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GROUNDWATER AND FACTORS AFFECTING ITS QUALITY: EXAMPLES FROM THE ROVANIEMI DISTRICT OF NORTHERN FINLAND AND WESTERN NICARAGUA

by

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with 54 figures, 19 tables and 5 appendices

ACADEMIC DISSERTATION

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Groundwater conditions, groundwater quality and factors affecting the latter were studied in the Rovaniemi district of Northern Finland and in western Nicaragua, areas differing climatically, geologically and in terms of groundwater conditions and patterns of land use.

Groundwater quality in the Rovaniemi district was studied in dug wells and some wells drilled into the bedrock, in natural springs and in three fracture zones in the bedrock. Samples of surficial deposits and bedrock were analysed to assess the effects of their composition on groundwater quality. Geophysical methods were used to identify the fracture zones. The quality of the groundwater in Nicaragua was studied in the agricultural areas of Tisma, León-Posoltega and Diriamba and in the agricultural and gold mining district of Santo Tomás-La Libertad together with that of the surface water at a number of sites, and the composition of the surficial deposits and its effects on water quality. The effects of the properties of soil on binding and transport in surficial deposits and waters were also studied.

The aquifers studied in the Rovaniemi district were virtually in a natural state. The groundwater quality was in general good and slightly acidic on average. The problems of the groundwater quality were minor and mainly due to geological origin, e.g. high iron, manganese, uranium or radon concentrations in places. Only a few of the wells showed any evidence of water quality problems caused by human activity. The research proved the feasibility of geophysical methods in locating bedrock fracture zones. Pollution and erosion are problems in Nicaragua. Toxic residues partly due to previous cultivation of cotton were found in many wells. The shallower wells had fairly high nitrate concentrations and high counts of coliform bacteria. The deep drilled wells had groundwater of good quality. The groundwater was mostly neutral or slightly alkaline. Especially in rainy seasons detrimental substances and also nutrients are transported with erosional material to lower areas, waterways and are also infiltrated to groundwater. On the other hand the composition of surficial deposits with well weathered expanded lattice clays are able to retain toxins well and retard their passage into the groundwater.

Key words (GeoRef Thesaurus, AGI): environmental geology, ground water, water quality, water wells, springs, surficial geology, soils, drilled wells, fracture zones, surface water, geochemistry, hydrochemistry, pollution, weathering, Rovaniemi, Finland, Nicaragua

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INTRODUCTION AND PURPOSE OF THE RESEARCH

The best-known aquifers in Finland are mostly located in large eskers or other sand or gravel formations. There are many centres of population, however, that still rely on surface water sources as there are no adequate groundwater reserves in the vicinity. Abundant rainfall can cause problems where surface water supplies are concerned, through pollution with flood water, for instance, and spells of warm weather can cause problems with algal growth. There are many places in Finland where the aquifers contained in surficial deposits are susceptible to pollution on account of the shallow depth of cover material, the proximity of settlement or other forms of land use.

Where groundwater accounted for only 15 % of the raw water supplies to waterworks in Finland in the 1950s, the figure was about 33 % in 1970 (Saviranta & Vikman 1990) and about 59 % in 2002, according to the Finnish Environment Institute (http://www.vyh.fi/hoito/vesihuo/hankinta/hankinta.htm). The aim is that the proportion should reach 70 % by 2010, which would mean that 56 % of the population would be using groundwater in their homes. According to The Finnish Environment Institute 4.5 million inhabitants are being served by municipal waterworks and about 0.7 million rely on small water consortia, cooperatives or private wells. It should also be noted that 9 % of the water distributed by public waterworks is artificial groundwater produced by basin recharge or sprinkler methods (http://www.vyh.fi/hoito/vesihuo/hankinta/hankinta.htm).

Private wells are still used in the more sparsely populated parts of the Rovaniemi district and in most cases they are dug wells in till or sandy deposits. Bedrock drilled wells are not as common as dug wells and bedrock groundwater is rarely exploited by municipal waterworks. Bedrock groundwater can be a good alternative to groundwater from Quaternary deposits, particularly in areas where reserves of the latter are inadequate, and it can also be a safe alternative in the event of environmental hazards, especially in places with a thick surficial cover, as it is improbable that toxic substances could seep through substantial horizons of densely packed material. These reserves may also be needed in the event of more widespread environmental disasters or climate changes if these lead to long periods of drought and consequent reduction in conventional groundwater and surface water reserves. Bedrock fracture zones are of significance both for the availability of groundwater and for the assessment of environmental impacts, as faults and fracture zones direct the flow of water in the bedrock and regulate the spread of dissolved substances into the surroundings, allowing their influence to extend over substantial distances in places. Bedrock fracture zones can have good groundwater supplies, as an example the Leppävirta municipality in eastern Finland, where is enough water available in the drilled bedrock wells for the needs of approximately 6000 inhabitants of the municipality. The best yield in drilled wells of these fracture zones was in a depth of less than 100 metres from the ground surface (Rönkä et al. 1992, Tikkanen et al. 1994).

The Rovaniemi district in Northern Finland was chosen as part of the study because of its abundant data of Quaternary deposits and bedrock of earlier researches. The data on Quaternary deposits in the Rovaniemi area

(Map sheet 3612) required for the present purposes were extracted from the Geological Survey's Quaternary mapping data. A map of these deposits (scale 1:100 000) has been published for the area (Kujansuu 1975), and also a map sheet explanation to this (Kujansuu et al. 1982), and a more recent map, to a scale of 1:20 000, has been published for the map sheet 3612 04-12 (Väisänen et al. 1993, Nenonen et al. 1994, 1996, Väisänen & Maunu 1996, Johansson et al. 1996, 1997, 1998a, 1998b, Mäkinen & Väisänen 1998). This mapping also entailed determination of groundwater quality by means of samples from wells and natural springs. A new set of bedrock data for the Rovaniemi area was generated in the 1990s, the map sheet explanation being published by Perttunen et al. (1996) and the map itself by Väänänen et al. (1997).

Research in the Rovaniemi district was carried out into the quality of groundwater in the Quaternary deposits and fracture zones of the bedrock. In the case of the Quaternary deposits the emphasis was on esker chains and till areas, where assessments were made of the effects of the geological and geochemical properties of the material and land use on groundwater quality. In the case of bedrock groundwater, the purpose of the study was to test geophysical methods for locating fracture zones and assess the effects of the composition and geochemical properties of the bedrock on the groundwater quality. It is important to know geological properties of the bedrock for locating bedrock groundwater aquifers as possible paths for contaminants in bedrock fracture zones. Attention was also paid to the differences in quality between the bedrock and Quaternary aquifers.

The initiative for the studies in Nicaragua was received from two universities, Universidad Nacional Agraria (UNA) and Universidad Nacional Autónoma de Nicaragua (UNAN), and the study areas for the research were chosen with cooperative partners from the universities. The interest for the research was focused on western, densely populated agricultural areas and on the coastal area, where erosion, storms and flooding annually in rainy season cause problems. The aim of the study was to investigate in these areas presumed contamination of groundwater, surface water and surficial deposits. The farms for the research were chosen together with the collaborators and municipal agricultural advisors, who personally knew local farmers and circumstances of the farms.

The gold mining district of Santo Tomás-La Libertad was chosen to be part of the study at a proposal of local civil cervants and environmentalists. The research data was needed for civil cervants for planning water supply system of the area for instance.

The climate, geology, groundwater circumstances and forms of land use in Nicaragua differ greatly from the situation in Finland. The areas studied in Nicaragua are located around 12° N lat., while the Rovaniemi district lies close to the Arctic Circle, at 66° N lat. The annual mean temperature in Rovaniemi is +0.2°C (Ilmatieteen laitos 1991), while those for most of Nicaragua are in the range +25 … 30°C, and annual precipitation in Rovaniemi is just over 500 mm, whereas in western Nicaragua it varies approximately from 1200 mm to 1800 mm (Hodgson 1990, JICA & INAA 1993). The Rovaniemi region has an ancient bedrock and the Quaternary deposits which have accumulated over a period of 2-3 million years. Nicaragua, in turn, has in its western part numerous young volcanoes and deposits composed of the products of their eruptions, while its unconsolidated sediments otherwise consist of ancient weathering products.

Groundwater problems are in Nicaragua extremely common. Serious environmental loading and pollution is encountered, and, for a variety of reasons, environmental management and protection have been neglected. Little notice is taken of the environment laws, and not enough is done to enforce them. As in many other developing countries, agriculture in earlier times took the form of the exclusive cultivation of a small number of crops, e.g. cotton, for many years consecutively, and this has led to pollution of the environment on account of the protracted use of large quantities of toxic chemicals. The concentration on just a few crops may also lead to impoverishment of the soil, and the water and wind erosion experienced in many places has destroyed the cultivable horizon completely. The high rates of evaporation from the ground surface further compound the problems in areas, which in any case suffer from a shortage of water.

It is essential to possess a good knowledge of the geological and geochemical properties of surficial deposits and groundwater characteristics such as directions of flow and the quality and quantities of the water available in order to trace the transport, binding and disintegration of detrimental substances in the environment. The long-term use of toxic chemicals can be regarded as posing hazard for the health of humans and animals. These substances are transferred and enriched in food chains, passing from the soil and water into plants and thereby - as well as directly, through drinking water - into animals and human beings.

The emphasis in the research conducted in Nicaragua was on the quality of the groundwater and surface water, the geological and geochemical characteristics of the surficial deposits and the effects of land use on water quality. The purpose was to get an overall picture of groundwater quality in the Rovaniemi district and the study areas of Nicaragua, and indicate differences between groundwater quality in the Rovaniemi region and Nicaragua due to different geological situations, climate and land use.

EARLIER RESEARCH

The majority of the numerous groundwater studies carried out previously in Finland have been concerned with aquifers in areas of eskers and other Quaternary formations, whereas little work has so far been done on the exploitation of bedrock aquifers, earlier work of this kind having dealt mostly with groundwater quality, although also to some extent with its availability (Laakso 1966, Lahermo 1970, 1991a, 1991b, Hyyppä 1973, 1976, 1986, Hartikainen 1976, Niini 1977, Rönkä 1983, Rönkä & Uusinoka 1980, Rönkä et al. 1980, 1992, Mälkki 1983, Lahermo & Blomqvist 1988, Valkiainen et al. 1992, Luukkonen et al. 1997, Karro & Lahermo 1999, Roman & Peuraniemi 1999, Roman et al. 2000, 2001, Tikkanen 2001). Some of the work has been concerned with radioactivity in groundwater, mainly radon concentrations (Asikainen & Kahlos 1977, Castrén et al. 1977, Juntunen 1991), and some with groundwater in both bedrock and surficial deposits. Other work has been directly connected with investigations into possible sites for the final disposal of nuclear waste, involving descriptions of bedrock properties and groundwater flows and their interactions extending to depths of as much as a kilometre. Research into bedrock aquifers has also touched upon the hydraulic properties of crush zones (Leveinen et al. 1998, Leveinen 2001) and the testing of geophysical methods (Vesterinen et al. 1988, Rönkä et al. 1992, Tikkanen et al. 1994, Lanne et al. 1998, Lanne & Väisänen 1999, Lanne et al. 2002). Further research has been carried out into saline groundwater in the bedrock of coastal areas (Lahermo & Kankainen 1986, Mitrega & Lahermo 1991, Ahonen & Blomqvist 1994), and the modelling of bedrock aquifers (Pitkänen et al. 1988, Hautojärvi & Rasilainen 1991, Simbierowicz & Olin 1991).

Some of the groundwater research in the Rovaniemi district has been connected with national surveys, but separate work has also been carried out. Lapland Regional Environment Centre has studied groundwater occurrences near Rovaniemi in the eskers Jokkavaara, Kolpeneenharju, Kroopinpalo, Palovaara, Mäntyvaara, Mellavaara and Kuolajoki in order to determine the amounts of water contained in them and its quality. A survey of hydrogeological conditions, including directions of groundwater flow, permeability of Quaternary deposits, pumping tests, drillings and geophysical measurements, has been conducted in the Jokkavaara esker with a view to the creation and extraction of artificial groundwater. An inventory of sand and gravel resources and groundwater reserves together with a land use plan was produced for the Rovaniemi Rural District Council in 1993 (Väisänen 1997).

The Finnish Environment Institute carried out national surveys of well water in the 1960s and 1990s (Wäre 1961, Korkka-Niemi et al. 1993, Korkka-Niemi 1994, 2001), which included data on groundwater quality and its spatial and seasonal variations. The earlier of these projects also included a few sites located close to Rovaniemi. The same institute also conducted a monitoring programme over the whole country in 1975-1999 in which records were kept of the groundwater table and the quality of the water (Soveri et al. 2001).

A national investigation into the quality of the groundwater available in sparsely populated areas and environmental factors affecting this was carried out by the Geological Survey of Finland in 1978-1982, involving some 5900 sites (Lahermo et al. 1990), including some in the Rovaniemi district, and the same organization initiated a new groundwater monitoring programme in 1992 that included four sites in the immediate surroundings, where analyses of water quality were made four times a year (Backman et al. 1999). The most recent survey of groundwater, extending over the whole country, took place in 1999 and involved assessments of the quality of the water in 1000 wells (Tarvainen et al. 2001, Lahermo et al. 2002).

A joint project was initiated by the National Institute of Health, the Geological Survey of Finland, the Radiation and Nuclear Safety Authority and the National Cancer Registry in 1996 with the aim of creating a scientific basis for evaluating the health risks associated with substances ingested with drinking water in Finland, the main emphasis being on drilled wells (Gustavsson et al. 2001). Particularly interesting were the results obtained with regard to arsenic and radioactive substances contained in groundwater.

Many of the investigations into the surface waters and groundwater reserves, surficial deposits and state of the environment in Nicaragua have taken place in the context of development aid, and a number of them have been devoted to mapping the occurrence of toxic residues in surface waters, groundwater and surficial deposits or to solving cases of toxic effects on people or animals. The greatest proportion of these studies have been focused on the surroundings of the capital, Managua, and other densely populated areas in the western part of the country (Hodgson 1990, 1997, Mathus & Beck 1991, Lacayo & Fomsgaard 1992, Plata et al. 1994, Scharp 1994, Beck 1996, Bethune et al. 1996, Cuadra et al. 1997, Hradezký 1997, Lacayo et al. 1997, Lacayo 1998, Krásny & Hecht 1998, Johansson et al. 1999, CIGEO 1999). By comparison, very little information is available on the situation in the more sparsely populated interior of the country, and most of it is based on more specialized small-scale investigations (e.g. Spalke 1993, Empresa Minera La Libertad 1994, Vázquez 1995, 1996). More prominent work has nevertheless been carried out on the dissemination of mercury and lead from gold mining at Santo Domingo in the surficial deposits and waterways of the Sucio and Siquia river basins in the uplands of the interior (Mendoza 1997, Rosén 1997), and a plan for the utilization of water reserves in the country as a whole has been produced jointly by Danish advisers and a number of Nicaraguan organizations (Ministerio del Exterior 1997). The Japan International Cooperation Agency also carried out a development aid project connected with water supplies in the Managua area in the early 1990s, in which accounts were produced of the groundwater reserves of the area, the quality of the water and the composition and structure of the surficial deposits. Similarly, an international development programme devoted to the “Sustainable Use of Water Resources in the Cuenca Sur del Lago de Managua” has been carried out in the catchment area south of Lake Managua. There have also been a number of research projects concerned with erosion and the effects of volcanic eruptions on composition of surficial deposits (e.g. Nimlos 1992, La Femina et al. 1994, Webber et al. 1994, Alfsen et al. 1996).

The studies in Nicaragua for this research were carried out in a small pilot project in 1994 and in 1997-2000 in the projects with the aid of the Ministry of Foreign Affairs of Finland, Department of Development Cooperation (Kukkonen et al. 1995, 1998a, 1998b, 1999, Laitinen et al. 1999, Väisänen et al. 2000, 2001).

OCCURRENCE OF GROUNDWATER AND FACTORS AFFECTING ITS QUANTITY AND QUALITY

The best groundwater reserves in surficial deposits are to be found in thick beds of highly permeable, coarse, sorted material such as those in eskers or marginal formations, and also in littoral and river bed deposits. The groundwater cycle is rapid in coarse, well-sorted material and the water is well oxygenated, so that the amounts of dissolved substances are small. Thick, coarse-grained Quaternary deposits in Finland usually contain aquifers that are at least 5-10 metres in depth and often over 20 metres, and it has been calculated that the water stored in an esker will usually correspond to 5-10 times the quantity forming from the annual precipitation (Kauranne et al. 1972). Wells sunk into esker aquifers for the purposes of raw water extraction frequently have yields of 1000-3000 m³/day. A well with a yield of 1000 m³/day requires a groundwater formation area of 1-1.3 km² (Mälkki 1999).

Tills are normally classified as being of low hydraulic conductivity, and areas of basal till with a high proportion of fines and a dense structure are usually only able to provide enough water for private households. The conductivity of cohesive type of Quaternary deposits such as finesand, silt and clay is low, and again groundwater yields will be poor, although the situation will be affected by the presence of more permeable horizons beneath them and also by the nature of the bedrock.

The groundwater table in till areas of Finland is customarily at a depth of about 2-4 metres, and can be as deep as 30-50 metres in eskers (Kauranne et al. 1972). Monitoring results compiled by the Finnish Environment Institute over the period 1975-1999 for a total of 53 sites in different parts of the country suggest that seasonal fluctuations in the groundwater table are of the order of 0.1-1.0 metres, with a mean of 0.6 metres (Soveri et al. 2001).

Groundwater in bedrock flows through spaces formed by crush zones, faults and fractures, and yields are affected above all by the extent of fracturing, which is in turn dependent on the rock types present and their fracturing properties. Crush zones and fracture systems in bedrock generally vary in length from a few kilometres up to some tens of kilometres (Härme 1961). Most wells drilled into intact bedrock yield sufficient water only for use by individual households. Rönkä (1983) maintains that the mean yield for wells drilled into the bedrock in Finland is 28.5 m³/day, according short length pumping (24 hours), that for acidic igneous rocks (e.g. granite) 27.9 m³/day (mean for 195 wells), that for schists 28.9 m³/day (124 wells), that for mafic rocks (e.g. gabbro)

26.9 m^3/day (33 wells) and that for rapakivi granite 31.1 m^3/day (7 wells). The best yields in his material were achieved with wells of depth 41-50 metres (Rönkä 1983). Another source quotes figures of 51 m^3/day in granite or granite-gneiss areas, 57 m^3/day in mica schists and 18 m^3/day in quartzite (Tie- ja vesirakennushallitus 1970).

