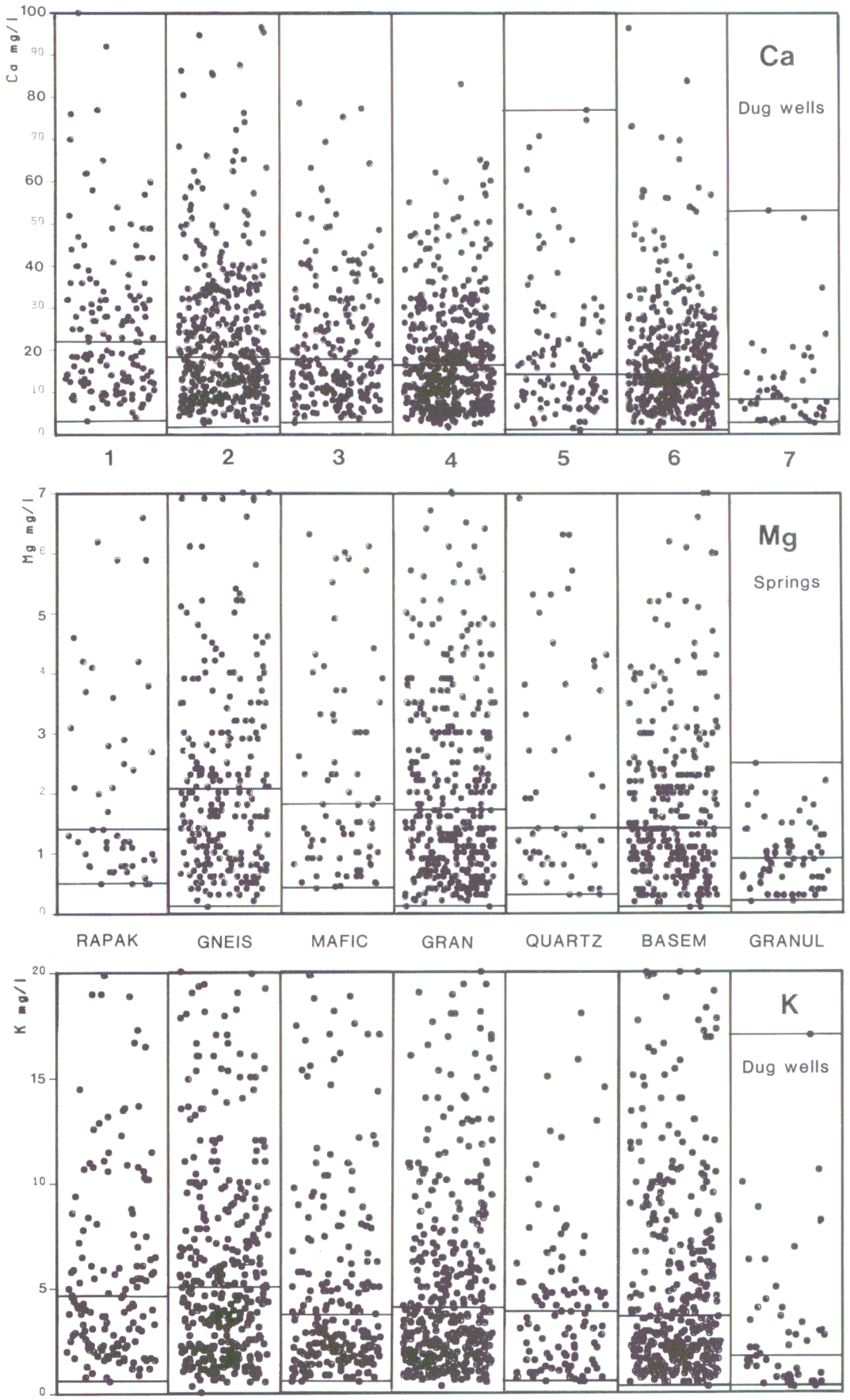


Fig. 41. Scatter diagram of Ca concentrations in dug well, Mg concentrations in spring and K concentrations in dug well categories according to lithologies. For further explanation see Fig. 39.

Kuva 41. Kuilukaivojen vesien kalsiumin ja kaliumin ja lähdevesien magnesiumin jakautumat eri kivilajiryhmissä (vrt. kuva 39).

Figure 38 presents a statistical comparison between the specific conductivity of spring and well waters with reference to bedrock composition. The highest median concentrations of dissolved constituents in the spring, dug well and drilled bedrock well categories are in rapakivi areas. This is because they are situated in densely populated coastal areas, where both anthropogenic and marine factors increase the dissolved load of shallow overburden and bedrock groundwater. Also many aquifers are covered with clay deposits enhancing dissolved load of water. In the other rock groups the highest concentrations are found in areas composed of mafic and ultramafic rocks, while the lowest are in groundwater in the granulite and basement (mainly composed of gneisses

intermingled with granitic veins) areas. The distinctly higher concentrations of dissolved electrolytes in areas composed of quartzites are probably due to the mixing of drift from neighbouring mafic rock types with till in overburden. The same systematic relationships between water quality and rock types, although at different levels of concentrations, are seen in the spring, dug well and drilled bedrock well categories. Consequently, geological, marine and anthropogenic factors affect water quality in the same way in both overburden and bedrock aquifers.