Volcanic rocks, as are commonly encountered in Nicaragua, have highly desirable hydraulic properties in this sense. Basalts, for example, frequently have a high incidence of fracturing and blister structures, while the weathering crusts that develop on lava deposits in the intervals between volcanic eruptions can be of considerable significance for hydraulic conductivity (Mälkki 1999). The thicknesses of weathering crusts of volcanic and metamorphic rocks can commonly reach more than 30 metres, or even 100 metres in places in the tropics (Thomas 1974). The pronounced evaporation that takes place in tropical regions detracts somewhat from groundwater recharge.

The groundwater recharge is regulated by the amount of precipitation, evaporation, the proportion of the precipitation received in the form of snow, the duration of ground frost, the nature of the vegetation, the topography, the moisture content of the soil and the thickness, material composition, structure and porosity of the surficial deposits. Over 50 % of the annual precipitation received by an area can be absorbed into the groundwater in eskers in a natural state, for example, and the proportion can even reach 75 % in gravel pits (Hatva et al. 1993).

Ollier (1969) quotes porosities of 25 % for gravel, 35 % for sand, 40 % for silt and 45 % for clay and in bedrock porosities of 1 % for granite and basalt, 10 % for limestone, 18 % for schists and sandstones. In the end, the presence of fracture zones and cracks is more significant for groundwater yields from bedrock than are the fracturing properties of the rock types or their porosity. Groundwater quality is influenced by the rock types present in the bedrock and overlying deposits, the geochemical properties of the minerals and their resistance to weathering. The solubility of elements depends on the reactions which they are capable of undergoing under low-oxygen or anoxic conditions. The amounts of substances dissolving in groundwater increase with residence time, so that concentrations in spring water, with a rapid turnover, will be 2-4 times less than those in dug or drilled wells (Lahermo et al. 1990). Electrical conductivity, which generally reflects the amounts of dissolved substances, tends to be lowest in the coarse-grained, highly permeable horizons of eskers and to increase in other soil types and formations in the sequence: other sand and gravel deposits < glaciofluvial deposits < littoral deposits < ice-marginal end moraine complex < cover moraine < morainic landform < fluvial deposits < other clay < Litorina clay (Korkka-Niemi 2001).

The most common problem with groundwater quality in Finland arises from excessive iron and manganese. This concerns in particular groundwater contained in clay and other fine-grained deposits, in which reducing conditions prevail, which promote the dissolving of ferrous iron and manganese (Backman et al. 1999). Especially the iron-bearing sulphide minerals present in mica schist and black schist areas are easily soluble in the groundwater, giving it a detrimentally high iron content. Sulphur and heavy metal concentrations are higher than average in the tills and esker materials of black schist areas and the groundwater is more than usually acidic (Loukola-Ruskeeniemi 1999, 2001). Acidity, warming of the climate and alterations in land use can frequently have the effect of increasing the environmental mobility of heavy metals (Tarvainen 1996).

The majority of bicarbonate (HCO_3^-), the most common anion in groundwater, is of atmospheric origin or derived from carbon dioxide contained in the soil pores or generated through the decomposition of organic matter, although some is also the result of the dissolving of carbonate minerals (Lahermo et al. 1996). The decomposition of organic matter also gives rise to organic acids, predominantly humic and fulvic acids, which acidify the surface of the podzol horizon and promote the leaching of nutrients and trace elements bound to the soil particles out of the soil (Boyle & Voigt 1973, Petersen 1976, Andersson 1988).

Groundwater composition is influenced by dry and wet deposition on the ground surface, and it is these that constitute the principal sources of sulphur and nitrogen compounds (SO_2, SO_4^{2-}, NO_x, NO_3^- and NH_4^+), chloride and sodium. At least 70 % of the nitrogen deposition is in the form of NO_3^- or NH_4 nitrogen, mostly on account of the increase in the volume of traffic (Lahermo et al. 1990). Some of the sulphate present in this airborne deposition is derived from sulphur dioxide, most of which enters the atmosphere as a consequence of the combustion of fossil fuels (Lahermo et al. 1996).

Rain and the meltwater from snow also affect groundwater quality. Pleym (1991) maintains that the pH of rainwater is 5-6 if no changes in quality have been caused by human activity. Pollution from industry, traffic and agriculture nevertheless increases the quantity of dissolved substances in the groundwater and can lead to a reduction in pH.

The poor buffer capacity of the Finnish Quaternary deposits is attributable in part to the Precambrian bedrock, which is poor in calcium and contains large numbers of acidic rock types, and in part to the limited mean thickness of the overlying deposits, so that the water percolating through them has little opportunity to dissolve minerals. This means that the groundwater is mostly slightly acidic and susceptible to further acidification and contains little in the way of calcium or magnesium salts or other dissolved substances (Backman et al. 1999).

Volcanic eruptions entail the release of huge quantities of gases into the atmosphere, including sulphur dioxide (SO_2), carbon dioxide (CO_2), hydrochloric acid (HCl) and hydrofluoric acid (HF), which can react together to produce various compounds, of which the most significant is sulphuric acid (H_2SO_4) (Andrews et al. 1996). Changes in groundwater quality can also be brought about by excessive extraction of water relative to the size of the aquifer.

The majority of the substances dissolved in groundwater are derived from the weathering of minerals (Hall et al. 1996), which may take place either mechanically, chemically or biologically. The rate at which a rock type is affected by weathering depends on the conditions under which it was laid down, the chemical properties of the minerals, the chemical reactions themselves, the amounts of water influencing the reactions and the prevailing climate. The higher the temperatures at which the minerals have formed, the more easily they will be affected by weathering (Goldich 1938). Thus granite, for example, which crystallizes out of the magma at about 600°C, is very much more resistant to weathering than are the magmatic rocks that form at 1200°C (Driscoll 1986). The susceptibilities of certain rock types to weathering, after Mälkönen (1976) and Qvarfort (1989), are presented in Table 1.

Chemical weathering processes lead to the release of basic cations, so that the pH of the soil water rises. The susceptibility of silicate minerals in bedrock or surficial deposits to weathering is dependent on their crystalline structure and chemical composition (Lahermo et al. 1996). Laterite, commonly encountered in the tropics, includes large amounts of the oxides of iron and aluminium, and it may also contain large amounts of quartz and kaolinite (Thomas 1974). Silicon that has been released by weathering usually becomes enriched *in situ*. In tropical areas it is more soluble than aluminium or iron, so that soils tend to be deficient in it (Koljonen 1992). Upon the weathering of silicates the free cations are also

Table 1. Susceptibility of certain rock types to weathering (Mälkönen 1976, Qvarfort 1989).

Extremely prone to weathering	Prone to weathering	Weather normally	Resistant to weathering	Very resistant to weathering
calcite-bearing rocks - limestones - marble	basic rocks - greenstone - gabbros - diabases - diorites - basalts - mica schists	gneisses granites mica schists	granitic surface rocks, quartz-rich porphyries	pure quartz rocks - quartz-sandstone - quartzite

available to adsorb to clay and humus particles through cation exchange processes. These readily exchangeable cations nevertheless remain only temporarily bound, on account of their weak electromagnetic forces (Appelo & Postma 1996). The susceptibilities of silicates to weathering, after Goldich (1938) and Berner (1971), are presented in Figure 1.

The final product of the weathering of silicates is gibbsite, or aluminium hydroxide

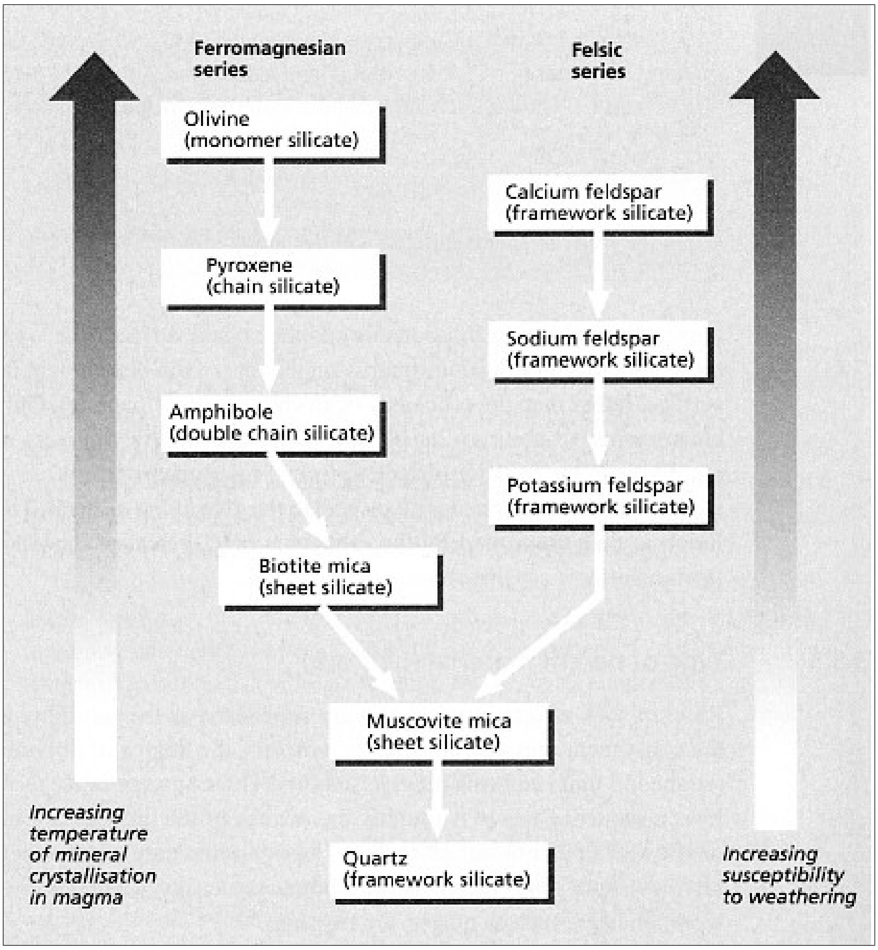


Fig. 1. Susceptibility of silicates to weathering, after Goldich (Goldich 1938, Berner 1971).

$[Al(OH)_{3\ gibbsite} \leftrightarrow Al^{3+} + 3OH^{-}]$. Gibbsite is typically found in tropical areas with an abundant rainfall. Aluminium is also to be found in abundance in schists, gabbros and basalts, granites and granodiorites, sandstones and kaolin, occurring in the latter in the form of kaolinite, $Al_2Si_2O_5(OH)_4$ (Koljonen 1992, Reimann et al. 1998).

Other weathering products are e.g. illite and vermiculite $[(Mg, Fe, Al)_3(Al,Si)_4O_{10}(OH)_2 \times 4H_2O]$. Illite, which is a variety of muscovite containing water molecules, can also be further weathered to yield vermiculite or smectite (Melkerud 1983). Of these clay minerals, smectite in particular has weak ion bonds, so that ion exchange will readily occur. Thus Birkeland (1974) notes that smectite has a cation exchange capacity of 80-100 mE/100 g (dry wt.), chlorite and illite 10-40 mE/100 g and kaolinite 3-15 mE/100 g. The granitic rocks encountered in Finland have higher uranium and radon concentrations than do most ordinary rocks. The uranium-bearing minerals zircon and monazite are fairly resistant to weathering, but apatite weathers easily (Koljonen 1992).

DETRIMENTAL SUBSTANCES IN GROUNDWATER AND SURFICIAL DEPOSITS

Detrimental substances contained in groundwater and surficial deposits are elements or inorganic or organic compounds that pose a risk to health. Some of these substances accumulate in the body over a period of time. The main means by which such substances are transported in surficial deposits is water, in which they may be dissolved in the form of ions or organic or inorganic metal complexes, suspended in the humus, bound to soil particles or present as gases (Yong et al. 1992). Some of these detrimental substances eventually decompose, others are retained in the surficial deposits, while others pass into the surface water or groundwater, and some compounds such as chlorated water-soluble hydrocarbons decompose in the surficial deposits to yield harmless products. The majority of the substances entering the soil through dry or wet deposition are retained there or in the plants, and heavy metals are also efficiently retained in the soil. Some compounds are decomposed by microbial action in the root zone, some being reduced to forms in which the plants can use them as nutrients for growth. Where a cool, moist climate prevails, the detrimental substances in the surficial deposits mostly move in a downward direction, but in a warm, dry climate they will move upwards (Kabata-Pendias & Pendias 1992). Some bacteria are able to metabolize iron and manganese, causing these to be precipitated, usually in bands at the interface between the oxidative and reducing parts of the soil stratigraphy. Reactions of this kind are also exploited nowadays in the biological treatment of waste water (Mälkki 1999). Microbiological decomposition processes are slow in Finland, on account of the cold climate and nutrient-poor soils, but are very much faster in a tropical climate such as that of Nicaragua.

The transport of detrimental substances in the surficial deposits takes place by advection, diffusion, dispersion or evaporation. Advection means that dissolved or suspended substances are carried with the moving water (Tolppanen 1989, Setälä & Assmuth 1990), while diffusion is based on the movement of molecules and their tendency to equalize out any irregularities in the distribution of substances in a medium, and is the most efficient form of transport in fine-grained or poorly sorted overburden or material with a small pore size such as fine-grained tills and clays (Soveri & Kauranne 1972, Aalto 1985). The transport of material as a consequence of diffusion together with mechanical mixing caused by variations in groundwater flow rates is referred to as dispersion (Wierenga 1996). These three types of transport, advection, diffusion and dispersion, are affected by the structure of the surficial deposits, the quantity of water present in them, temperature and the amounts of compounds forming complexes and colloids. Evaporation is a significant mechanism in the case of elements and compounds with a high vapour pressure, such as mercury, selenium, arsenic, cyanide and organic compounds (Tolppanen 1989, Yong et al. 1992).

The retention of detrimental substances in the soil takes place principally by sorption, a term which is frequently used to cover a wide range of mechanisms that apply to everything from liquids to solids (Yong et al. 1992), i.e. adsorption, cation exchange, complex formation, absorption and co-precipitation. Adsorption implies that molecules or particles from a gaseous or liquid facies become attached to the surface of another substance, and this is also the case in effect with cation exchange reactions and the formation of complexes, while absorption implies inclusion in the structure of the other substance. In the case of co-precipitation the attachment may be either superficial or structural. Retention of detrimental substances by absorption or co-precipitation is more permanent than by adsorption (Schulin et al. 1995, Räisänen 1989a). Retention is influenced not only by the composition and structure of the surficial deposits but also by chemical conditions such as acidity, redox status and the chemical properties of the detrimental substances themselves, as these may form organic or inorganic complexes or chelates with water-soluble compounds or bind to colloids (including oxides and hydroxides of iron and manganese), humus or clay minerals or silicon compounds possessing a negative surface charge (Rose et al. 1979, Heikkinen 2000).

Detrimental substances are retained more permanently by ions with a small molecule, such as fluorides or hydroxyls, than by ones with large molecules, such as nitrates or perchlorates, as the former are themselves more durable. Some more heavily charged ions, such as phosphates or carbonates, bind cations, and thus also detrimental substances, and are less soluble than nitrates or perchlorates, for instance (Yong et al. 1992). Some of the most efficient binders of detrimental substances among the organic compounds are those containing a negatively charged group, e.g. the fulvic acids or humin. An inorganic compound will bind inorganic detrimental substances such as heavy metals, arsenates and cyanide most effectively, while an organic compound will bind organic substances, but also heavy metals (Leppänen 1998).

The highest cation exchange capacity, and also the highest capacity for binding detrimental substances, is possessed by organic material, and also vermiculite and smectite among the clay minerals, as these have the highest specific surface areas (Kauranne et al. 1972, Rose et al. 1979, Yong et al. 1992). The consequence of this is that the surficial deposits that contain the finest material and the largest proportions of organic matter, i.e. that have the highest specific surface areas, contain considerably more heavy metals than the coarse-grained types that contain little organic matter. Thus the concentrations of many heavy metals in clays are two or three times those to be found in the fine fractions of till (Salminen et al. 1997).

The purification of water contaminated with detrimental substances that has percolated into the ground is most efficient in the soil layers and in the gravitational water zone above the groundwater table, where biological activity is most pronounced (Sandborg 1993). Bacterially contaminated water can be purified by passage through a permeable layer of fine-grained material to a depth of 4-5 metres, or even 2-3 metres if the Quaternary deposits are covered by a humus layer (Hatva 1985). Purification will slow down in the groundwater layer itself, but will continue if oxygen is available, dissolved in the water. The purification of contaminated groundwater requires a long flow distance, and observations suggest that the residence time should be at least 50-60 days (Hatva 1987). The groundwater table in eskers is often at such a depth that there is little danger of the water being contaminated if the area is in a natural state.

The rate of contamination of groundwater depends on the hydrogeological conditions, e.g. the thickness of the surficial deposits, their grain size, compaction and exchangeable ion capacity, the amount of groundwater present and its rate of flow. Flow and recharging rates are relatively rapid in eskers, and flow rates can be as much as 2-15 m/day in gravel horizons and up to a few kilometres a day in volcanic and sedimentary aquifers (Mälkki 1999). Detrimental substances can spread rapidly with groundwater flow over extensive areas under such conditions, of course, and contaminated groundwater from the surficial deposits can sink as far as the bedrock crevices and fractures.

Many of the substances dissolved in groundwater are essential trace elements at low concentrations but may be harmful when present in abundance. Chloride with high concentrations is regarded as possibly carcinogenic (Komulainen 1996) and fluoride is also detrimental at higher concentrations (Sosiaali- ja terveysministeriö 1994). Bromide, Br^-, is generally held to be harmless, but bromate, BrO_3^-, is deleterious and the quality recommendations for drinking water set its upper concentration limit at 10 µg/L (Sosiaali- ja terveysministeriö 2000). It is conveyed into the environment after weathering as sea spray and in the gases erupting from volcanoes, for instance (Koljonen 1992). High nitrate or nitrite concentrations can pose risks on account of the nitroso compounds that can form in the body, which have been shown in animal experiments to be carcinogenic (Hallikainen 1993). Nitrogen is found in minerals principally in the form of ammonium ions, NH_4^+, and as it is available for use by plants in this form. This means that ammonium concentrations in water are usually low (Lahermo et al. 1996).

Sulphur is harmless in elemental form but many of its compounds, such as SO_2 and H_2S, are toxic (Reimann et al. 1998). Barium is also toxic in solution (Koljonen 1992). Molybdenum, selenium and certain nickel compounds are important trace nutrients, but are toxic at high concentrations. Most nickel compounds are fairly soluble at $pH < 6.5$ but insoluble at higher pH. Nickel enters the environment mainly through human activities and volcanic eruptions. Cobalt is also toxic at high concentrations, and is distributed in the environment through weathering, industrial emissions and fertilizers (Reimann et al. 1998).

Soluble aluminium is toxic to humans, water organisms and especially fish (Driscoll et al. 1980, Baker & Schofield 1982, Henriksen et al. 1984, Hall et al. 1985). In humic water aluminium tends to form complexes bound to organic matter. Under tropical conditions mobility of aluminium enriched in laterites is poor (Koljonen 1992). Al^{3+} is the dominant form of aluminium present under acidic conditions, insoluble aluminium hydroxide, $Al(OH)_3$, under neutral conditions and soluble $Al(OH)^-_4$ under alkaline conditions. As a general rule it may be presumed that aluminium is not in a soluble form at pH between 5 and 9 (Andrews et al. 1996), but the solubility of Al^{3+} increases markedly once the pH falls below 5.5 (Reimann et al. 1998), leading Lahermo et al. (1990) to observe aluminium concentrations of over 1 mg/L in water with a pH below 5.8. Its poor mobility in alkaline environments is shown by the fact that its concentration in sea water is no more than 0.1-1.1 µg/L (Lahermo et al. 1996).

Cadmium is also toxic, but there is very little cadmium in the groundwater in Finland (Lahermo et al. 1996). Dissolved chromium is to be found in both a trivalent (Cr^{3+}) and a hexavalent form (Cr^{6+}). Trivalent chromium is fairly innocuous, but the hexavalent form is toxic (Gauglhofer & Bianchi 1991). Copper is also toxic at higher concentrations and lead is regarded as one of the most pernicious environmental toxins (Lahermo et al. 1996). Some compounds of silicon and vanadium can also be toxic (Koljonen 1992).

Moderately high concentrations of iron in domestic water supplies cause problems of taste and smell that are largely aesthetic in character, but very high levels, over 200 mg/L, for example, can be toxic. It occurs in water as ferrous iron, Fe^{2+} under reducing conditions and at pH in the range 5-8 (Appelo & Postma 1996). Ferric iron, Fe^{3+}, is soluble only under highly acidic conditions, pH <3.0 (Berner 1978, Hatva 1989, Hem 1989, Lahermo et al. 1996).

The inorganic arsenic compounds are more toxic than the organic ones, and trivalent arsenic is more toxic than pentavalent (World Health Organization 1981). It is present in water and surficial deposits most often in inorganic forms, certain of which have been shown to be carcinogenic. The passage of arsenic compounds into the environment takes place mostly through weathering of rocks or volcanic activity, together with human activity. Its solubility is low at pH values close to 7, but it is more soluble under highly alkaline conditions than under highly acidic ones (Pantsar-Kallio & Manninen 1997).

The uranium frequently occurring in granite is the origin of this radon, ^{222}Rn, which is the most dangerous of the radioactive substances to be found in water due to the cancer risks involved. Radon has a half-life of 3.8 days. The recommendation of radon concentrations in domestic water should be below 300 Bq/L (Sosiaali- ja teveysministeriö 2001) and the private wells below 1000 Bq/L. High uranium and radon concentrations in nature are usually to be found in the same areas, although not necessarily in adjacent wells, for instance. The reason for this lies in the deviant geochemical behaviour of radium-226, which is an intermedi-ate in the series of uranium degradation products. High radon concentrations measured in private drilled wells in Finland are in areas with a granite bedrock (Salonen 1994).

Some detrimental substances are highly resilient, e.g. chlorphenols, and others are metabolized, e.g. ammonium, which is oxidized to nitrate in well oxygenated water (Hatva 1987). Once loads become too great, these toxins can no longer be retained in the surficial deposits, however, but enter the surface water and groundwater (Harmsen 1977, Stigliani 1995, Schulin et al. 1995).

Toxic residues in soil and water are an especially serious problem in developing countries, where these substances have been in widespread use for decades. Toxic chemicals are traditionally classified according to their purpose and chemical composition, i.e. the nature of the effective ingredient (Turunen 1985).

Insecticides are divided into organochlorine compounds, i.e. chlorated hydrocarbons, organophosphorus compounds, carbamates, which are similar to the organophosphorus compounds in their mode of action, and natural plant-based insecticides and their derivatives. In addition to these traditional chemicals that affect the nervous system of insects and mammals, a number of regulators of insect growth, synthetic compounds that function in the manner of hormones, have been developed. Efforts are nowadays being made to move away from the use of organochlorines, which are slow to degrade and the most dangerous to the environment, and to favour compounds that are less persistent. Environmentally harmful organochlorines such as DDT, lindane and endosulphane, which are poorly soluble in water but highly soluble in fats and therefore accumulate easily in the fatty tissues of human beings and animals (Turunen 1985).

Rodenticides are mainly hydrofluoric acid derivatives, those in common use being anticoagulants, i.e. their efficacy is based on the prevention of blood coagulation. The most common herbicides, or weedkillers, are phenoxy compounds (2,4-D, MCPA), carbamates, propachlor and atrazine, while others include the benzoic acid derivatives and certain ammonium compounds such as paraquat, which is also toxic to humans, causing lung damage. The herbicides damage the cell membrane structures in plants and interfere with photosynthesis.

The fungicides, used to prevent plant diseases, include both inorganic heavy metal compounds and organic compounds, and contain a wide range of effective ingredients. They are not usually particularly toxic to mammals, but some exceptions are to be found, such as the dinitrophenol derivatives and organic mercury compounds used for seed dressing, the latter being capable of accumulating in the brain, kidneys and liver and of passing into a foetus through the placenta or into a mother's milk via the mammary glands. The action of fungicides is based on disturbance of intracellular functions (Turunen 1985).

The binding of pesticides in the surficial deposits, their transport into surface waters and groundwater and their degradation are dependent on the composition and chemical properties of the substances and surficial deposits concerned and on local climatic conditions. The grain size, the specific surface area of the grains, organic matter content and its quality, pH and redox conditions, water permeability, compaction and porosity, the ability to bind clay minerals and precipitates (sorption properties) and the amounts of exchangeable cations present influence binding and transport of toxic chemicals (Matinvesi et al. 1994). Correspondingly, the relevant properties of the toxic substances themselves are those that affect the nature of the chemical bonds. The photolytic stability, i.e. the extent to which they are degraded under the influence of ultraviolet or visible light, their biological activity, or how susceptible or resistant they are to decomposition by soil microbes, and their adsorption properties, or how easily they will bind to soil particles affect the stability of these chemical bonds. The transport of toxins in surficial deposits is usually evaluated in terms of their solubility in water and their binding capacity with respect to organic matter, as they usually enter rivers or lakes through surface runoff or on account of erosion, being bound to soil particles in water. Changes in acidity of surficial deposits or water can affect the binding or degradation of some substances (Torstensson 1987).

Toxins are decomposed to water, carbon dioxide and inorganic compounds, and this may take place in stages, through the formation of intermediates or metabolites, which can be more or less harmful than the original compound and may be degraded more slowly or more rapidly. The half-life quoted for a toxic chemical usually indicates the time required for this first stage in degradation to take place (Laitinen 1997). Chemical and microbiological reactions take place more slowly at greater depths in the surficial deposits than at the surface, which means that the degradation of toxic substances will be slower (Torstensson 1987, Heinonen-Tanski 1986). In general, they are regarded as being rapidly degradable if they have a half-life of less than a week, moderately slowly degradable is they have a half-life of 1-3 months and very slowly degradable if their half-life exceeds 8 months (Ylä-Mononen 1993).

Proposals were made on the initiative of the United Nations as long ago as 1971 for the restriction or banning of the use of the more dangerous toxic chemicals such as DDT, dieldrin and toxaphene. The banning or restriction of these persistent organic pollutants (POP) are presently negotiated world-widely, consisting among other things of aldrin, dieldrin, endrin, DDT, chlordane and toxaphene. The use of the most dangerous pesticides was prohibited in Nicaragua in 1993 (Comisión Nacional de Agroquímicos). In addition to POP restrictions were placed on certain others, notably chlordimeform, aldicarb and parathion methyl (Beck 1996).

DESCRIPTIONS OF THE AREAS STUDIED

The Rovaniemi area in Northern Finland

The Rovaniemi district as studied here is situated on sheet 3612 of the 1:100 000 Basic Map of Finland (66°25'-66°40' N lat., 25°30'-26°06' E long.) (Fig. 2). The map sheet covers an area of 799 km^2, 9.4 % of which are waterways (Väisänen et al. 1993, Nenonen et al. 1994, 1996, Väisänen & Maunu 1996, Johansson et al. 1996, 1997, 1998a, 1998b, Mäkinen & Väisänen 1998).

According to records for Rovaniemi Airport (195 m a.s.l.) the area has a mean annual temperature of +0.2°C and mean annual precipitation of 535 mm, while measurements made at the Apukka meteorological station 20 km to the north-east (106 m a.s.l.) give a mean annual temperature of -0.2°C and a precipitation of 522 mm. In both cases these means are for the normal period 1961-1991 (Ilmatieteen laitos 1991).

The topography of the area is characterized by hills and NW-SE-oriented valleys. The influence of the bedrock on the topography is to be seen in the river valleys, the bedrock of which contains fracture and weakness zones in places, the largest of these being the NW-SE-oriented crush zone forming the valleys of the rivers Ounasjoki and Kemijoki (Kujansuu et al. 1982). Lake Kursunkijärvi to the south of Rovaniemi also lies in a bedrock fracture zone (Väänänen et al. 1997). Absolute altitudes vary in the range 63-243 m a.s.l., the lowest-lying areas being in the Kemijoki valley in the south-western part of the area and the highest on the tops of the hills Silmäselkä (243 m), Iso

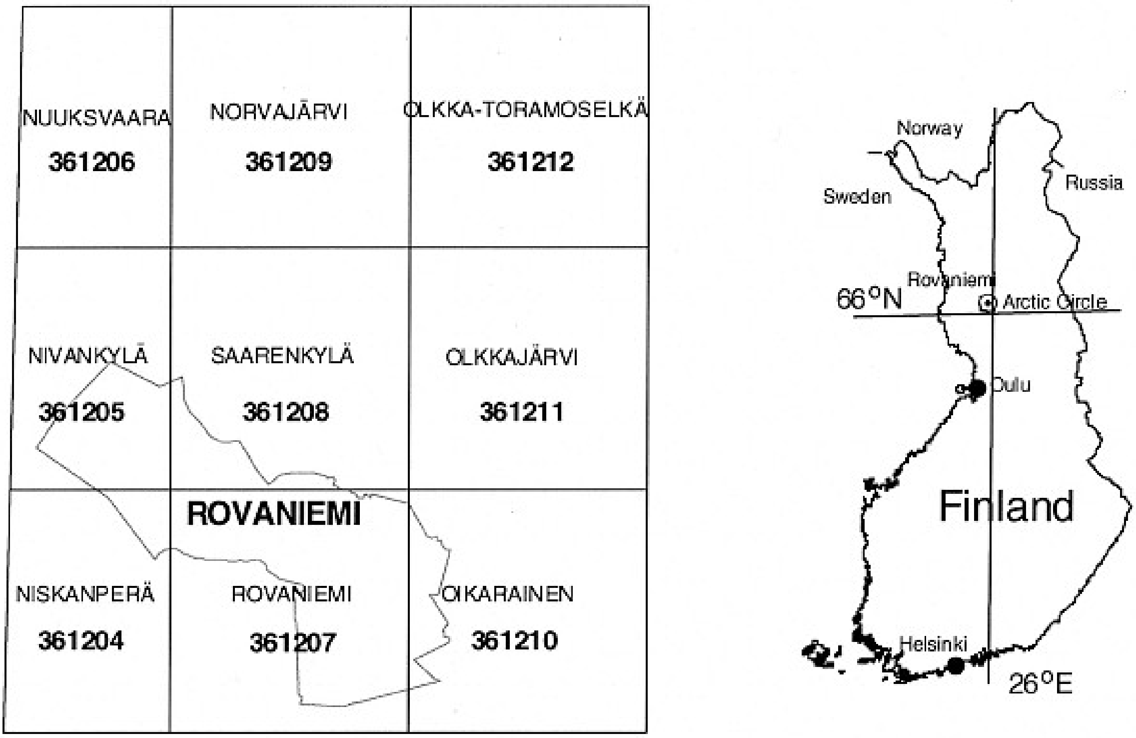


Fig. 2. The area studied in the vicinity of Rovaniemi, map sheet 3612 (1:100 000).

Olkkavaara (231 m), Vennivaara (229 m), Ronikivalo (227 m), Nuuksvaara (223 m) and Isorakka, part of Ounasvaara (213 m). The terrain rises regularly northeastwords in such a manner that the lowest parts in the northeastern part of the area are at an elevation of about 140 m a.s.l. (Kujansuu et al. 1982).

Bedrock of the Rovaniemi district

The bedrock of the Rovaniemi district may be broadly assigned to two major stratigraphic units of distinctive composition (Fig. 3), the Central Lapland Granitoid and the Palaeoproterozoic Peräpohjola Schist Belt (Perttunen et al. 1996). The northern part of the area is dominated by migmatites and granites, the main rock types of the Central Lapland Granitoid. Being resistant to weathering, these form a continuous area of hills. The porphyric granite that intersects with the migmatites in plac-

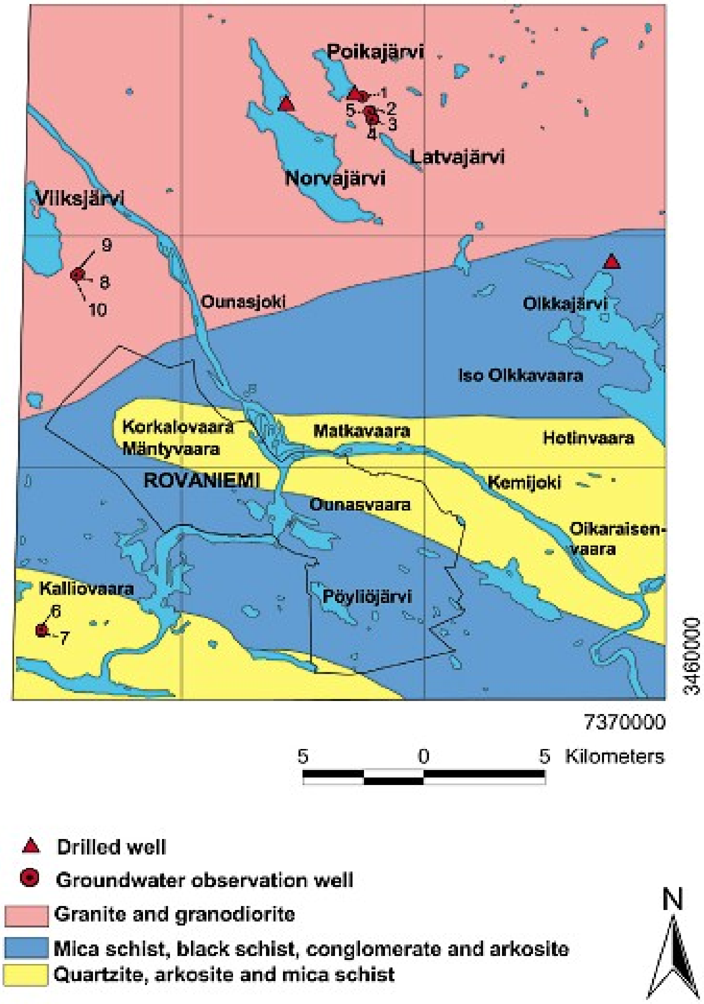


Fig. 3. Bedrock of the Rovaniemi district, generalized from Väänänen et al. (1997), and the sites of the groundwater observation wells and bedrock drilled wells studied in the area. Base map©National Land Survey of Finland, Permission number 516/MYY/03.

es is about 1770 Ma in age, and this may be taken as a minimum age for the migmatites themselves. The principal minerals in this porphyric granite are potassium feldspar, quartz, plagioclase and biotite, with some magnetite etc. present as well, while the granite also contains some titanite and zircon, which incorporate radioactive uranium and thorium. The southern part of the district features some well-preserved schists, sedimentary rocks of the Palaeoproterozoic Peräpohjola Schist Belt that are composed of highly resistant quartzites and also calcareous arkosites, mica schists, mica gneisses and amphibolites in places, with ages of 2500-1890 Ma. The schists of this southern area can be divided into a number of lithostratigraphic units, the Kalliovaara, Ounasvaara, Iso Olkkavaara, Hotinvaara and Oikaraisenvaara Formations (Perttunen et al. 1996, Table 2).

The Kalliovaara Formation, which covers a considerable proportion of the southern part of the map sheet area, is probably several hundred metres thick, while the Ounasvaara Formation is well exposed around Juhannuskallio, Keskirakka and Isorakka and on the summit of Korkalovaara, around which granite and pegmatite dykes in quartzites are common. The Iso Olkkavaara Formation has been subject to substantial recrystallization and features large amounts of granite and pegmatite in the form of dykes and disseminations. The Oikaraisenvaara Formation is principally composed of arkose quartzite and arkosite, with varying concentrations of mica and calcium silicate, while the Hotinvaara Formation is mainly grey sericitic and arkositic quartzite, with mica gneiss in its uppermost part (Perttunen et al. 1996).

The Korkiavaara, Mäntyvaara, Matkavaara and Kiimajänkä Formations are mostly composed of arkosites, a substantial proportion of which contain carbonate and calcium silicates. Associated with these arkosites are massive or layered amphibolites and mica schists.

The Korkiavaara Formation is located between Kalliovaara and Lake Pöyliöjärvi in the

Table 2. Bedrock stratigraphy of the Rovaniemi map sheet area, after Perttunen et al. (1996).

CENTRAL LAPLAND GRANITE COMPLEX	granites (1770 Ma), migmatites, metasediment and volcanite lithodemes (Hamaramaa volcanogenic-sedimentogenic lithodeme)
INTRUSIVE ROCKS	diabases, gabbros, granite disseminations and dykes
PALAEOPROTEROZOIC SUPRACRUSTAL ROCKS	
PÖYLIÖJÄRVI Formation	mica schists and gneisses, interlayers of graphite and pyrite-bearing schists, calcareous schists and amphibolites
KORKIAVAARA Mäntyvaara, Matkavaara and Kiimajänkä Formations	arkosites, calcareous arkosites, mica schists and mica gneisses, amphibolites (mafic volcanites)
KALLIOVAARA Ounasvaara, Iso Olkkavaara, Hotinvaara and Oikaraisenvaara Formations	quartzites, arkosites, arkose gneisses, mica schists and mica gneisses

southern part of the map sheet area, while the markedly folded Matkavaara Formation has been deposited on top of the Iso Olkkavaara Formation and is composed of alternating calcium silicate-bearing arkosites, mica schists and possibly massive amygdaloidal amphibolites in places.