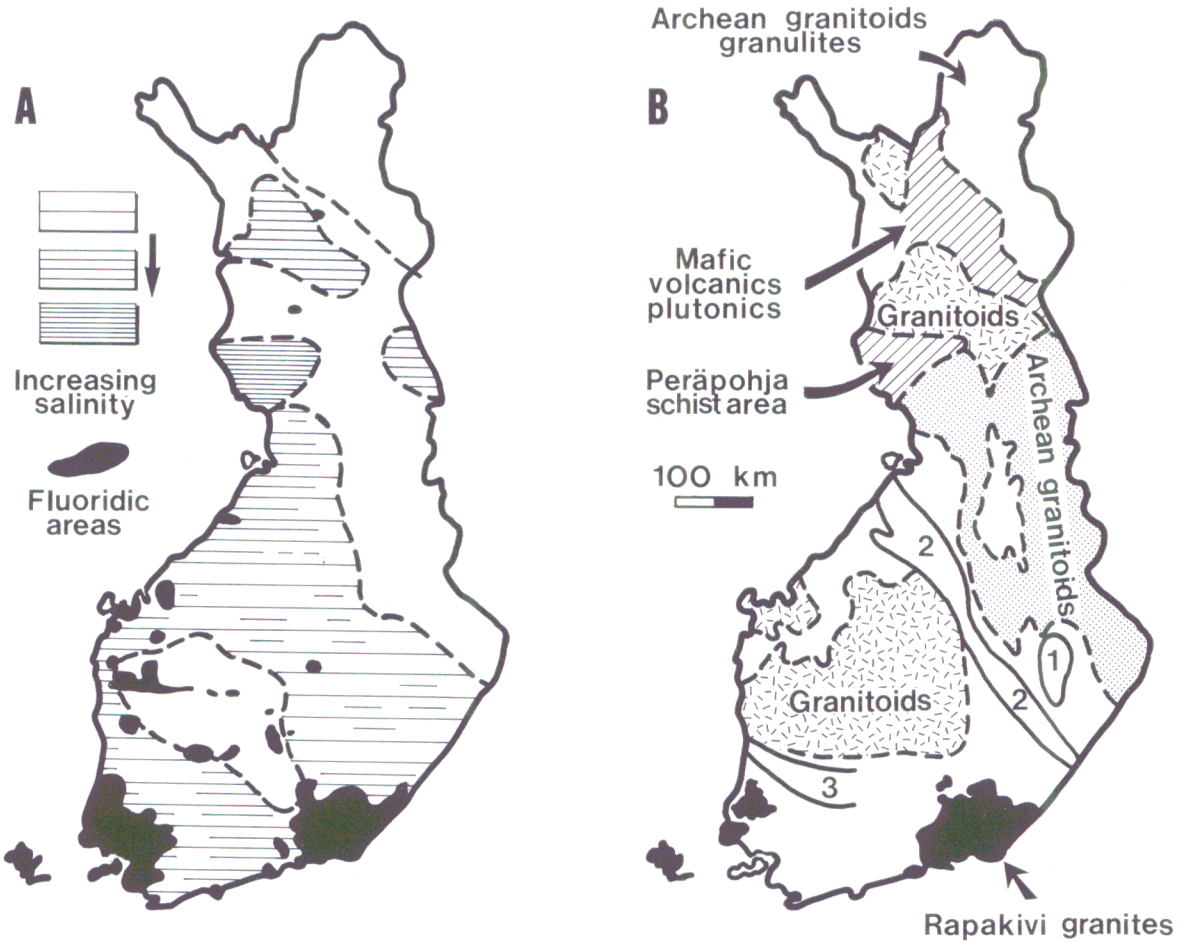
Some scatter diagrams were computed to illustrate the effect of lithology on water quality parameters (Figs. 39, 40 and 41). In spring waters the pH values are lowest in rapakivi granite areas and highest in granulite and quartzite areas. The low pH level may be ascribed, at least partly, to acid SO_4-dominant airborne deposition, which is heaviest in southeastern and southern Finland. This conclusion is supported by the high SO_4 values in spring waters in those areas. The pH values are higher in drilled bedrock well waters, indicating a more effective water-rock interaction.

Certain trends are evident in the mutual concentration levels of cations and anions in relation to rock type. The HCO_3 and SO_4 concentrations are highest in rapakivi granite areas except in the spring category, where the highest HCO_3 concentrations are in amphibolite areas. Even in the granite areas the SO_4 concentrations are higher than in mafic rock areas, which is surprising. The abundance of SiO_2 is highest in the groundwaters of rapakivi granite, granite and gneiss areas. Calcium systematically follows the distribution pattern of EC and HCO_3. The median Mg values are highest in gneiss and granite areas. By far the highest Na concentrations are found in rapakivi areas, probably due to relict sea salts in coastal aquifers. Potassium concentrations seems to be more closely related to the geological environment since the highest abundances are in granitoid areas although anthropogenic sources also contribute. Fluorides show the highest correlations with rock sources, i.e. F values are roughly 10 times higher in rapakivi granite areas than in other rock types (cf. p.31, Figs. 21, 22 and 40).

Two maps showing the main features of bedrock composition and groundwater quality were compiled to summarize the effect of bedrock composition on groundwater quality (Fig. 42).

Fig. 42. A: Schematic salinity distribution and areas of highest fluoride values in dug well waters. Hydrogeochemical patterns drawn on the basis of specific conductivity, total hardness, alkalinity and fluoride maps. B: Main features of the Precambrian bedrock (after Simonen 1980). 1. The Outokumpu sulphide mineral belt. 2. The Laatokka-Perämeri (Ladoga-Bothnian Bay) sulphide mineral potential belt. 3. The Pori-Vammala-Tampere sulphide mineral potential belt (after Kahma 1973, cf. also Fig. 36).

Kuva 42. Kaavamainen esitys veden liuenneiden aineiden määrän ja fluoridin alueellisesta jakautumisesta verrattuna kallioperän pääpiirteisiin (kts. myös kuva 36). Kartassa A on esitetty kuilukaivovesien liuenneiden aineiden määrän alueellista jakautumista lisääntyviä ainesmääriä (increasing salinity) ilmaisevalla asteikolla. F-pitoiset alueet on merkitty mustalla. Kartassa B on esitetty kallioperän pääpiirteet sekä Outokummun (1), Laatokka-Perämeren (2) ja Tampere-Vammala-Pori (3) sulfidimalmi-potentiaaliset vyöhykkeet (vrt. Kahma 1973).



CONCLUDING REMARKS

The environmental factors contributing to the chemical composition of shallow groundwater in overburden and bedrock are divided into atmospheric, geological, marine and anthropogenic factors. Many of the factors act together, and hence their individual contributions cannot definitely be separated from each other.

Atmospheric factors, i.e. the composition and amount of rain water and the enrichment processes caused by evapotranspiration, have a strong impact on the initial concentrations in shallow groundwater, particularly in natural, weakly mineralized spring water. A marked or, sometimes dominant, contribution of SO_4 (and to lesser extent NO_3) concentrations in rain water often exceeding those in groundwater, result in biogeochemical decay or adsorption of these elements in humus- or sesquioxide-rich topsoil.

When coloured-surface and dot maps for various chemical parameters are consulted it appears that under natural, undisturbed conditions geological factors manifest themselves most clearly as EC values and HCO_3, Ca and Mg concentrations that are higher in mafic and ultramafic or carbonate-rich bedrock areas (such as the Perä-pohja schist area) than in silicic ones. Hence, in general, less mineralized waters are met in the large granitoid and granulite areas in northern and eastern Finland than in schist belts with mafic and ultramafic components. pH, SiO_2, Na and K exhibit more complex interrelationships and may be anomalously high in silicic rock environments, regardless of the total mineralization of water. The most striking geogenic influence is shown by F, which exhibits values of an order of magnitude or more higher in areas of rapakivi granites or related coarse-grained K-rich granites than anywhere else.

Likewise, U concentrations in bedrock groundwater are closely connected with granites or migmatites intermingled with granitic veins in southern Finland.

The statistical grouping of the hydrogeochemical parameters into different rock categories changes the picture slightly. The highest abundances of dissolved electrolytes (EC, Ca) were found in areas composed of rapakivi granites, followed by silicic gneisses and mica schists, mafic and ultramafic rocks and granitoids. The concentrations were lowest in areas of basement rocks (mainly silicic gneisses) and in granulite environments. Only spring waters exhibited the highest Ca and HCO_3 concentrations in a mafic environment. In rapakivi granite areas the SO_4 values are high in the spring, dug well and drilled bedrock well waters. It comes as something of a surprise that, somewhat high pH values are met in granulite areas with less mineralized waters. The Mg and K concentrations are highest in gneiss and schist environments, while SiO_2 does not show any definable dependence on aquifer and rock groups.

The geological structure of an aquifer and the depth of occurrence and flow regime of the groundwater have a stronger impact on water quality than has the lithologic composition or texture of the aquifer material. Aquifers confined by impervious clay, silt or peat layers differ from open unconfined aquifer systems by showing higher abundances of dissolved components, such as Fe and Mn as indicating of a more reducing environment. Diluted shallow groundwater in overburden is gradually transformed into deeper, more mineralized bedrock groundwater by a dynamic exchange system.

Marine factors, i.e. relict sea salts in overburden and in bedrock, increase the concentrations of dissolved components, particularly those of SO_4, Cl and Na in the broad coastal belt of western Finland that was inundated by the postglacial Litorina Sea. Real marine components are, however, difficult to discern among the geological and anthropogenic end members. Direct intrusion of aquifers by seawater, with the consequent implications for quality, seems to be rare.

Anthropogenic sources of elements and compounds are countless as a result of urban development, agriculture and industry. NO_3 and K are the most sensitive inorganic indicators of pollution, although the abundances of all components show a tendency to increase. Some airborne contamination is ubiquitous (SO_4, NO_3) and is most clearly seen in natural, weakly mineralized spring waters. Local point-source pollution may introduce high concentrations of pollutants into aquifers, most commonly through deficiently maintained and protected wells.

The varimax-rotated factor model made on the pooled material suggests that the strongest modifier of shallow groundwater chemistry is pollution ("contamination factor": NO_3, K, EC, Na, Cl, Ca, Mg, CO_2 and SO_4) followed by marine influence ("salinity factor": EC, Na, Cl, Ca and Mg) and the geographical elevation, i.e, the distance from sea ("elevation factor": SO_4, SiO_2 and F). The last two factors are linked together although here elevation refers strongly to coastbound rapakivi granite areas. These low-lying coastal areas are anomalous in respect of F and SO_4 without showing any causal dependence.