The Mäntyvaara Formation consists of calcium silicate and carbon-bearing arkosites and amphibolites, while the Kiimajänkä Formation, which is superimposed on the Hotinvaara Formation, is known only through a few tremolite boulder fields and arkosite exposures. Uppermost in the stratigraphy are the mica gneisses and schists of the Pöyliöjärvi Formation, which constitute the most common supracrustal rocks in the area alongside the quartzites. Also associated with these are pyritic schists and black schists, and the formation similarly contains aluminium-rich mica gneisses with garnet inclusions, among other things. This garnet mica gneiss forms layers many tens or even hundreds of metres in thickness that can be followed for a number of kilometres. The arkositic rocks and mica schists include both sodium-dominated and potassium-dominated types, and the mica schists throughout the map sheet area are relatively rich in iron (Perttunen et al. 1996). The bedrock fracture zones of the study are located in the northern part of the area with migmatites and granites and in the southern part with schists and quartzites.

According to the classification in Table 1 the rocks of the Rovaniemi district are moderately susceptible to weathering or somewhat resistant. The typical granite minerals of the Rovaniemi district, plagioclase, biotite and potassium feldspar, give rise to kaolinite, $Al_2Si_2O_5(OH)_4$, upon weathering, at the same time releasing sodium, calcium (from plagioclase), magnesium (from biotite), potassium (from biotite and potassium feldspar) and bicarbonate (from all three) and leaving quartz as a residue (Appelo & Postma 1996). The magnetic pyrites commonly found in black schists weather more readily than do iron pyrites (Sipilä & Salminen 1995).

Finland can be divided into major geochemical provinces, and a further division of these into smaller areas in which elements with similar geochemical properties exist together, as a result of either enrichment or impoverishment. According to Koljonen (1992) the northern part of the Rovaniemi district belongs to the Central Lapland granitoid region, which has a bedrock composed mainly of granites and contains very few alkaline rocks. The granitoids comprise mainly quartz, feldspar and schists (biotites), and the tills of the region are enriched in barium, sodium and wollastonite and impoverished among other things in arsenic, cobalt, copper, lithium, lead, sulphur, antimony and zinc. The till is also poor in most of the main nutrient elements, as is common in areas of high-silicon rocks in general. In this geochemical province division the southern part of the Rovaniemi district consists of schists and gneisses, and the chemical composition of till is near the averages for the fine fraction of till in Finland. The concentrations of bromine, cobalt, chromium, copper, iron, magnesium, molybdenum, nickel, vanadium, tungsten and zink are slightly below the average (Koljonen 1992).

Quaternary deposits of the Rovaniemi district

The dominant Quaternary deposit in the Rovaniemi district is till, accounting for 56.9 % of the land area of map sheet 3612 (Fig. 4). About 6 % of till deposits is covered with peat deposits with a thickness less than a metre. Most of till was deposited as a basal till taking the form of a cover moraine that follows the outline of the bedrock surface. A further 6.5 % of the surface area is taken up by hummocky moraines formed of unoriented till mounds and short till ridges representing groove casts. Bedrock exposures account for 4.5 % and they are at their most abundant on the top and the

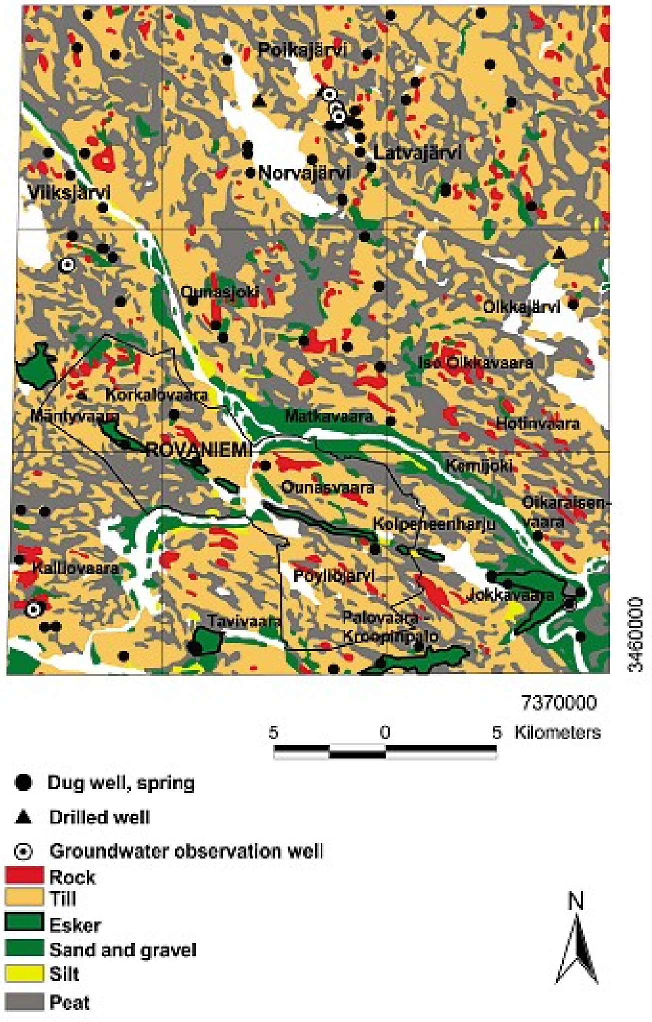


Fig. 4. Quaternary deposits of the Rovaniemi district (map sheet 3612) and springs, wells and groundwater observation wells studied in the area. Base map©National Land Survey of Finland, Permission number 516/MYY/03.

upper slopes of hills. Glaciofluvial deposits account for only 1.2 %, but they are nevertheless of considerable significance as locations of aquifers and as sources of extractable sand and gravel. They are to be found in two long esker chains (Figs. 4 and 5). Sand and gravel are also to be found in littoral and fluvial deposits, which make up another 2.7 % of the land area. Peat deposits are to be found in depressions practically throughout the area, with an incidence of 25.1 % (Väisänen et al. 1993, Nenonen et al. 1994, 1996, Väisänen & Maunu 1996, Johansson et al. 1996, 1997, 1998a, 1998b, Mäkinen & Väisänen 1998) and a mean thickness of over two metres (Kujansuu et al. 1982). The mean thickness of the Quaternary cover as a whole is 14.5 metres (Mäkinen 1975), since, although such material is frequently absent from the crests of the hills and is generally less than two metres thick in such places, it can reach several tens of metres in the larger eskers and in the river

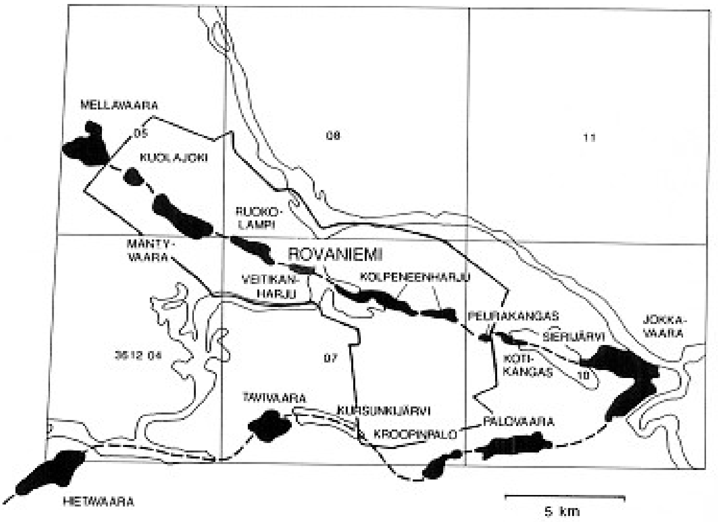


Fig. 5. The eskers of the Rovaniemi district. The directions of flow of the glacial rivers responsible for their deposition are marked with broken lines. Base map©National Land Survey of Finland, Permission number 516/MYY/03.

valleys (Kujansuu et al. 1982). The mean thickness of Quaternary deposits in Northern Finland is 5.9 metres (Mäkinen 1975) and that for Finland as a whole 8.6 metres (Okko 1964).

The Rovaniemi district has been buried beneath a continental ice sheet on several occasions in the course of the 2-3 million years of the Quaternary era, as evidenced by the existence in numerous places of till horizons of differing ages and distinct character in terms of structure, colour, grain size and the rock types of the stones contained in them. Three such deposits have been encountered in Rovaniemi itself, the two younger ones being assigned to the Weichselian glaciation (Ber & Kujansuu 1974). Horizons of sorted material have been found between these two till beds at Saarenkylä, north of the city centre, for instance, and gyttja and silt layers between the youngest two beds and the oldest one attributable to the Eemian Interglacial (Sutinen 1992), i.e. to the time interval 130 000-117 000 B.P. (Mangerud 1991). This allows the oldest till horizon to be interpreted as dating from the Saalian glaciation, over 130 000 B.P. Another site where layers of sorted and organic material have been found beneath till is at Häkinvaara in the rural district of Rovaniemi (Sutinen 1992), and peat with ^{14}C dates of >35 000 and >42 700 years B.P., has been found between two till horizons at Permantokoski, 20 km east of Rovaniemi (Korpela 1969).

Although it is estimated that the climate during the Peräpohjola Interstadial was somewhat colder than at present (Korpela 1969, Hirvas 1991), it has been deduced from microfossils contained in the organic gyttjas and peats located between the till horizons that there must have been periods when it was warmer than nowadays, as it is evident that the fern *Osmunda regalis* was growing in the Rovaniemi area during the warmest phase of the last interglacial, the Eemian (Sutinen 1992).

There is little evidence in Northern Finland of till horizons dating from before the Weichselian glaciation, the few observations to date having been made in Central and Eastern Lapland (Hirvas 1991, Johansson 1995). According to Mangerud (1991), the Early Weichselian occurred around 117 000-75 000 B.P., the Middle Weichselian around 75 000-25 000 B.P. and the Late Weichselian around 25 000-12 000 B.P.

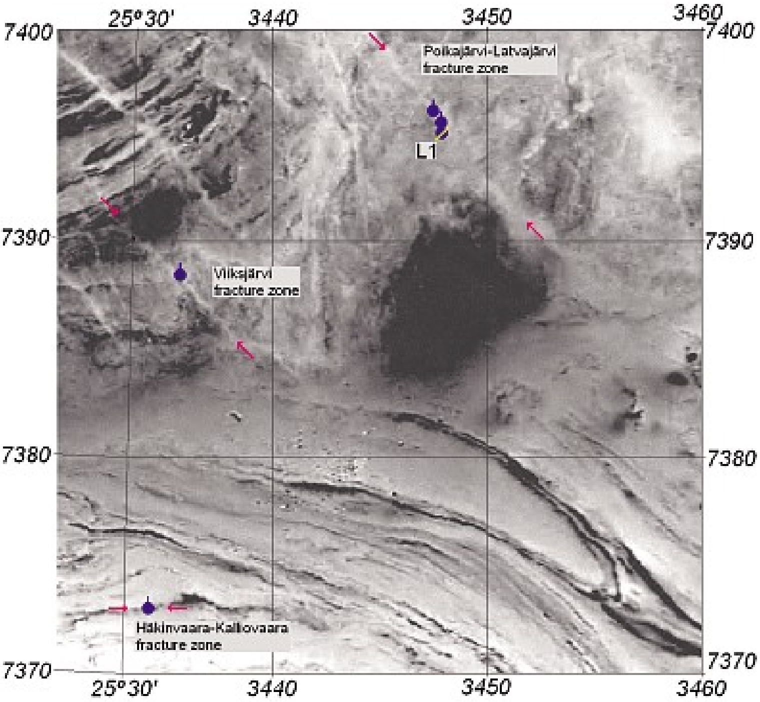


Fig. 6. Grey-tone map of the Rovaniemi map sheet area (3612), based on low-altitude aeromagnetic data obtained by the Geological Survey of Finland. The Poikajärvi-Latvajärvi and Viiksjärvi bedrock fracture zones are visible as light-coloured streaks. The sites of the groundwater observation wells are presented with balls. The line L1 shows the site of the seismic soundings and ground resistivity soundings in the Poikajärvi-Latvajärvi fracture zone.

The direction of glacial flow during the Early Weichselian, as deduced from striae, was 335°-345° (Korpela 1969), and this is also reflected in the topography of the area in the Rovaniemi district and the fracture zones in its bedrock, as identified in low-altitude geophysical measurements made by the Geological Survey of Finland (Fig. 6).

The youngest direction of glacial flow, applying to the very last stage in the Late Weichselian, was between west and WNW, 270°-295° (Hirvas 1991). This stage, which was notable for the transport of till in the area, is represented by 285° striae and grooves on the rock face of Juhannuskallio on the summit of Ounasvaara (Kujansuu et al. 1982).

It is generally accepted that the Rovaniemi district emerged from beneath the ice of the last glaciation just over 10 000 years ago (Saarnisto 2000), although with the exception of the summits of the highest hills, it remained covered by the waters of the Ancylus Lake for some time. The highest markers of the Ancylus shoreline were deposited at a time when the water depth in the area was generally over 100 m, the highest identified ancient shoreline in Rovaniemi being on the top of Ounasvaara (213 m). By 6200 B.P. the water level had reached 80 m because of land uplift (Saarnisto 1981), and that time the crests of all the eskers were visible (Fig. 7).

The biggest aquifers in the Rovaniemi district and also the best reserves of sand and gravel are found in two esker chains (Fig. 5). The northern one is running from northwest to southeast and the southern one approxi-

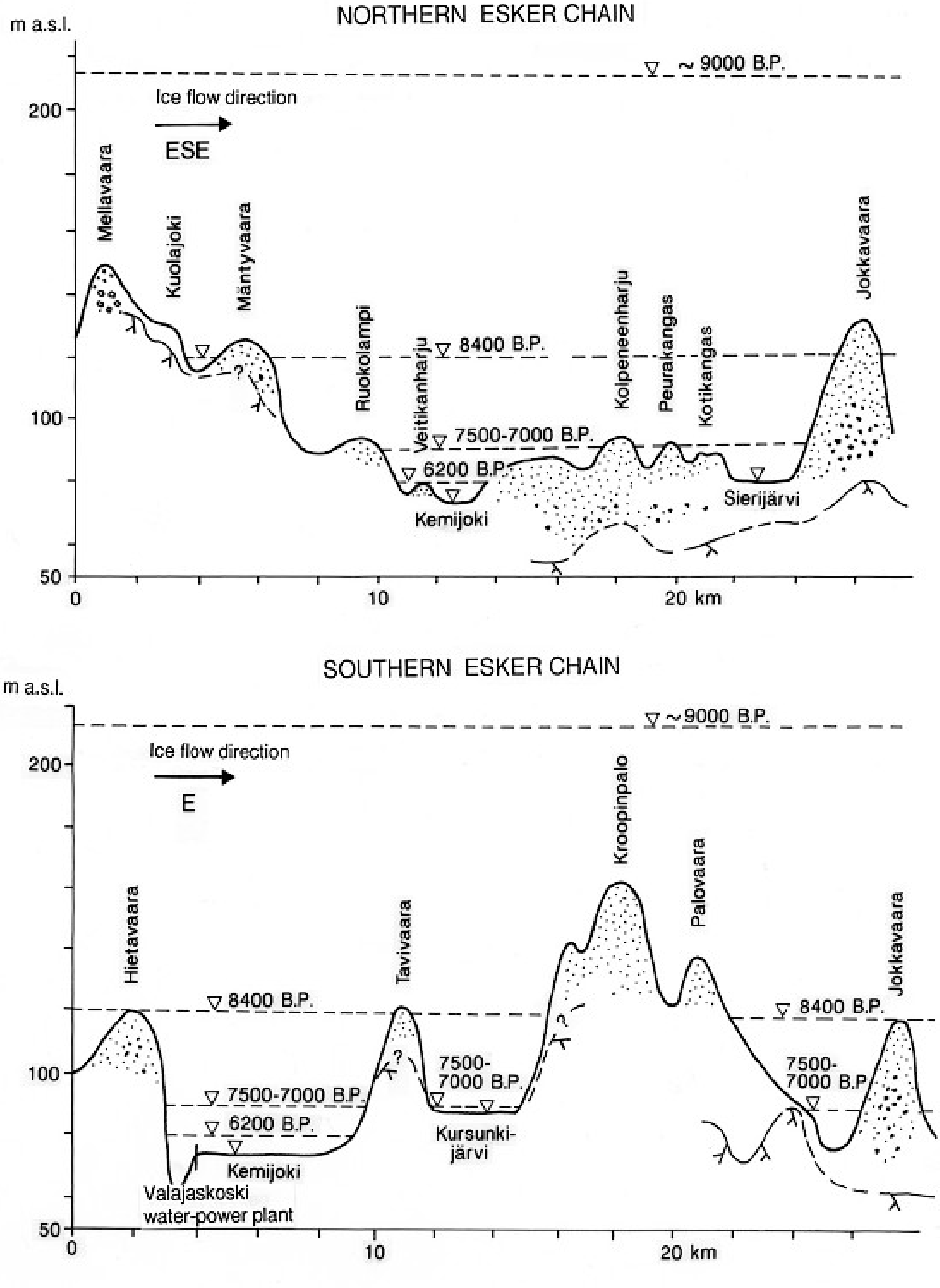


Fig. 7. Relation of esker chains in the Rovaniemi district to water level after the last glaciation. The bedrock surface depths are based on drillings and seismic soundings. The dates are based on earlier studies, according to which the glacier melted at Rovaniemi district approximately 9000 B.P. The direction of the profiles are the same as the direction of flow of the glacial rivers shown in Fig. 5.

mately from west to east. The courses of the meltwater channels that deposited these were partly determined by the terrain, the topography of the bedrock surface and the fracture zones and weaknesses in the bedrock, e.g. in the Hietavaara, Tavivaara and Kursunkijärvi areas, but there are also places where the subglacial rivers responsible for the eskers behaved in a manner independent of the immediate landforms, passing over bedrock thresholds, e.g. at Mellavaara. The reason for the latter behaviour lies in the high hydrostatic pressure generated in the network of tunnels and channels through which the water flowed in the base of the glacier, which caused the meltwater to flow "uphill" in places. The Jokkavaara esker formation in the Rovaniemi district marks the junction of the major esker chains (Fig. 5). The esker formations typically possess flat tops, on account of the levelling action of the water that covered them immediately after melting of the glacier, and some of them have delta-like plateaux (Kujansuu et al. 1982).

Both the city of Rovaniemi and the rural district are supplied with groundwater from the eskers of Jokkavaara, Kroopinpalo-Palovaara, Kolpeneenharju, Mäntyvaara and Mellavaara, the pumping stations being distributed over a wide area in order to avoid overloading the aquifers at particular points. As much as 9000 m³/day has been extracted from Kolpeneenharju for use by the city of Rovaniemi at times, and a figure of 8888 m³/day was still recorded in the mid-1990s (Britschgi & Gustafsson 1996).

Since the esker is only 1.7 km² in area, however, and the estimated rate of groundwater recharge is 1400 m³/day, this represents a considerable level of over-exploitation. More recently, extraction from this source has been reduced as new pumping stations have been opened. The groundwater from Kolpeneenharju in any case had to be filtered through an additional soil bed after pumping in order to reduce its iron content, and the use of other sources enabled this costly practice to be discontinued. The mean groundwater consumption in the city of Rovaniemi in 2001 was 8000 m³/day (Pertti Määttänen, Director of Water Supplies and Refusal Disposal, Rovaniemi City Council, pers. comm.).

Jokkavaara is one of the most significant Quaternary formations in the Rovaniemi district as far as both groundwater reserves and sand and gravel extraction are concerned, and is classified by the Finnish Environment Institute among the major groundwater areas in the country. With a surface area of 5.7 km² and a mean annual precipitation of about 500 mm, it has a calculated charge rate of about 4100 m³/day, if we assume that 60 % of the precipitation will contribute to the groundwater (Väisänen 1997). Since it has been estimated that the amount of water stored in the aquifer may be equal to 5-10 times that received annually from precipitation (Mälkki 1986), it may be concluded that Jokkavaara contains some 7.5-15 million cubic metres of water at any one time. Rovaniemi Rural District Council began groundwater pumping there in 1978 (Kujansuu et al. 1982), and the mean extraction rate in 1996 was 1900 m³/day (Britschgi & Gustafsson 1996). It was estimated in the late 1980s that the esker contained some 53 million cubic metres of sand and gravel (Johansson et al. 1989) and the thickness of the Quaternary deposits at its centre before large-scale extraction began was more than 50 metres (Väisänen 1997). Valid permits still exist for the extraction of sand and gravel from Jokkavaara, in addition to which large quantities have been obtained from Kroopinpalo and Hietavaara.

The subglacial meltwater systems that gave rise to the eskers also included erosional landforms created by the rivers, as exemplified by the intervening exposed rock faces, e.g. between Jokkavaara and Palovaara and between Mäntyvaara and Mellavaara. A similar patch of exposed bedrock is encountered southwest of Hietavaara, where the potholes of

Sukulanrakka were formed.

Glaciofluvial erosion was less marked in the southern part of the area, on account of the quartzite bedrock, whereas the northern part featured somewhat softer rocks. It is in this quartzite area that the eskers of Hietavaara, Tavivaara and parts of Kroopinpalo and Mäntyvaara accumulated, the formation of the last-mentioned esker probably having been influenced by the location of a bedrock fault line at that point. Clear evidence of the power of the meltwater streams involved in the deposition of the eskers is provided by the thick gravel, stone and boulder cores possessed by these formations, especially in the case of Jokkavaara, Palovaara-Kroopinpalo and Hietavaara. The coarse-grained esker material is poorly sorted in places and resembles till in its grain-size distribution, which points to deposition in subglacial tunnels filled with stones, boulders and water. These coarse-grained esker cores are excellent for the creation of aquifers. The involvement of less powerful meltwater streams in the formation of the eskers of the northern chain is evident from the predominantly sandy nature of the material, the presence of gravel interlayers being indicative of fluctuations in flow (Väisänen 1997).

Nicaragua

The Central American republic of Nicaragua has a total area of 129 494 km², about one third of that of Finland, and borders on Honduras in the north and Costa Rica in the south, possessing more than 300 km of Pacific coast in the west and about 500 km of Caribbean coast in the east (Fig. 8). The climate varies between tropical and subtropical, and the vegetation ranges from rain forests to a subtropical vegetation in the Interior Highlands. The Pacific coast and western uplands experience a dry season from November to April and a rainy season from May to October, whereas rainfall is considerably higher in the eastern parts of the country, which are influenced by the Caribbean Sea. Thus annual precipitation varies from 400 mm in the western uplands to as much as 6300 mm on the damp Caribbean coast (Cunningham et al. 1984). The topography varies in western parts of the country from coastal lowlands to mountains over 1000 metres high (Fig. 9).

Outlines of the geology of Nicaragua

Nicaragua can be divided topographically and geologically into three regions: the Pacific coast, the Interior Highlands of the central part and the Atlantic coast (Fig. 8). The Pacific coast can then be divided in turn into the coastal plain and the NW-SE-oriented Nicaraguan depression, with its chain of volcanoes between the coastal plain and the depression. The volcanoes are of Quaternary origin and their peaks are mostly higher than 1000 m a.s.l. The highest peak is that of San Cristóbal, 1745 m. The Nicaraguan depression is a rift valley about 500 km in length and 50 km wide, broken up by a number of fault lines and extending from the north-west corner of the country into the northern part of Costa Rica (Weyl 1980). The lowest points in the depression lie at 35-50 m a.s.l., and it also contains the country's two largest lakes, the Lago de Managua and Lago de Nicaragua, which discharge their waters into the Caribbean Sea via the Río de San Juan. To the northeast of this depression the land rises to heights of 500-1000 m to form the uplands and mountains of the inland region. The highest mountains in the north of the country reach 1500-2000 m a.s.l.

The chain of volcanoes has arisen at the contact between two tectonic plates, as Nicaragua is located almost entirely on the western edge of the Caribbean plate, with the Cocos plate to the west tending to thrust

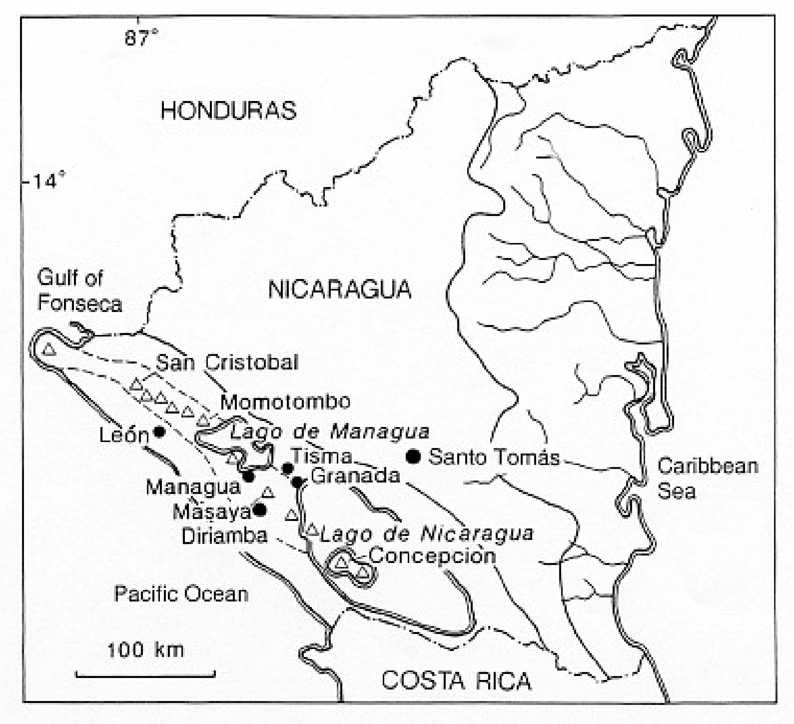


Fig. 8. Nicaragua and its regions. The volcanoes of the Nicaraguan depression are indicated by triangles (Kukkonen et al. 1995).

under it (Weyl 1980, Hodgson 1997). The area has been tectonically active since the beginning of the Cenozoic period, i.e. for about 66 million years (Weyl 1980), although the majority of the volcanoes that have arisen at the intersection between the two plates have become active only during the Quaternary (Anon. 1996). Some of them are still active today, and western Nicaragua can be regarded as a seismically unstable area on account of the plate tectonic movements (Martínez & Rodríguez 1995), as exemplified by the disastrous Managua earthquake of 1972.

It was the plate tectonic movements that raised the Pacific coastal block and created the Nicaraguan depression (Weyl 1980), in connection with the changes brought about by volcanic action over a period that began some 15 million years ago that led to the formation of an overland connection between North and South America, where there had previously been a shallow sea. Later the sea bed sediments gave rise to sandstone, schists and limestone. Some rocks underwent metamorphosis on account of the pressure and heat, and these now represent some of the oldest rocks to be found in Central America. Some of these are present in the bedrock of northern Nicaragua, for instance. The rocks of Central America can be divided into five major groups: 1) sedimentary, predominantly sandstone, schists and limestone, 2) intrusive, i.e. granite and other similar coarse-grained rocks, 3) volcanic, originating from

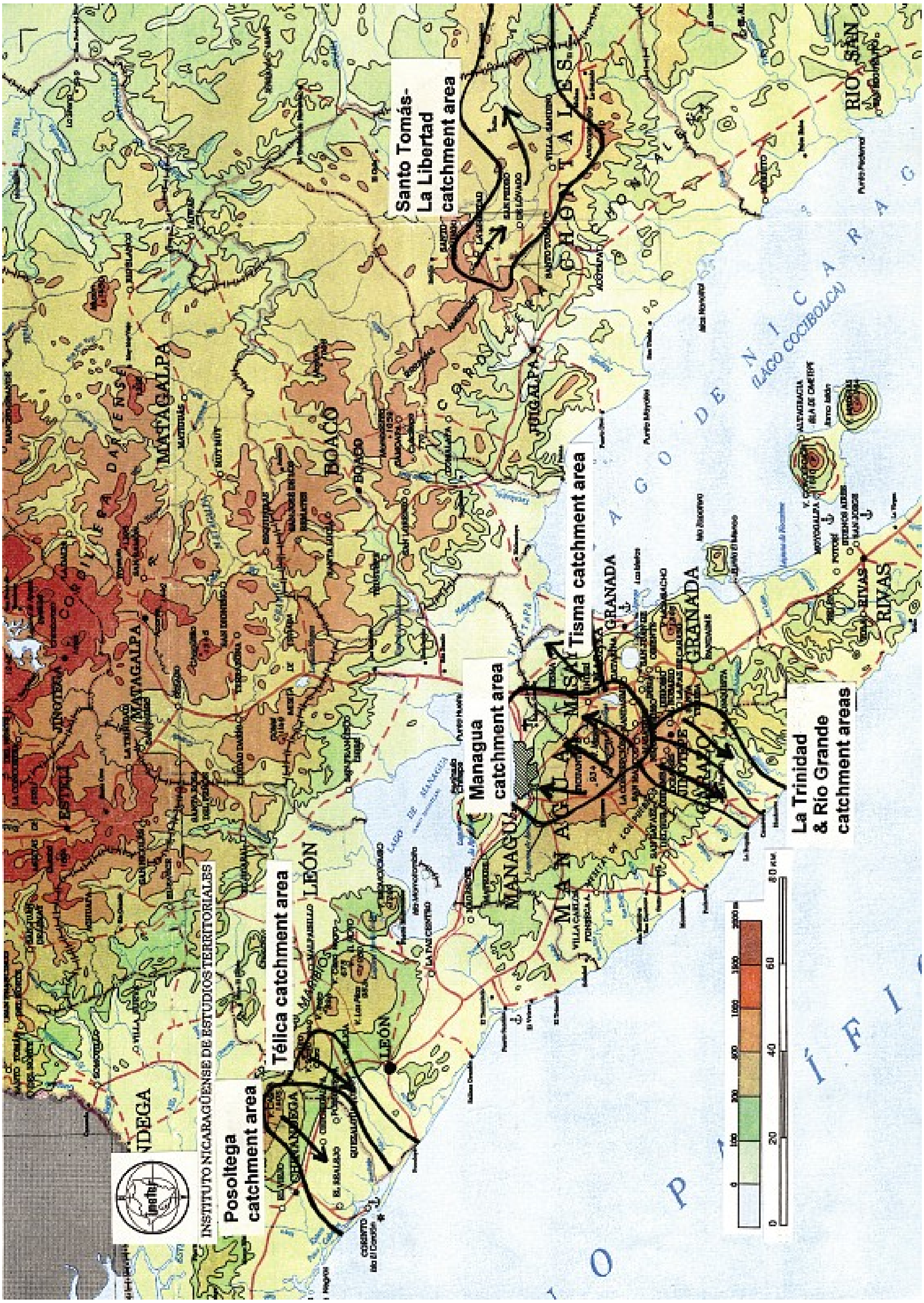


Fig. 9. The areas studied in Nicaragua modified after INETER (1991). The arrows in the catchment areas indicate the estimated directions of groundwater flow.

lava and ash, 4) ultramafic, incl. peridotite and serpentines, and 5) metamorphic, i.e. schists, gneiss, quartzite and others (Cunningham et al. 1984).

In the northern part of Nicaragua the Palaeozoic rocks (245-57 Ma) are covered by younger Mesozoic (66-245 Ma) and Tertiary formations (less than 66 Ma), while the southern part has Cretaceous deposits (66-144 Ma) overlain by thick Tertiary (65-3 Ma) volcanites and marine sediments (Weyl 1980). Tertiary volcanic deposits are commonly encountered in the Interior Highlands and mountains of the central part of the country (Anon. 1996). Thus over half of the surface area of Nicaragua is characterized by Tertiary volcanites overlying metamorphic rocks and a crystalline basement (Cunningham et al. 1984).

The hydrogeological characteristics of volcanic rocks alter over long periods of times, their porosity and permeability declining as a consequence of the filling of cavities and cracks with mineral material. Thus the pores of intact lava rock account for less than one percent of its volume, whereas in a volcanic rock of the blister lava type the figure may be 10-50 %. Also, the vertical permeability of a lava deposit will usually be low relative to its horizontal permeability, the main barriers in young volcanic rocks being veins. The pyroclastic rock materials transported in lava flows are usually porous, but they are still not particularly permeable because they contain a large amount of fines. Groundwater flow can be increased considerably, however, by the presence of alluvial, lacustrine or marine interlayers (Erdélyi & Gálfi 1988).

In the Nicaraguan depression Tertiary and Quaternary deposits – lavas and pyroclastic deposits – are overlain by alluvial sediments. The Nicaraguan depression emerged from beneath the sea about 3-1.6 Ma ago (Weyl 1980). The coastal plain between the chain of volcanoes and the Pacific Ocean consists of Quaternary and Tertiary sedimentary and volcanic rocks, for the most part overlain by marine sediments and alluvial sediments (Anon. 1996, Fig. 10). An extensive coastal area at the Caribbean Sea consists of sedimentary rocks overlain by alluvial sediments (Cunningham et al. 1984).

As seen in the stratigraphic diagram of the Quarternary deposits of the Managua district, after Hodgson (1997), presented in Figure 11, the stratigraphy is made up of volcanic debris of varying ages and pyroclastic or alluvial gravel deposits. The horizons can be divided into four groups: 1) alluvial deposits, uncemented or only slightly cemented pyroclastic layers, 3) cemented pyroclastic layers of the Las Sierras Group, and 4) rocks connected with the Nejapa-Ticomo and Miraflores lineaments. A later interpretation of the geology of the Managua district that departs somewhat from this was published in 1997 (Hradecký).

In western Nicaragua hard deposits, known as *talpetate* deposits, occur over a total area of 240 km² (Marin et al. 1971), being most common to the south and east of Managua. They are products of compacted volcanic ash. It can be compacted hard by either geogenic or pedogenic diagenetic processes, where the geogenic processes are ones that occur during deposition of the ash and the pedogenic ones are later processes of extraction and enrichment. The principal minerals involved in this cementing action are silicon and carbonates. Talpetate deposits are generally a few tens of centimetres thick and effectively prevent the penetration of water into the surficial deposits. Talpetate horizons are also to be found in other Central American countries and in Mexico and can vary somewhat in composition. Talpetate horizons are estimately to have a strength of 20-40 kg/cm², but there are some on the more gentle slopes of the volcanoes south of Managua, with gradients of 8-30 %, that have a strength of only 3-6 kg/cm². These are believed to have been laid down during a drier period than the present and undergo weathering if freely exposed to air, and they are also prone to erosion (Nimlos 1992).

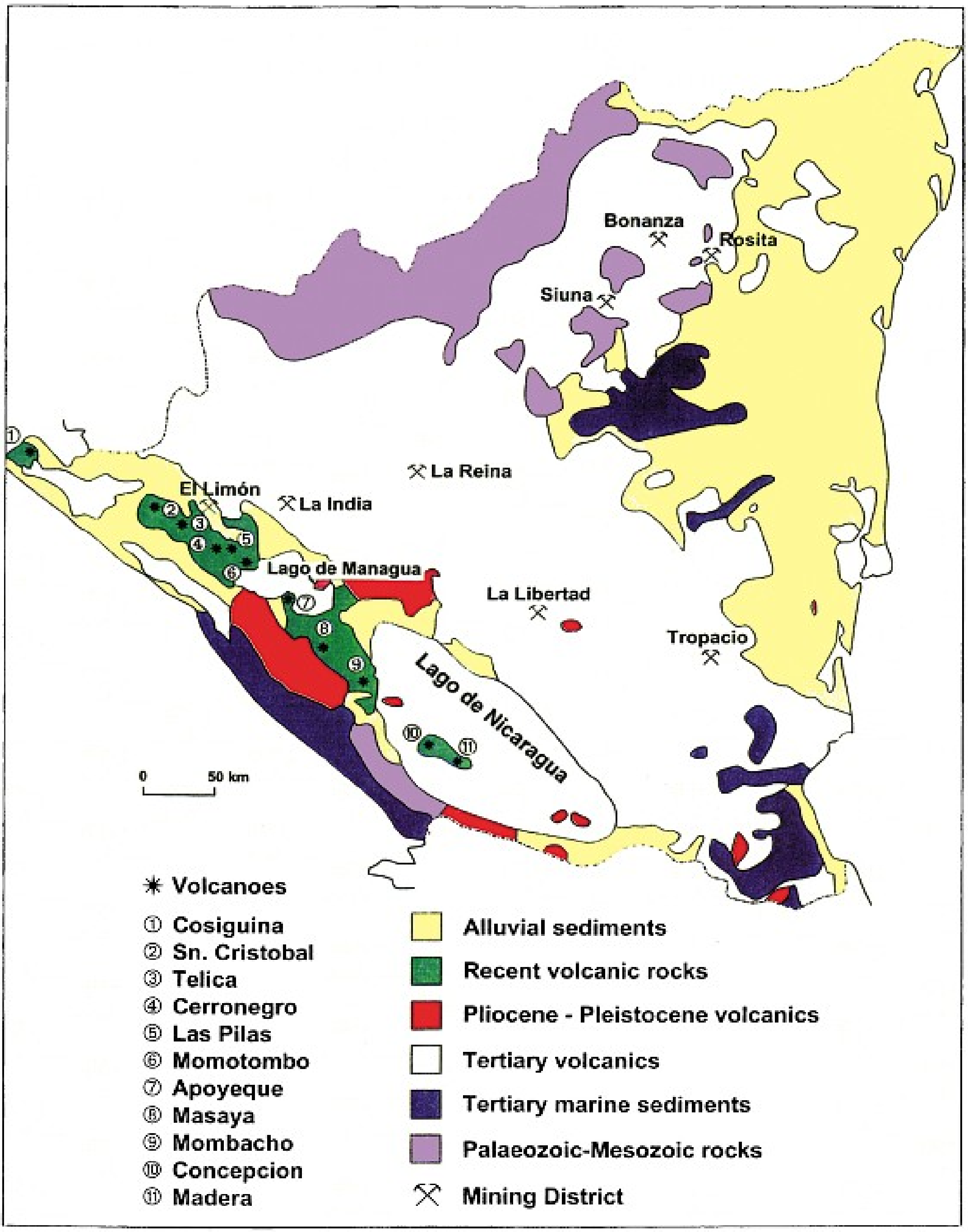


Fig. 10. General outlines of the bedrock, surficial deposits and Quaternary volcanoes of Nicaragua, with existing mining areas (Anon. 1996).