Dissolved organic matter ("humus factor": colour, COD or $KMnO_4$ consumption, O_2) and oxidizing or reducing conditions ("redox factor": colour, Fe, Mn, O_2) are causally linked with each other, e.g. with the Fe and Mn contents in humus-rich confined waters partially depleted in dissolved O_2. The interaction of water with silicate and carbonate minerals seems to have a comparatively minor effect on water chemistry ("pH factor": pH, HCO_3, CO_2).

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Tiivistelmä

SUOMEN HAJA-ASUTUSALUEIDEN POHJAVESIEN HYDROGEOKEMIALLINEN KARTOITUS

Geologian tutkimuskeskuksen maaperäosasto kartoitti vuosina 1978–1982 pohjaveden laatua kautta koko maan. Vesinäytteitä pyrittiin kokoamaan kaksi näytettä peruskarttalehteä kohti, vaikka tämä ei aina ollut mahdollista tai tarkoituksenmukaista Pohjois-Suomen harvaan asutuilla seuduilla. Kaikkiaan koottiin noin 5900 vesinäytettä luonnontilaisista ja katetuista lähteistä, tavallisista kuilukaivoista ja kallioon poratuista kaivoista. Tutkimushankkeen tavoitteena oli paitsi järjestetyn vedenhankinnan ulkopuolisten haja-asutusalueiden pohjaveden laadun kartoitus, myös luonnollisten ja ihmisen vaikutuksen alaisten ympäristötekijöiden osuuden selvitys pohjaveden laadun säätelijöinä. Veden, maan ja kiven vuorovaikutussuhteiden selvitys on tärkeätä vesien likaantumis- ja happamoitumisilmiöiden ymmärtämiselle.

Kootuista vesinäytteistä mitattiin heti näytteenottopaikalla pH, sähkönjohtavuus (EC) hapetuspelkistys- eli redox-potentiaali (Eh), lämpötila, liuennut O_2 ja CO_2. Laboratoriossa tehtiin käsittelemättömästä tai suodatetusta ja hapotetusta näytteestä seuraavat 21 määritystä: pH, EC, väri, kemiallinen hapenkulutus eli $KMnO_4$-luku (COD), alkaliteetti (HCO_3), SO_4, Cl, F, SiO_2, NO_3, suodatetusta (0.45μm) ja typpihapolla (suprapur) kestävöidystä näytteestä Ca, Mg, Na, K, Fe, Mn, Zn, Cu, Ni, Pb, Cd sekä suodatetusta ja rikkihapolla kestävöidystä näytteestä U. Lisäksi arvioitiin seuraavat pohjaveden laatuun vaikuttavat ympäristötekijät: Maa- ja kallioperän geologiset ominaisuudet ja rakenne, maankäyttötapa ja kaivon kunto. Ne merkittiin numero- ja kirjainkoodein hanketta varten laadittuihin kortteihin (kuva 1). Aineistoa käsiteltiin tilastollisesti ja siitä laadittiin todellisten arvojen pistekarttoja ja väripintakarttoja tasoitusmenetelmää käyttäen.

POHJAVESIESIINTYMIEN JA NÄYTEPAIKKOJEN LUOKITUS

Asutuskeskusten tarpeisiin riittäviä vesimääriä saadaan harjuista ja reunamuodostumista kuten Salpausselistä. Ne ovat maamme pinta-alasta kuitenkin vain 3–4 %. Tällä hetkellä pohjavesi muodostaa noin puolet yleisten vesilaitosten jakamasta vedestä. Vielä 20–25 % haja-asutusalueiden väestöstä käyttää oman kaivon vettä. Useimmiten ne on tehty vain vähän vettä antaviin moreenimuodostumiin.

Tätä tutkimusta varten pohjavettä sisältävät geologiset muodostumat luokiteltiin seuraavalla tavalla (kts. myös kuva 5):

1) Suuret glasifluviaaliset muodostumat, joihin kuuluu harjuja (kuva 1) ja reunamuodostumia. Suomen tärkeimmät pohjavesiesiintymät ovat niissä. Ne voidaan jakaa ympäristöstä pohjavettä kokoaviin, synkliinisiin, ja ympäristöstä pohjavettä luovuttaviin, itsenäisiin tai antikliinisiin, muodostumiin.

2) Pienet glasifluviaaliset suojapuolen muodostumat tai rantakerrostumat. Näitä on erityisesti eteläisellä ja lounaisella rannikkoalueella.

3) Osaksi tai kokonaan saven peittämät kerrostumat, joiden aines voi olla glasifluviaalista, huuhtoutunutta moreenia tai pohjakerrostumien alimpia hiekkaisia kerroksia (kuva 3). Näissä on usein salpavettä.

4) Moreenikerrostumat, joissa yksityistalouksien kaivot ovat yleisimmin (kuva 4). Hienoainespitoisen moreenin päällä on usein huuhtoutunutta pintamoreenia.