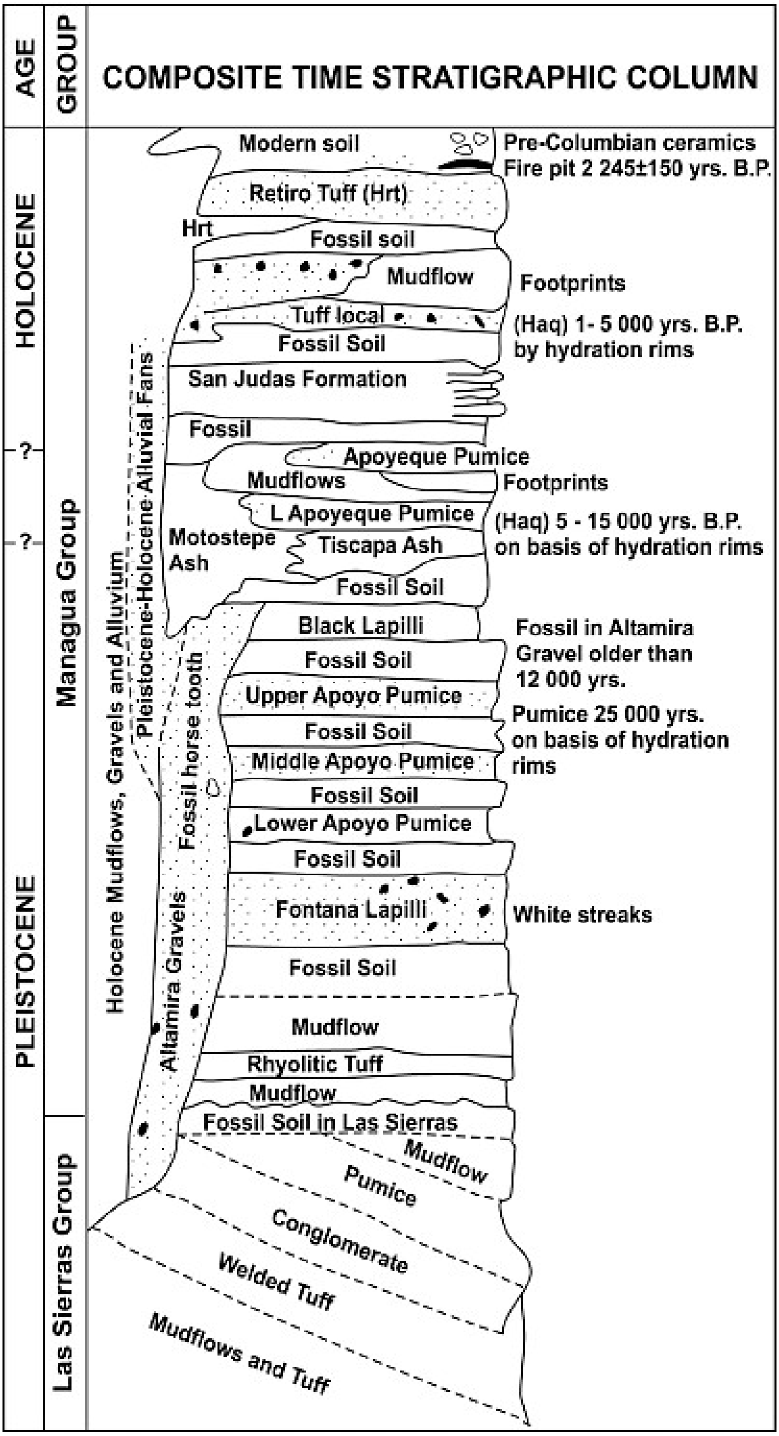


Fig. 11. Quaternary deposits of the Managua district, after Hodgson (1997). The stratigraphic sequence is about 12 metres thick (cf. Weyl 1980).

The cemented volcanic ash deposits have usually originated as tuff formed in hot ash flows, but they can also contain ash deposited directly from the eruption. The hot mixture of gas, water and ash released from the volcano condenses to tuff on cooling and becomes mixed with mineral soil, and further compaction takes place under the influence of the groundwater as silicon and carbonates leach out of the overlying unconsolidated sediments, become enriched in the tuff and are precipitated as hard material. The main properties of tuffs are their strength, density and hydraulic conductivity (Nimlos & Hillery 1990). A typical tuff deposit consists of a series of superimposed horizons, each of which may vary in thickness from a 1 to 50 metres (Nimlos 1992). These may vary greatly in compaction, and may range in density from 0.70 to 2.35 g/cm² (Ross & Smith 1961). Tuff horizons containing silicon and carbonates occur in areas with little rainfall, as heavy rains will wash the carbonate out, leaving them vulnerable to the effects of erosion. Carbonate-bearing horizons do not occur over very extensive areas in Nicaragua, partly on account of the relatively high rainfall (Nimlos 1992).

Areas studied in Nicaragua

The Tisma and Diriamba areas near Managua and the Posoltega area in the vicinity of León on the Pacific coast are all located in the western part of Nicaragua, where the majority of the country's approximately 5 million inhabitants live. The Santo Tomás and La Libertad areas, on the other hand, are situated in the uplands of the interior, about 180 kilometres east of Managua (Fig. 9).

Tisma

The area studied for the present purposes at Tisma was about 5x10 km in size and located 40 km east of Managua. The map coordinates of the village of Tisma are 12°05'N, 86°01'W. The mean annual temperature in the area is +27.5°C and mean annual precipitation approximately 1200 mm. Potential evaporation is usually higher than the actual precipitation (JICA & INAA 1993). The area has absolute altitudes ranging from 30 m to 270 m a.s.l.

The topography of the Tisma region has been affected by the eruptions of the Masaya volcano which have been recorded since 1529 (McBirney 1956). The study area is for the most part located in the Nicaraguan depression, but the terrain rises against southwest, onto the lower slopes of the Masaya volcano. The surface horizons around the Masaya volcano are extremely porous, being derived from Holocene lava flows dating back to 10 000 B.P. or less, the eruption of A.D. 1790, for instance, being known to have generated a lava horizon extending north for 20 km, almost reaching Lago de Managua. Considerable importance is assigned to these extremely permeable horizons with good hydraulic properties as far as groundwater recharge is concerned, and there can be a water-saturated layer as thick as 50-130 metres in places (Johansson et al. 1999). The northeastern part of the area lies in the Nicaraguan depression at altitudes of 30-50 m a.s.l. and the ground surface is composed mainly of flood deposits with fine sand.

An existing report on groundwater resources in the Managua district (JICA & INAA 1993) names the Tisma area as part of the main aquifer of Managua. The young lava deposits of the Tisma area are superimposed on volcanic deposits of the Las Sierras Group, denser basalts, agglomerate and tuff breccia than those to be found in the surface layers, which also feature fossilized silt interlayers of thicknesses of up to 100-250 metres. It is these that, in the opinion of Johansson et al. (1999), offer the best potential for groundwater recharge. These deposits of the Las Sierras Group are believed to overlie older Tertiary deposits known as the El Salto Formation, which is composed of tuff-bearing sandstone and sandy schists and marls. It is regarded as constituting the impermeable basal layer for the aquifers of the Managua district. The El Salto Formation has been shown by drilling to begin at a depth of about 200 metres and by geophysical measurements at 130 metres (JICA & INAA 1993).

Bethune et al. (1996) describe the Managua aquifer as comprising 400-600 m of pyroclastic sediment dating from the last stage of the Tertiary, overlain by less permeable Tertiary limestones and schists (Zoppis Bracci & Del Guidice 1958). The groundwater in the deep layers is in all probability artesian in character, while perched groundwater is to be found at higher levels in places. Quaternary flood deposits of sand, silt and clay with an admixture of volcanic ash and gravel are to be found close to Lago de Managua, but these are of little significance for groundwater recharge on account of their poorer hydraulic properties (Plata et al. 1994).

Tisma forms part of the agricultural belt of western Nicaragua, which continues northwestwards into the León district, the main crops produced around Tisma being grain and fruit for consumption in Managua. Tisma is the most important study area of UNA (The Agricultural University in Managua) which aims to develop agriculture in the area, and it was thus selected for the present study and included in the UNA project for development of the countryside. Instruction and opinion building regarding environmental protection are also among its central development objectives (Kukkonen et al. 1999).

León-Posoltega

The town of León is located close to the Pacific coast about 100 km north-west of Managua, its centre having the map coordinates 12°26'N, 86°53'W. The sites studied here were situated in the drainage basins of the rivers Posoltega, Mitapan and Río Télica and covered an area of about 5x11 km near the town. Mean annual precipitation is 1861 mm, with as much as 415 mm falling in September, at the height of the rainy season (Krasný & Hecht 1998). The terrain around León and Posoltega is flat agricultural land, with altitudes from 50 to 200 m a.s.l., but there are a number of volcanoes within a distance of 15-40 km, the highest of which are Momotombo (1280 m a.s.l.), El Hoyo (1050 m), Télica (1060 m), Casita (1405 m), San Cristóbal (1745 m) and El Concho (1105 m). Some of these are active, as indicated by continuous gas emissions, and the most recent eruption was that of the Cerro Negro (675 m), located close to El Hoyo, in the late 1990s. An area of over 50 km^2 is covered by volcanic material derived from eruptions of the Télica volcano (La Femina et al. 1994).

Northern part of the study area of León-Posoltega is located on the lower slopes of the Télica volcano and the southern part on the coastal plain, which is for the most part composed of sedimentary rocks overlain by alluvial deposits (Cunningham et al. 1984). Cretaceous and Tertiary marine sedimentary rocks, including sandstone, tuff schist, limestone, volcanic conglomerates and agglomerates are also to be found on the Pacific coast, in the León area studied here (INETER 1995).

The León-Posoltega district is more often suffering from flooding than the other study areas. The hurricane Mitch in 1998 inflicted major damage on León area, including the loss of thousands of lives and the destruction of fields, houses, cattle and wells by landslides. Exceptionally heavy rains were also experienced at the time of the fieldwork in September 1999, when a rainfall of 680 mm in four days was recorded in Managua (information from the local newspapers *El Nuevo Diario* and *La Prensa*). A number of villages in the León-Posoltega area had to be evacuated on account of flooding. The main crops cultivated in the area are maize, durra, rice, soya, sugar cane, peanuts and bananas.

Diriamba

Diriamba is situated in the mountain area known as the Sierras de Managua, belonging to the chain of volcanoes dividing the Nicaraguan depression from the Pacific coast. The sites in the province of Diriamba, situated 40 km south of Managua and 25 km from the Pacific Ocean, were concentrated in an area 2x3 km at altitudes of 90-100 m a.s.l. in the drainage basins of the rivers La Trinidad, Tepano and Río Grande, close to the village of La Trinidad, 11°44'N, 86°20'W. The terrain in this area rises sharply in an inland direction, so that the town of Diriamba, only 15 km away, is at a height of over 1000 m a.s.l. Innumerable small streams flow down from the mountains to the ocean, converging in their lower reaches to form larger rivers, of which the Río Grande and Río La Trinidad are two. The dominant rocks of the mountain area are Quaternary pyroclastic deposits. The village of La Trinidad is located at the coastal plain, which consists of Tertiary sandstones, limestones and heterogeneous clastic sediments (Weyl 1980). The principal economic activities in the Diriamba district are agriculture and cattle rearing. The volcanic soils mean that the area is a fertile one, and the main cash crops are coffee, maize, beans and durra. Coffee is grown on the higher land, at altitudes of 600-700 m a.s.l., while cotton was grown in the lower-lying areas in 1955-1972.

Santo Tomás-La Libertad

Santo Tomás and La Libertad are located in an undulating upland area about 180 km east of Managua, 12°04'N, 85°05'W. The area concerned is about 5x20 km in size, about 350-540 m a.s.l. Mean annual precipitation is 1807 mm a year (Hodgson 1990).

The dominant rocks of the Santo Tomás and La Libertad areas of the central uplands are Tertiary volcanites with ages of 15-1.6 Ma. These are poorly permeable when intact, but are rendered highly permeable locally by faults and weathering (INIFOM-AMUNIC 1997). They include basalt, andesite, rhyolite, dacite and tuff as well as sandstone, limestone and calcareous conglomerates (INETER 1995). Older volcanites of the andesitic Matagalpa Group, dating from earlier in the Tertiary, with ages of 58-15 Ma, are also encountered in places, and Quaternary weathering products are common deposited in the depressions, usually in dark, plastic, clay-bearing horizons 2-4 metres in thickness that are highly impermeable and crack easily in dry weather (Hodgson 1990). Thus apart from the volcanic activity and tectonic movements in the earth's crust, the composition and topography of the soils have been shaped by weathering, the transport of material under the influence of erosional forces and redeposition.

The main forms of economic activity are mining and cattle rearing. The suspected principal environmental problems in the Santo Tomás district are attributable to the La Libertad and Santo Domingo gold mines, which have been worked for more than a hundred years. Open-cast mining began on the upper reaches of the Río Mico, which flows through the area, in 1856, and the ore was treated by the amalgam method, which involves the use of four ounces of mercury (124.64 g) to every ounce of gold (31.16 g). It is estimated that a total of 2 million tonnes of ore were treated in this way in the area of La Libertad and the nearby Santo Domingo between 1856 and the 1990s, and that some 16 tonnes of mercury escaped into the environment during that time, of which 6 tonnes became retained in the sediments of the Río Mico and 10 tonnes was carried away in the river or deposited in the environment in the form of airborne particles. Also, the mercury used in this process contained some 20 % lead impurities, which will also have been released into the environment (Empresa Minera La Libertad 1994), and further lead must have arisen from minerals ground in the course of the gold treatment process (Mendoza 1997). The latest estimates are that about 1.3-1.7 kg of mercury is released into the environment for every kilogramme of gold produced. This would imply emissions of 16 kg of mercury per month into the air and 21 kg into the water from the amalgam processes of the Santo Domingo mine alone, i.e. a total of about 25 tonnes over a period of 100 years. The amount of mercury required for extracting a kilogramme of gold in Nicaragua is at least ten times greater than that used in comparable processes in Brazil, for instance (Rosén 1997).

Cyanide-based methods for the processing of gold ore were introduced in 1936, and a changeover to the exclusive use of this approach was implemented later. At first the waste liquids were conducted directly into the Río Mico and Río Siquia, and it is estimated that a total of 8 tonnes of mercury and 0.75 tonnes of cyanide were emitted into the environment over the period 1936-1956. The cyanide method is regarded as the less noxious of the two, because cyanide compounds decompose fairly quickly (Empresa Minera La Libertad 1994). Nowadays the cyanide is recycled, but it is still suspected that some may escape into the rivers. Thus this method has also been criticized to some extent.

The worst environmental consequences of the mining operations are regarded as being the emissions of mercury and lead and the effects of the slurry released into the rivers on water quality, the latter being compounded by the large quantities of natural solid material washed into the rivers during the rainy season in particular. Demands have been made that private gold miners should use recyclable cyanide rather than lead-bearing mercury, on account of the health risks attached to the latter (Vásquez 1995, 1996, Mendoza 1997, Empresa Minera La Libertad 1994).

Groundwater shortages are a major problem at Santo Tomás during the dry season, where water supplies are rationed to one day in eight during the most difficult period, in April and May. Domestic water is obtained from a reservoir charged by rivers and streams from the surrounding mountains, and some groundwater is available from four wells. A solution to this problem has been proposed which entails making use of the Río Mico, which still contains ample quantities of water even in the dry season, whereas research has shown that the groundwater resources in the Santo Tomás area are inadequate (Spalke 1993). The studies here were focused on the quality of the water in the Río Mico and in some wells, and the occurrence of heavy metals in the water and river sediments as a consequence of the activities of the gold mines and individual gold panners.

RESEARCH METHODS

Fieldwork

Rovaniemi sites

Groundwater quality in the vicinity of Rovaniemi was studied in eskers, till areas and three fracture zones in the bedrock. The groundwater in Quaternary deposits was studied by analysing samples from dug wells and natural springs and the bedrock groundwater from drilled wells (Figs. 3 and 4). The groundwater data are mostly derived from investigations carried out in connection with Quaternary mapping, national groundwater surveys and groundwater monitoring. The principal aquifers near Rovaniemi are located in the eskers of Jokkavaara formation, Palovaara-Kroopinpalo and Kolpeneenharju (Fig. 5), which are parts of the two esker chains in the area. The most extensive sets of data are available for Jokkavaara, for which a survey of extractable land resources and groundwater has been carried out and a land use plan has been produced (Väisänen 1997).

Determinations were made of the composition of the Quaternary deposits at Jokkavaara, the thicknesses of the horizons, depths of the bedrock surface and positions of the groundwater table by means of corings, ground penetrating radar and seismic soundings. The cores were analysed for grain size at the Geological Survey's laboratory. The ground penetrating radar measurements (using a SIR Model 08 equipment) were made over a distance of 8 km covering various parts of the esker formation, and the refraction seismic soundings, to assess the thicknesses and structure of the horizons, the height of the groundwater table and the depth of the bedrock surface, were taken along four transects, a total distance of 1.4 km, using a 24-channel BISON 7000 Series DIFP seismograph, with small explosive charges as the excitation source. The data were downloaded to a PC for subsequent processing (Bison 7000 Series DIFP Seismograph Instruction Manual 1990). The times of flight of the seismic waves were used to deduce distance-time curves on the basis of which the various horizons and their velocity lines could be identified. The numerical calculations were performed using interpretation software developed by the Geological Survey which makes use of the benchmark or detail interpretation approaches, the former yielding the depths of the horizons at the ends of the transect and the velocities, and thus providing information on the location of the groundwater table and the total thickness of the unconsolidated sediments, while the latter indicates detailed fluctuations in the contacts between horizons along the transect and is of use for describing the topography of the bedrock surface and the positions of fracture zones. The thickness of the Quaternary deposits and the groundwater table were also determined in the Palovaara esker (Fig. 5) by means of seismic soundings.

Water quality in a well located on the finesand-dominated foreslope of the Jokkavaara esker has been examined regularly by the Geological Survey since 1993 as part of its groundwater monitoring programme (Backman et al. 1999). In the case of bedrock groundwater, the present research was concentrated on fracture zones, which were identified from low-altitude geophysical data. The youngest fracture zones and faults are visible as linear minima and lineaments on aeromagnetic maps (Fig. 6), and electrical conductivity in general increases in fractured bedrock, partly on account of the presence of groundwater, whereas intact rock units have a lower conductivity. Such anomalies are particularly prominent in imaginary component observations. The more exact locations of the conductivity zones identified on the basis of the airborne readings were determined by VLF-R measurements.

The depth dimensions of soundings obtained by the VLF-R technique are dependent on the electrical conductivity of the earth's crust and can vary from a few tens of metres to over 100 m. Observations can be used to deduce both the mean resistivity and changes in resistivity with depth. The fracture zones studied here were located in the Poikajärvi-Latvajärvi fracture zone east of Norvajärvi (map sheet 3612 09), in the Häkinvaara-Kalliovaara area (map sheet 3612 04) and in the Viiksjärvi area (map sheet 3612 05). Seismic soundings were used to confirm the precise locations of the fracture zones and produce broad assessments of soil depth and structure and the height of the groundwater table. Geophysical method tests were performed by ground resistivity soundings using an AGI/Sting multi-electrode system and by gravitational and slingram (HLEM, 14 kHz/60 m) methods, Sampo soundings (wide band electromagnetic frequency sounding method, Jokinen 1999), gravity and ground-magnetic total field methods in the fracture zones of Poikajärvi-Latvajärvi and Viiksjärvi (Lanne et al. 1998, Lanne & Väisänen 1999, Lanne et al. 2002). Core samples and chemical analyses were also used to study the thickness, structure and composition of the Quaternary cover, and groundwater observation wells were installed at the coring points for the monitoring of water quality.

Ten polyethylene groundwater observation wells of diameter 51/45 mm extending down to the bedrock surface, a distance of 7-16 m (Table 3), were installed in the Poikajärvi-Latvajärvi (five wells) and Viiksjärvi fracture zones (three wells), both in the granite area, and the Häkinvaara-Kalliovaara crush zone (two wells) in the

Table 3. Locations of the coring sites and groundwater observation wells. The tubes for the wells were inserted down to the bedrock surface, although owing to the presence of boulders from the fractured rock, some of them did not extend to the same depths as were reached by coring.

Ground-water obs. well No.	Well depth, m	Total coring depth, m	Map sheet	Coordinates x	y	z
1	14.2	14.2	3612 09	7396 01	3447 46	128
2	16.2	17.6	3612 09	7395 39	3447 78	127
3	15.0	15.0	3612 09	7395 04	3447 92	122
4	15.5	18.0	3612 09	7395 02	3447 86	122
5	14.8	14.8	3612 09	7395 36	3447 72	127
6	10.5	11.9	3612 04	7373 02	3434 19	101
7	8.5	10.8	3612 04	7372 92	3434 19	102
8	8.8	10.8	3612 05	7388 36	3435 69	136
9	8.9	9.2	3612 05	7388 39	3435 72	137
10	6.9	9.3	3612 05	7388 31	3435 63	134

mica schist-quartzite area (Fig. 3), once preliminary interpretations had identified these zones as the best for groundwater occurrences. The tubes were perforated in their lower part, having openings of width 0.3 mm through which groundwater could percolate into them. In seven cases this water was extracted with a hand-operated pump, or "bailer", and in the other three cases the water came to the surface under its own pressure. The first groundwater samples were taken a week after the initial emptying of the observation wells. Samples of Quaternary deposits were also taken from various depths in connection with the coring and the installation of the observation wells, and bedrock samples were taken by boring.

Grain size and element analyses were performed on the samples of the Quaternary deposits, and rock type and mineral analyses on the bedrock samples, in addition to which the podzol structure of the soil was examined by means of element analyses carried out separately for the eluvial horizon (E), the illuvial horizon (B) and the unaltered subsoil (C) (App. 1). The rock type determinations were based on thin sections and the mineralogical determinations on the X-ray diffraction method.

The groundwater temperature, height of the water table, pH, electrical conductivity, dissolved oxygen content and CO_2 concentration (by titration against a NaOH solution) were measured at each sampling site, the field instruments being a WTW 91 pH meter, a WTW LF 90 electrical conductivity meter and a WTW OXI-96B oxygen meter. Water samples were taken into plastic bottles by taking untreated aliquots of 0.5 litres being used for anion determinations. The pH, electrical conductivity, colour, $KMnO_4$ consumption and alkalinity of the water were then assessed in the laboratory. An aliquot of 100 ml was then taken from each sample after filtering using Becton & Dickinson's disposable syringes (Plastipak 50 ml Luer-Lok, Sterile Syringe) and Schleicher & Schuell's disposable filters (FP 030/2, 0.45 mm) and acidified with 0.5 ml of 65 % suprapure nitric acid. The quality of the water from wells 1-5 was analysed six times over the period 1997-2001 and that from wells 6-10 four times. Groundwater samples were taken at distances of 0.3-0.5 m below the surface of the water or from water taps in 20 dug wells, and both these and the samples from the springs were subjected to the same determinations and analyses as those from the observation wells.

Sites in Nicaragua

Groundwater and surface water quality, composition of surficial deposits and toxic residues in the water and surficial deposits were studied in the agricultural areas of Tisma and Diriamba close to Managua, in the environs of León and Posoltega on the Pacific coast and in the cattle rearing and gold mining areas of Santo Tomás and La Libertad in the uplands of the interior of Nicaragua (App. 5). In most of the farms in Tisma, León-Posoltega and Diriamba on which samples were taken had previously been growing cotton and using considerably larger amounts of toxic chemicals than they do nowadays.

Sampling sites at Tisma

A total of 17 water samples were taken at Tisma, 40 km to the east of Managua (App. 2). Thirteen samples were from the groundwater in wells belonging to farms and one from a spring. One of these wells was analysed both in 1994 and 1997. The wells examined here varied in depth from 3 to 80 metres. Surface water samples were taken from one lake, the Laguna de Tisma in 1994 and 1997, and from the Río Tipitapa that flows into it. Altogether ten samples of surficial deposits were taken on seven farms, including six of those from which water samples were taken. The size of the samples of surficial deposits was approximately 200 g and the samples were taken at a depth of 5-40 cm (App. 4).

The following toxic chemicals were mentioned in the interviews as having been used on the farms of the Tisma area: Decis, Malathion, Deltamethrin, Cypermethrin, atrazine (weedkiller), Furadan (insecticide), Lorsban, Tamarón, endosulphane and Volatón. Empty packets from the officially banned toxin Karate were also found on one farm. All the above designations except for atrazine and endosulphane are brand names. These chemicals are usually applied once or twice a week during the growing season, and the remnants of the plants after harvesting are either burned or ploughed into the ground, or else fed to the animals on some farms. Since the cessation of cotton growing they have been concentrating of grain, vegetables and fruit, obtaining three harvests a year at their best. The work in the Tisma area was carried out in 1994 and 1997.

Sampling sites at León-Posoltega

A total of 15 water samples were taken in the surroundings of the town of León and at the village of Posoltega, 11 of which were groundwater samples from wells (App. 2). Surface water analyses were performed with respect to three rivers, and a rainwater sample was also taken in the town during a spell of torrential rain in September 1999, by simply allowing the rain to fall into a plastic vessel. A total of 47 samples of surficial deposits were taken at seven farms, on two cross sections of a road and on a section across the bed of the Río Télica, i.e. at sites 17-27. Sites 17-22 were in the northern part of the area, on the lower slopes of the Télica and Casita volcanoes, and the others on the agricultural plains close to the Pacific coast. The sampling depths in the farms were 0-5 cm, 5-15 cm, 15-30 cm and 30-60 cm (App. 4). The northernmost site of all, La Hoyada (17), was located at an altitude of about 180 m a.s.l. on the lower slope of Télica, in an ancient volcanic crater that has no outlet into the waterway system, so that floodwater simply accumulates there during the rainy season. The fertile fruit growing area contained inside the crater was destroyed almost entirely by landslides and floods at the time of the hurricane Mitch in 1998. The only usable well that survived the storm was 22 metres deep (Fig. 12) and was being used by as many as 87 families immediately after the catastrophe. This meant that water had to be rationed, of course. A water sample was taken from this well and samples of surficial deposits from the nearby fields.

Sampling sites 18-22 were situated on an agricultural plain at the foot of the Télica volcano, at heights of 120-140 m a.s.l. At site 19 a water sample was taken from a dug well of depth 67 m and samples of surficial deposits from a nearby maize field, while the drilled well at site 20, on the farm of La Trinidad (well Pp 124), served as a source for the local water

Fig. 12. A well located on the side of the volcano Télica which was the only source of water for 87 families when the other wells in the area were destroyed by a hurricane in 1998.

supply, the water being subsequently chlorinated. Samples of surficial deposits were also taken on this farm, in a eucalyptus plantation (Fig. 13) where no chemicals had been used for many years.

Fifty of the local farmers are affiliated to a project run by the international aid organization Caritas designed to improve farming conditions and harvest yields in the area. By contrast, chemicals had been spread on the fields of the farm of La Primavera, site 21, for weed and disease control purposes only a few weeks prior to sampling. The well examined at the farm of María de la Concección, site 22, was used jointly by three households, and that sampled at the farm of Juan Ramón, site 23, was 38 m in depth. Samples from cross sections of a road were taken near site 22.

Site 24 was situated on the farm of Hayde Larios in the village of Posoltega, at an altitude of 70-80 m a.s.l., where water samples were taken from a drilled well used, after chlo-

Fig. 13. Soil sampling in a eucalyptus plantation on the farm of La Trinidad near Posoltega.

Fig. 14. Water sampling from a dug well on the farm of German Pomares in Posoltega.

rination, as a local water supply. Samples of surficial deposits were taken from the adjacent soybean fields. The use of chemicals at the farm is nowadays restricted to the rice crop. At site 25, the farm of Entre Ríos at 70 m a.s.l., water samples were again taken from a drilled well (Pp 122), the water of which is chlorinated, but as elsewhere, chlorination was discontinued before sampling and the water run until the indicator dye showed that no chlorine was present. Samples of surficial deposits were taken from nearby pastureland. The farm still uses insecticides.

Site 26 , the cooperative farm of German Pomares, operated by 35 families, was located at an altitude of 50-60 m on the coastal plain not far from the village of Posoltega. Here water samples were taken from two dug wells (Fig. 14) and two rivers that flow through the farm, the Río Posoltega and Río San Pablo. The farm obtains its drinking water from a 3-metre deep well in the yard that is fitted with a sand filter, but cattle and other farm animals are allowed to wander around it freely.

The farm also has five drilled wells that are used for irrigation. The whole village was flooded at the time of the hurricane in 1998 and the population had to be evacuated. According to researchers at the Centro para la Investigación en Recursos Acuáticos de Nicaragua (CIRA), the groundwater table in the area was still about a metre above normal a year after the flooding. Samples of surficial deposits were taken in a field of sugar cane and a banana plantation on the farm, together with a surface water sample from the Río Télica as it flowed by the village of Télica (site 27) and samples of surficial deposits from a 10-metre deep section across the river bed.

Almost all the farms examined had previously grown cotton but had now moved over to cultivating grain, vegetables and fruit. Information gained from interviews suggests that the following toxic chemicals had been used in connection with cotton growing: toxaphene, 2,4-D, chlorpyriphos (Lorsban), deltamethrin (Decis), methyl parathion (MT 48, Tres balas), asephate (Orthene 95), Dicterex 95, methamidophos (Metamidafos, Monitor, MTD, Tamarón), methomyl (Nudrin, Lannate Dupón), DDT, paraquat (Gramoxone), metolachlor (Dual), fluormeturon (Cotorán), perfluidone (Destun), dieldrin and parathion. By comparison, the interview data indicated that the following are in use nowadays for the cultivation of food crops: methamidophos (Filitox, MTD 600), deltamethrin (Decis), copper (Bioquin), benzone, methyl parathion, alachlor (Alanex), imazapyrin (Pivot), carbendazin+cyproconazol (Alto Bravo), ethylene bisdithiocarbamat (Ambis), terbuconazole (Folicular), maneb (Manzate), pendimethalin (PROWL), mancozeb (Mancosep), zineb (Dithane), chlorpyriphos (Lorsban), amethryn (Gesapax), glyphosate (Round Up) and methalaxyl (Ridomil).

Sampling sites at Diriamba

Four water samples were obtained at the village of La Trinidad in the province of Diriamba, two from wells, of depths 8 and 25 metres, and two from a river (App. 2). The local inhabitants claimed that the surface water in the area was contaminated with waste water and other refuse. Two samples of surficial deposits were taken in a maize field, and area near the wells that had been left fallow at a depth of 5-15 cm and two samples in the river sediments (App. 4).

Sampling sites at Santo Tomás-La Libertad

The investigations at Santo Tomás were concerned with groundwater and surface water quality and the general composition of the river sediments, their heavy metal concentrations, and especially with the effects of the gold mines on the waterways and river sediments. Attempts were made to deduce locations of aquifers from maps and field observations. Santo Tomás is primarily a cattle-rearing area, while La Libertad, about 20 km away, is the centre for gold mining. Altogether 17 water samples were taken from these areas, of which 7 were from wells, one from the reservoir at Santo Tomás and nine from the rivers Lóvago, Río Mico and its tributary San Juan, flowing out of the mountainous area of La Libertad. These nine samples comprised four samples of Río Mico and San Juan taken in 1997 and repeat samples taken for monitoring purposes in 1999. A total of 17 samples of surficial deposits were taken from the beds of the rivers Río Mico, San Juan and Lóvago, road cuttings and a pit from which a local small-scale brickworks extracted a material weathered to the consistency of clay (App. 4). Again the initial sampling took place in 1997 and repeat samples were taken from the same four points in the river sediments and the sandy beds of the Río Mico and San Juan for comparative purposes in 1999. One sample was taken from the bottom of the Río Mico. This sandy material was used for making cement by local people.

The groundwater and surface water samples from Nicaragua were taken and pre-processed for determination of their physico-chemical properties in the same manner as the Finnish samples, in accordance with the practices of the Geological Survey of Finland. Water temperature and the water level in wells was measured whenever feasible. The field measurements of pH and electrical conductivity were done only of the water samples in 1999 with WTW 91 pH meter and WTW LF 90 electrical conductivity meter. The samples were stored in the cold until they could be dispatched to the laboratory in Finland. Some samples were examined in the microbiological laboratory of the Universidad Nacional de Ingeniería (UNI) within 24 hours for total coliform bacteria and faecal coliform bacteria. These samples were taken into plastic bags of UNI (Nasco WHIRL-PAK) and stored in the cold after sampling.

The water samples taken from the Río Mico in Santo Tomás were also analysed in Nicaragua for mercury content. One litre of sample was conserved with 2 ml of concentrated nitric acid. Similarly, where water samples were to be analysed in Nicaragua in the laboratorio of UNI for toxic residues, a volume of five litres was taken into a glass bottle, to which 50 ml of hexane was added. The samples were kept in the cold until used. Analyses of toxic residues were performed on samples from three drilled wells, six dug wells and two rivers. Samples intended for toxic analysis in Finland were frozen in an untreated state. The samples of surficial deposits for mercury and toxin determinations were kept frozen until they reached the laboratory.

Laboratory tests

Laboratory tests in Finland

The water samples both from Rovaniemi and Nicaragua were analysed for their physico-chemical properties (Table 4) and the samples of surficial deposits for concentrations of elements, and the measurements of grain size, humus content, specific surface area and density were made in the laboratories of the Geological Survey of Finland.

Anions in the water samples were determined of untreated samples. Alkalinity (mmol/L) was determined titrimetrically and bicarbonate concentrations (mg/L) by multiplying alkalinity (mmol/L) with the molecule weight of bicarbonate (61). The multielement determinations were carried out by inductively coupled plasma mass spectrometry (ICP-MS) and inductively coupled plasma atom emission spectrometry (ICP-AES) (Table 4), on filtered samples conserved with nitric acid (total salts <0.05 %). Some of the water samples of Northern Finland taken before 1990 were analysed with FAAS method (atomic absorption spectrometry, flame atomisation) and GAAS method (graphite oven atomic absorption spectrometry). Sulphate, calcium, sodium, potassium, iron, manganese and zinc were analysed with FAAS and aluminium, cadmium, cobalt, chromium, copper, nickel and lead with GAAS. Radon concentrations in the samples from the groundwater observation wells in the Rovaniemi district were analysed at the Helsinki City Council Environmental Laboratory by liquid scintillation counting of a 10 ml aliquot contained in a glass ampule filled with Lumagel.

The grain-size analyses of the samples of surficial deposits consisted of sieving coarse material through a Retsch series and an Analysensieb DIN4188.ISO 565-T.1 series of mesh sizes 20, 6, 3, 2, 0.63, 0.2 and 0.063 mm, followed by determination of the distribution of the fine-grained material (<0.063 mm) with a MICROMERITICS Sedigraph 5000D in the case of the Nicaraguan samples or a wet component run in a Sympatec Helos laser diffraction device for the Finnish samples. The latter is a particle size analyser that is suitable for both aerosols and suspensions (Helos 12LA Operating Handbook 1985). The specific surface area determinations were performed by the FLOWSORB II 2300 single point method for grain sizes under 0.063 mm. The specific surface area is determined by measuring the amount of the gas, which will be adsorbed on the surface of the sample, as a cover with thickness of one molecule, according to the Finnish translation of the handbook for Flowsorb II 2300 apparate, by Dr. Kaufmann in 1993. The gas used was a 30 % N_2/70 % He mixture and the cooling agent liquid nitrogen at -196°C, the gas removal temperature being 120°C/x1/Short, and the air pressure 774 mmHg/temperature 21°C/calibration coefficient 290 m^2. Humus content was determined colorimetrically.

The samples for the element analyses were dried at 35-36°C and sieved to obtain the <2 mm fraction. This was then extracted in a 1 M ammonium acetate solution, pH value 4.5 for the Finnish samples and some of those from Nicaragua and pH value 7.0 for the Nicaraguan samples, and analysed by the ICP-AES method. This ammonium acetate leach was used for analysing nutrients and elements dissolving easily.