5) Rakoillut kallioperä, joka on tärkeä yksityiselle vedenhankinnalle siellä, missä maapeite on ohut tai puuttuu (kuva 4). Kallion pintaa peittää erityisesti Keski-Lapissa ja paikoin Keski- ja Kaakkois-Suomessa vaihtelevan paksuinen rapautumiskuori.

VEDEN LAATUUN VAIKUTTAVAT YMPÄRISTÖTEKIJÄT

Veden laatuun vaikuttavat ympäristötekijät on tässä tutkimuksessa luokiteltu seuraavasti:

1) Ilmastolliset eli atmosfääriset tekijät. Ilmatietä pohjaveteen tulee koko ajan aineksia, joista tärkeimpiä luonnontilaisessa matalapohjavedessä ovat SO_4, NO_3, Cl ja Na (taulukko 1). Kuivana aikana evapotranspiraatio väkevöi liuoksia ja rikastaa suoloja maanpintaan, josta ne huuhtoutuvat sateiden mukana pohjaveteen.

2) Geologisiin tekijöihin kuuluvat maannoksessa tapahtuvat prosessit, maaperän kerrostumien rakenne, raekoko ja vedenjohtavuus sekä maan ja kallion mineraali- ja kivilajikoostumus. Niiden yhteisvaikutus on mutkikas. Muodostuman rakenne vaikuttaa usein enemmän pohjaveden ainessisältöön kuin kivilaji- ja maalajikoostumus (taulukko 2). Kivien mineraaleista joutuu rapautumisprosessin kautta pohjaveteen Ca, Mg, K, SiO_2, F ja U. Myös HCO_3, SO_4 ja Na ovat osaksi minerogeenisiä.

3) Merelliset eli mariiniset tekijät vaikuttavat erityisesti rannikkovyöhykkeellä pohjasedimenttien ja kallioperän pohjavedessä. Eniten näkyy reliktisten meriveden suolojen vaikutus kun taas nykyinen merivesi vain harvoin tunkeutuu akvifereihin. Merellisiä aineksia pohjavedessä ovat Cl ja SO_4, jota liukenee paikoin sekundäärisistä sulfidi- tai sulfaattisaostumista, Na ja vähemmän Mg. Merellisiä komponentteja joutuu veteen myös ilmatietä kuivana laskeumana ja sateena.

4) Ihmisen vaikutus eli antropogeeniset tai teknogeeniset tekijät tuntuvat miltei kaikkialla matalapohjaveden laadussa (taulukko 3). Luonnontilaisilla alueilla ilmatietä tuleva rikki- ja typpilaskeuma aiheuttaa lievää kontaminaatiota kun taas paikallinen likaantuminen lisää usein paljon liuenneiden aineiden määriä. Antropogeenisia aineksia ovat NO_3, Cl, K, ja Na, kun taas teknogeenisiä ovat mm. Fe, Zn, Cu ja Ni.

POHJAVEDEN LAATU

Pohjaveden yleistä laatua on havainnollistettu kolmiodiagrammoina erikseen lähde-, kuilukaivo- ja porakaivovesille (kuva 6). Yksityiskohtaisemmin veden ominaisuuksia ja liuenneiden aineiden määriä on kuvattu yhdistettyinä histogrammi-summakäyrinä kuvissa 7–10. Alueellisia laadun vaihteluja on kuvattu kunkin komponentin osalta pallo ja väripintakarttoina (kuvat 11–35). Korrelaatio ja faktorianalyysillä on valaistu veden ominaisuuksien ja ainespitoisuuksien välisiä riippuvuuksia ja yhteyksiä ympäristöön (kuva 37 ja taulukot 5–7). Kallioperän vaikutusta veden laatuun on havainnollistettu kivilajikoostumuksen mukaan jaotetuilla sirontakuvioilla (kuvat 38–41).
Lopussa on tiivistelmän luonteisena kaavamaisena esityksenä kartta kallioperän kivilajikoostumuksen suurpiirteisestä vaikutuksesta pohjaveden laatuun (kuvat 36 ja 42).

Pohjavesien ainesmäärät ovat pienimmät nopeasti vaihtuvissa lähdevesissä ja kasvavat kuilukaivoryhmästä porakaivoihin mentäessä, vaikka kahden viimeksi mainitun ryhmän kesken ei ole kovin suuria eroja (taulukko 2). Hiekasta ja sorasta ja toisaalta moreenista koostuvien pohjavettä sisältävien kerrostumien välillä ei ole mainittavia veden laatueroja. Molempien pitoisuudet saattavat nousta moninkertaisiksi, jos pohjavesiesiintymää peittää osaksi tai kokonaan savi-, siltti- tai turvepeite.

Pohjavedet ovat harvoja poikkeuksia lukuunottamatta hyvin pehmeitä tai pehmeitä ja joskus keskikovia $Ca(HCO_3)_2$ -vesiä. Rannikoilla tavataan kuitenkin myös Na-Cl tai joskus Na-Ca-Cl -valtaisia porakaivovesiä, jotka useimmiten ovat suuren suolaisuutensa vuoksi käyttökelvottomia. Lukuunottamatta hyvin laimeita, välittö-

mästi sadevedestä peräisin olevia lähdevesiä, sulfaattivaltaiset vedet ovat harvinaisia, ja niitä voi esiintyä sekundääristen sulfaatti-sulfidi-pitoisten savien ja silttien tai sulfidi-malmi-mineralisaatioiden vaikutuspiirissä.

Useat pohjaveden ominaisuudet tai ainekset heijastavat kallioperän tai siitä syntyneen maaperän mineraalikoostumusta. pH:n, EC:n, kokonaiskovuuden (Ca, Mg) ja alkaliteetin (HCO_3) arvot ovat suuremmat emäksisten kivilajien kuten amfiboliittien, gabrojen ja karbonaattikivien alueilla kuin pääasiassa happamien kivilajien kuten kvartsiittien, graniittien tai kiilleliuskeiden alueilla. Tämä näkyy helposti kun verrataan esimerkiksi Peräpohjan ja Keski-Lapin emäksisiä liuskealueita Pohjois- ja Itä-Suomen granuliitti-, graniitti- ja graniittigneissialueisiin. Eri komponenttien kohdalla on kuitenkin kivilajien koostumuksesta johtuvia eroja. Rapakivi-graniittialueilla pohjaveden F-pitoisuudet ovat 10–15 -kertaisia muiden kivilajialueiden pohjavesiin verrattuna yhtälailla lähde-, kuilukaivo- ja porakaivovesissä. Useat muutkin pohjaveden ainesosat ovat analyysien mukaan suurimmillaan rapakivigraniittialueilla. Tämä johtunee siitä, että niillä on paljon asutusalueita ja saven peittämiä esiintymiä, joiden pohjavesien suuret ainespitoisuudet vaikuttavat alavilla rannikkoalueilla olevien rapakivialueiden keskiarvoihin tavallista enemmän. Myös U-pitoisuudet ovat suurimmat maan eteläosan graniittialueilla, vaikka rapakivigraniitti ei ole voimakkaasti anomaalinen. SiO_2, Na ja K eivät ole samalla tavoin sidoksissa kivilajiin, vaan yhteydet ovat mutkikkaampia.

Savesta, hiesusta tai turpeesta koostuva eristekerros pohjavettä sisältävän kerrostuman päällä aiheuttaa sille ominaiset pohjavesigeologiset olot. Pohjavesi viipyy tällaisissa kerrostumissa tavallista pitempään, veden happi kuluu orgaanisten ainesten hajaantuessa ja olot muuttuvat hapettavista pelkistäviksi. Rannikoiden pohjavedessä on siksi tavallista enemmän liuenneita aineita etenkin, kun reliktisia mariinisia suoloja voi liueta pohjavesiin. Siten selittyvät rannikoiden pohjavesien paikoin suuri kovuus sekä suuret Cl-, SO_4-, Fe- ja Mn-pitoisuudet.

Kloridilla ei ole selvää yhteyttä meren läheisyyteen, vaikka eräiden rannikkoalueiden anomaliat epäilemättä johtuvat reliktisistä meriveden suoloista. Se jakautuu säännöttömästi ja sen perustaso on matala luonnontilaisessa pohjavedessä (0,5–1,7 mg/l) ja se on peräisin ilmasta tulleesta laskeumasta. Siellä, missä ei ole selvästi merivedestä peräisin olevia suoloja, suuret kloridipitoisuudet johtuvat likaantumisesta.

Herkimmin osoittavat likaantumista NO_3 ja K. Samalla nousee koko liuenneiden aineiden määrä. Tässä tutkimuksessa huomattiin, että vanhat ja huonokuntoiset, usein vielä kivi- tai puukehyksiset kaivot olivat likaantuneimpia (taulukko 3). Niitä oli erityisesti Itä- ja Kaakkois-Suomessa.

Hivenpitoisuuksina esiintyvien raskasmetallien (Zn, Cu, Ni, Pb, Cd) määrät ovat lähes aina alle laatusuositusten. Analyysien satunnaiset suuret pitoisuudet selittyvät enimmäkseen sillä, että raskasmetalleja on joutunut veteen näytteenoton tai -käsittelyn aikana tai ne ovat peräisin vedennostoon, johtamiseen tai varastointiin käytetyistä laitteista.

Koko aineistosta tehty varianssianalyysi osoittaa, että ihmistoiminta on suurin veden laatuun vaikuttava tekijä (likaantumisfaktori: NO_3, K, EC, Ca, Mg, CO_2, SO_4). Painotukseltaan seuraavina ovat ilmatietä matalapohjaveteen tai reliktisistä suoloista rannikkoalueiden pohjaveteen joutuvat elektrolyytit (suolaisuusfaktori: EC, Na, Cl, Ca, Mg), näytepaikan maantieteellinen korkeus (korkeus-faktori: F, SiO_2), veden humuspitosuuteen vaikuttavat tekijät (humusfaktori: $KMnO_4$-luku, Fe, O_2), hapetuspelkistysoloihin vaikuttavat tekijät (redoxfaktori: Fe, Mn, väriluku, O_2) ja kuudentena painoarvontaan pienempänä pH tasoon vaikuttavat tekijät (pH-faktori: HCO_3, CO_2). Korkeusfaktorilla ei ole todellista merkitystä, koska se johtuu rapakivialueiden ja SiO_2-anomaalisten alueiden sijainnista rannikkoon rajoittuvilla alavilla alueilla. Nämä kuusi faktoria yhdessä selittävät noin kaksi kolmasosaa veden laatuun vaikuttavista ympäristötekijöistä. Vertailun vuoksi faktorianalyysi tehtiin myös nopeasti vaihtuvista lähdevesistä. Se osoitti, että yhdistetyllä likaantumis- ja suolaisuusfaktorilla on suurin painoarvo, jota seuraavat humus- ja korkeusfaktorit.

HAJA-ASUTUSALUEIDEN VEDEN TERVEYDELLINEN LAATU

Yleisten vesilaitosten hiekka- ja sora-alueilta saatava vesi on yleensä moitteetonta, joskin paikoin veden alhainen pH ja suuret humus-, Fe- ja Mn-pitoisuudet aiheuttavat makuhaittoja ja esteettisiä tai teknisiä ongelmia. Liian korkeita NO_3- määriä (yli 30 mg/l) on hyvin harvoin. Rapakivialueilla F-pitoisuudet ylittävät joskus sallitun 3 mg/l:ssa.

Tämän tutkimuksen haja-asutusalueiden yksityiskaivojen veden laatu vaihtelee enemmän, koska kaivot ovat hyvin erilaisissa muodostumissa ja niiden kunto ja vesimäärät vaihtelevat suuresti. Yli 12%:ssa näytteistä NO_3-määrät ylittivät 30 mg/l. Muita terveydellisesti haitallisia aineksia on kuitenkin harvoin suositusten ylittäviä määriä. Siellä missä U-pitoisuudet ovat maan eteläosassa suurimmillaan, vedessä voi olla myös huomattavia määriä radonia, jota ei kuitenkaan analysoitu tässä tutkimuksessa. Raskasmetalleista Fe ja Mn ylittivät suositeltavan alimman ylärajan (0,3 ja 0,1 mg/l) 7–17–27%, ja 5–21–37%:ssa tapauksista lähteissä, kuilu- ja porakaivoissa tässä järjestyksessä. Zn, Cu, Pb, ja Cd ylittivät suositeltavat ylärajat (1,0, 0,3, 0,05 ja 0,005 mg/l) aniharvoin (1– 3%, 1%, 1% ja 1%). Alumiinia ei ole analysoitu tässä tutkimuksessa. Jälkeenpäin erityisen happamista vesistä (pH alle 5,8) tehdyt tarkistukset osoittivat, että pitoisuudet voivat olla useita satoja mikrogrammoja litrassa, ja joissakin tapauksissa yli 1 mg/l suositeltavan ylärajan ollessa vain 0,2 mg/l. Happamat pohjavedet jakautuvat tasaisesti kautta maan yhtälailla lähteiden, kuilukaivojen ja porakaivojen tai eri muodostumien osalle. Tämä osoittaa, että pohjaveden happamoitumiseen vaikuttavat ilmaperäisen happaman laskeuman ohella monet muutkin tekijät.

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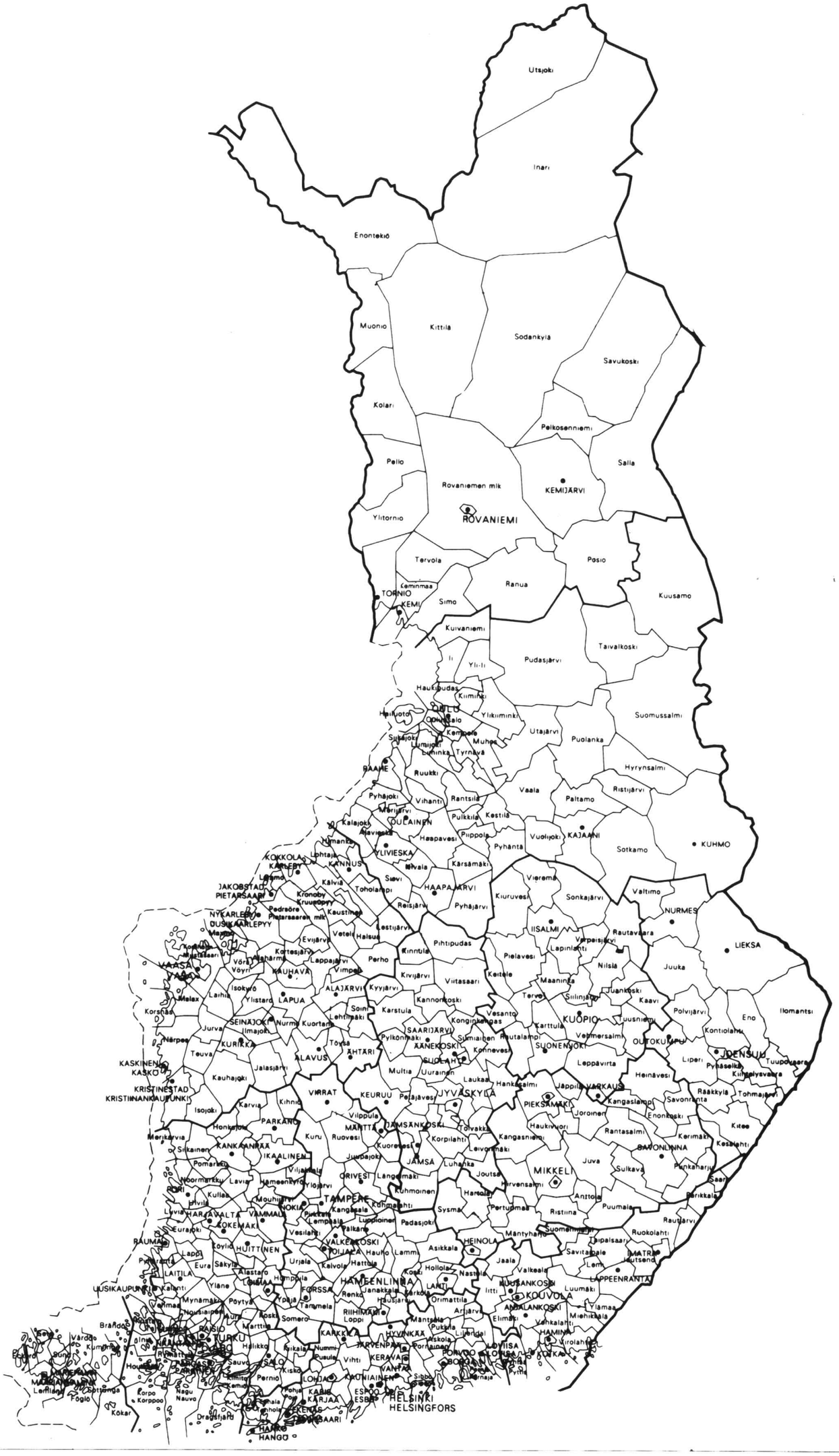
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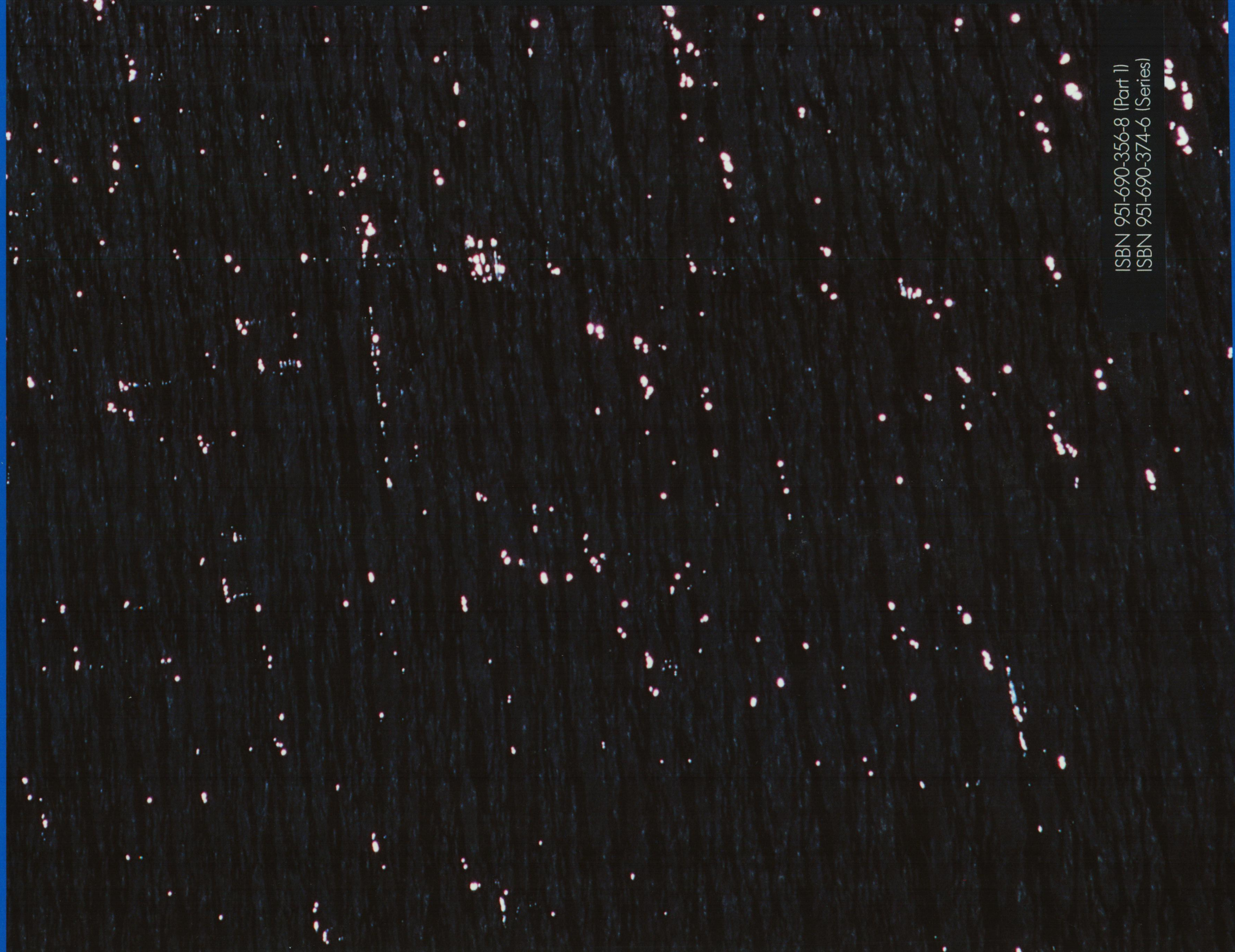

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