The ammonium acetate solution with pH value 4.5 was selected to correspond approximately to that of rainwater in Finland. The mean pH value of rain water at Juotas measuring station of Finnish Environment Institute, quite near Rovaniemi was 4.7 in 1992 (Järvinen & Vänni 1994) and 4.87 in 1997 (Vuorenmaa et al. 1999). The hydrogen ion concentrations in 1 M ammonium acetate solution with pH 4.5 are about 10 times greater than would be the case at a rainwater pH that was in equilibrium with atmospheric carbon dioxide, the pH of which would be 5.5-5.6 (Drever 1988, Bernes 1993).

Most of the samples from Nicaragua, on the other hand, were extracted in a neutral solution of ammonium acetate, pH 7, which corresponds better to conditions in that country, where both rainwater and pH values of surficial deposits tend to be higher, according to the available previous research data. Element concentrations were also determined after aqua regia (HNO_3+HCl) extraction, which reflects solubility in the acids occurring in nature. The solubility of minerals in aqua regia varies greatly, oxides being poorly soluble, as also are silicate radicals, but the metallic elements acting as their cations are readily soluble, while carbonates, sulphides and phosphates dissolve almost entirely (Koljonen 1992).

Analyses of silver, aluminium, arsenic, boron, barium, calcium, cadmium, cobalt, chromium, copper, iron, potassium, lithium, magnesium, manganese, molybdenum, sodium, nickel, phosphorus, lead, sulphur, antimony, silicon, strontium, titanium, vanadium and zinc were performed after ammonium acetate extraction, and the same except for antimony after aqua regia extraction. Some of the Rovaniemi samples of the sites of the groundwater observation wells 1-5 were also analysed for beryllium, lanthanum, scandium, thorium and yttrium after aqua regia extraction.

The 1999 samples of surficial deposits from Nicaragua were also extracted with nitric acid by the microwave oven technique (EPA Method 3051) for ICP-AES analysis of the same elements as with ammonium acetate extraction, together with zircon and gold (aqua regia extraction). For the determination of mercury, the samples of surficial deposits were extracted with nitric acid at 90°C by the HGA technique and were analysed with CVAAS technique (cold vapour atomic absorption spectrometry). For determination of gold concentrations in the Nicaraguan river sediment samples were extracted with aqua regia, coprecipitation was done with mercury and analysis by GAAS technique (graphite oven atomic absorption spectrometry). Electrical conductivity and pH were determined from dried samples after sieving and extraction with water. The relative distribution of clay minerals was determined by X-ray diffraction (PHILIPS PW 1730/10, with a Cu/Ni filter).

Toxic residues in the samples of surficial deposits in 1997 from Nicaragua were determined at the laboratory of the Agrifood Research Finland (MTT) by extraction in an aqueous solution of acetate followed by salting out and liquid-liquid partition with dichlormethane and hexane. The organic phase was then dried with sodium sulphate and concentrated by evaporative centrifugation. The concentrated sample was analysed by gas chromatography-mass spectrometer, employing standard methods (PCB 53) for quantifying the compounds. In the case of the water samples, salt was added and liquid-liquid partition performed with dichlormethane, after which the analysis proceeded as for the samples of surficial deposits. In addition to atrazine, deltamethrin, diazinon, malathion, lambda-cyhalotrin, simazine and cypermetrine, the following organochlorides were analysed: aldrin, o,p'-DDT, p,p'-DDT, o,p'-DDD, p,p'-DDD, o,p'-DDE, p,p'-DDE, dieldrin, α-endosulphane, ß-endosulphane, endosulphane sulphate, endrin, HCB (hexachlorbenzene), α-HCH, ß-HCH, δ-HCH, heptachlor, cis-heptachloroid, cis-chlordan, mirex and oxichlordan. The detection limit for organochloride compounds in the samples of surficial deposits was 0.001 mg/kg and the mean limit for other toxic substances 0.02 mg/kg, the corresponding limits in water samples being 0.02 µg/L and 0.5

Table 4. Analyzing methods of the water samples in the Geological Survey and the detection limits.

Measurements	Method	Analytical detection limit
pH	By potentiometry	
Electrical conductivity mS/m, 25°C	By potentiometry	
Colour	By comparison	
$KMnO_4$ consumption mg/L	By titrimetry	
Alkalinity, HCO_3 mg/L	By titrimetry	
Br mg/L*	By ion chromatography	0.1
Cl mg/L	By ion chromatography	0.5 & 0.2
F mg/L	By ion chromatography	0.1
NO_3 mg/L	By ion chromatography	1 & 0.2 & 0.1
PO_4 mg/L	By ion chromatography	0.02
SO_4 mg/L	By ion chromatography	0.5 & 0.2
Ag µg/L*	ICP-MS	0.01
Al µg/L	ICP-MS	1
As µg/L*	ICP-MS	0.05
B µg/L*	ICP-MS	0.5
Ba µg/L*	ICP-MS	0.04
Be µg/L*	ICP-MS	0.1
Bi µg/L*	ICP-MS	0.03
Ca mg/L	ICP-AES	0.1
Cd µg/L	ICP-MS	0.1 & 0.02
Co µg/L	ICP-MS	0.5 & 0.02
Cr µg/L	ICP-MA	0.5 & 0.2
Cu µg/L	ICP-MS	0.5 & 0.04
Fe mg/L	ICP-MS	0.05 & 0.03
K mg/L	ICP-MS	0.5 &0.01
Li µg/L	ICP-MS	0.3
Mg mg/L	ICP-AES	0.1 & 0.05
Mn µg/L	ICP-MS	20 & 0.02
Mo µg/L*	ICP-MS	0.03
Na mg/L	ICP-AES	0.5 & 0.4
Ni µg/L	ICP-MS	0.5 & 0.06
Pb µg/L	ICP-MS	0.5 & 0.03
Rb µg/L*	ICP-MS	0.01
Sb µg/L*	ICP-MS	0.02
Se µg/L*	ICP-MS	0.5
Sr µg/L*	ICP-MS	0.1
Th µg/L*	ICP-MS	0.02
Tl µg/L*	ICP-MS	0.02
U µg/L	ICP-MS	1 & 0.01
V µg/L*	ICP-MS	0.02
Zn µg/L	ICP-MS	20 & 0.1

* Analysed since 1992

µg/L. The confidence level of the analyses was ± 10-15 %.

Determinations of toxic substances were also carried out on a few of the 1994 samples of surficial deposits and the 1999 samples at the Institute for Environmental Research, University of Jyväskylä. Here the samples were analysed for organochlorine and organophosphorus compounds and a few other groups of toxins. After extraction in a petroleum ether: acetone:hexane:ethyl ether mixture in a Dionex ASE 200 solubilization extractor, DDT, DDD, DDE, toxaphene, aldrin, dieldrin, chlorpyriphos and methyl parathion were quantified by gas chromatography with an EC detector employing 30 m quartz capillary columns (phases HP-5 and HP-1701). Deltamethrin, imazapyrine, methamidophos and atrazine were quantified by liquid chromatography with an UV detector, using a running solution of acetonitrile in water. Methamidophos was also quantified by SIM mass spectrometry.

Laboratory tests in Nicaragua

The 1997 samples of water and surficial deposits were analysed for toxic substances with the Varian 3400 chromatograph of the Universidad Nacional de Ingeniería (UNI, Programa de Investigación y Docencia en Medio Ambiente, PIDMA, Laboratorio de Cromatógrafo de Gases), employing the EPA 608 and ASTM D4861-88 methods. The determinations covered the organochlorine compounds HCB, HCH, lindane, aldrin, oxichlordan, heptachlor, p,p'-DDT, p,p'-DDE (4,4'-DDE), dieldrin and p,p'-TDE, the organophosphorus compounds dichlorphos, diazinon, ronnel (phenchlorphos), chlorpyriphos, malathion, ethyl parathion, ethion and carbofenothion, and also mercury concentrations in the 1997 surface water samples from Santo Tomás.

Toxic residues in the 1999 water samples were determined in the laboratories of the Centro para la Investigación en Recursos Acuáticos de Nicaragua, Universidad Nacional Autónoma de Nicaragua (CIRA-UNAN), by methods 6431-LLE GCM and 6630 b and c, according to the international handbook of standard methods for the analysis of water and waste water, 18th edition. The analyses were focused on the organochlorine compounds lindane, α-HBC, ß-HBC, δ-HBC, heptachlor, heptachlor h-epoxy, α- and ß-endosulphane, dieldrin, endrin, p,p'-DDT, p,p'-DDE, p,p'-DDD and toxaphene, of which α-HBC, ß-HBC and δ-HBC are metabolites of the decomposition process of lindane (Korhonen & Miettinen 1994), and on the organophosphorus compounds ethoprophos, naled, phorate, terbuphos, diazinon, methyl parathion, malathion, fenthion, ethyl parathion, chlorphenphop, S,S,S-tributyl phosphorthioate, ethion, azinphos methyl and fluaziphop-P. For reference purposes, a few water samples from Nicaragua were also analysed for toxic residuals in the laboratories of the Agrifood Research Finland.

Total coliform bacteria and faecal coliform bacteria were determined at the microbiological laboratory of UNI under the Programa de Investigación y Docencia en Medio Ambiente (PIDMA-UNI, Laboratorio de Microbiología), employing the NMP dual-phase culture method as described in the standard methods handbook, which involves culture of the sample, diluted 1:1000, in a lactose solution at 37.5°C in the first phase to establish the presence of coliform bacteria and at 37.8°C at the second phase to quantify them. A further culture was then performed at 44°C to determine faecal coliforms. The results are expressed as the most probable number per 100 ml, NMP/100 ml (Número Más Probable). The maximum permissible concentration of coliform bacteria in drinking water, as laid down by WHO (Organización Mundial de la Salud, OMS), is less than 2.2 per 100 ml (NMP).

RESULTS

Groundwater of the Rovaniemi district and its chemical composition

Groundwater in the Rovaniemi district was examined in 83 sites including 48 springs and 10 dug wells in till areas, two springs and 10 dug wells in sand and gravel deposits, three bedrock drilled wells and 10 groundwater observation wells in bedrock fracture zones. Four sites of them - two springs and a dug well in sand and gravel deposits and a spring in till area - belong to the groundwater monitoring project of the Geological Survey of Finland. The groundwater samples from Quaternary deposits were slightly acid on average and had low electrical conductivities showing low concentrations of dissolved substances (Table 5).

An overall view of the chemical composition of the groundwater in the Rovaniemi region is presented in triangular diagrams for main anions (HCO_3^-, SO_4^{2-} and Cl^-) and cations (Ca^{2+}, Mg^{2+} and Na^++K^+) in Figures 15 and 16. The groundwater of all the samples are composed of 72 equivalent percent bicarbonate, 17 equivalent percent sulphate and 11 equivalent percent chloride. The corresponding equivalent percentages are 56, 24 and 20 for the groundwater of the till deposits, 78, 17 and 5 for the groundwater of the sandy deposits and 86, 8 and 6 for the bedrock drilled wells and the groundwater observation wells. The cation equivalent percentages in all the samples are 54 for calcium, 24 for magnesium and 22 for sodium and potassium. The corresponding equivalent percentages are 43, 24 and 33 for the groundwater of till deposits, 66, 19 and 15 for the groundwater of the sandy deposits and 47, 35 and 18 for the bedrock drilled wells and the groundwater observation wells. The data in Figures 15 and 16 include the analyses of four groundwater monitoring sites near Rovaniemi since 1993.

The groundwater composition is mainly calcium-bicarbonate type. The distribution pattern of the anions is more concise in sandy deposits and in the drilled wells and the groundwater observation wells than in till deposits (Fig. 15). A part of the samples in till deposits have high equivalent percentages of sodium and potassium due to some shallow wells with human impact. High sodium and potassium concentrations were also found in springs of natural state and in shallow wells and some springs of sandy deposits.

The mean pH value was higher in the bedrock drilled wells and the groundwater observation wells (field measurements) than in the groundwater of till or sandy deposits (Fig. 17). The laboratory measurements of pH diverged from the field measurements by no more than 0.5. The data in Figure 17 include all the analyses of the groundwater monitoring sites since 1993. The mean value of the electrical conductivity in the drilled wells and the observation wells was also higher (Fig. 18). The highest amounts of electrolytes in till deposits were found in some shallow wells and in the groundwater monitoring site of the Korkalovaara spring. Higher electrical conductivities in shallow wells were also found in sandy deposits showing effects of human activity on water quality.

The concentrations of bromide, phosphate, silver, arsenic, beryllium, bismuth, cadmium, cobalt, chromium, lead, antimony, selenium, thorium, tallium and uranium of all the samples were in most cases lower than the detection limit (Table 5). The frequency distributions of some main properties and concentrations are presented in Figures 19-21.

The distribution patterns in Figures 19-21 are positively skewed showing mainly low concentrations of dissolved electrolytes. The dug wells in sandy parts of the Rovaniemi district tended on average to have higher sulphate, boron, barium, strontium and vanadium concentrations in their water than the sampling sites in till areas.

Table 5. Chemical composition of the groundwater of the Rovaniemi district in terms of median and mean concentrations of dissolved substances and results of the analyses of water from springs in sandy areas and wells drilled into the bedrock.

	SANDY DEPOSITS				TILL DEPOSITS				DRILLED WELLS			OBS. WELLS	
	Spring1	Spring 2	Wells (10)		Springs (48)		Wells (10)		Well 1	Well 2	Well 3	(10)	
			Med.	Mean	Med.	Mean	Med.	Mean				Med.	Mean
Field measurements													
pH	6.4	6.4	6.7	6.6	6.2	6.3	6.3	6.2	6.1	6.3	7.7	6.7	6.7
EC mS/m	6.5	5.1	8.6	10.6	3.2	3.7	3.8	6.3	87.7	15.8	15.2	9.9	9.4
Temp. ^{0}C	5.0	2.0	5.8	6.0	4.0	4.0	4.3	4.5	4.0	10.0	4.5	3.3	3.2
CO_2 mg/L	27	4	11	15	12	14	15	21	30	50	6	22	34.0
Lab. measurements													
pH	6.2		6.7	6.6	6.4	6.4	6.4	6.4	5.1	6.8	7.8	6.4	6.4
EC mS/m	5.9		7.2	8.2	3.1	3.9	3.7	5.6	93.2	16.8	15.4	6.7	6.8
Colour Pt mg/L	5	5	5	16	5	11	5	4	5	5	5	35	129
$KMnO_4$ mg/L	2.0	1.6	3.5	8.4	3.2	7.0	3.7	3.4	4.7	2.3	2.0	3.3	13.1
Alkalinity													
mmol/L	0.45	0.30	0.59	0.68	0.18	0.18	0.20	0.34	0.60	1.32	1.22	0.64	0.64
HCO_3 mg/L	27.5	18.3	36.0	41.4	10.4	11.0	12.2	20.4	36.6	80.5	74.4	39.0	38.9
Br mg/L	<0.1		<0.1	<0.1	<0.1	<0.1	<0.1	0.1		<0.1	<0.1	<0.1	<0.1
Cl mg/L	1.3	2.2	1.4	1.8	1.0	2.3	1.8	2.5	229.0	4.8	2.0	0.8	0.9
F mg/L	<0.10	0.10	<0.10	<0.10	0.10	0.10	0.10	0.10	0.46	<0.10	2.40	0.10	0.20
NO_3 mg/L	2.3	<1	<1	<1	<1	1.6	<1	2.1	18.0	5.9	<1	<1	<1
PO_4 mg/L	<0.02		<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.06	0.11
SO_4 mg/L	4.8	4.3	5.6	8.3	2.6	3.0	1.3	3.9	8.5	3.4	5.0	1.7	1.9
Ag µg/L	<0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	<0.01
Al µg/L	8.7	7.9	12.2	63.7	6.9	21.1	10.6	18.9	16.7	3.8	3.5	19.4	112.9
As µg/L	<0.05		0.11	0.14	<0.05	<0.05	<0.05	<0.05		0.05	0.05	0.07	0.16
B µg/L	3.0		2.1	11.5	1.6	2.4	5.3	9.0		5.1	15.8	1.9	2.6
Ba µg/L	184.0		26.5	48.0	6.3	7.8	17.5	19.0		23.5	26.6	21.2	23.9
Be µg/L	<0.1		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1	<0.1
Bi µg/L	<0.03		<0.03	<0.03	<0.03	<0.03	<0.03	<0.03		<0.03	<0.03	<0.03	<0.03

Table 5. cont.

	SANDY DEPOSITS				TILL DEPOSITS				DRILLED WELLS			OBS. WELLS	
	Spring1	Spring 2	Wells (10)		Springs (48)		Wells (10)		Well 1	Well 2	Well 3		(10)
			Med.	Mean	Med.	Mean	Med.	Mean				Med.	Mean
Ca mg/L	4.5	4.8	10.2	11.1	2.0	3.0	2.8	4.2	47.8	12.7	15.4	5.9	5.8
Cd µg/L	<0.1		<0.1	0.1	<0.1	<0.1	<0.1	0.2	0.3	<0.1	<0.1	<0.1	<0.1
Co µg/L	<0.5	<0.5	<0.5	0.9	<0.5	<0.5	<0.5	<0.5	0.5	<0.5	<0.5	0.5	1.0
Cr µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.7	3.2	0.8	1.6
Cu µg/L	0.4	1.8	1.0	31.3	0.7	1.8	1.3	7.6	51.8	94.2	2.7	0.5	1.0
Fe mg/L	<0.05	<0.05	<0.05	0.12	<0.05	<0.05	<0.05	<0.05	0.11	<0.05	0.06	4.85	9.79
K mg/L	1.7	1.0	2.0	4.0	1.6	3.4	4.6	5.7	36.0	1.8	1.0	1.4	1.5
Li µg/L	0.3		0.9	0.6	0.5	0.4	0.5	0.5		3.0	1.9	2.2	2.0
Mg mg/L	2.9	1.2	1.1	1.5	0.6	0.9	0.7	1.1	18.8	9.4	5.0	2.5	2.7
Mn µg/L	<20	26	<20	<20	<20	<20	<20	<20	120	<20	23	165	153
Mo µg/L	0.13		0.04	0.05	0.26	0.43	0.10	0.13		0.40	9.90	1.80	2.50
Na mg/L	1.7	1.8	2.7	8.9	3.3	10.8	10.7	25.0	860.0	5.1	6.9	3.9	4.0
Ni µg/L	1.0	2.7	1.0	1.8	0.4	1.0	0.4	0.3	1.1	1.3	2.4	1.3	1.5
Pb µg/L	<0.5	<0.5	0.5	2.6	<0.5	<0.5	<0.5	<0.5	<0.5	0.6	0.9	<0.5	<0.5
Rb µg/L	4.1		2.6	3.3	1.2	1.5	2.7	3.1		0.7	2.2	1.2	1.6
Sb µg/L	<0.02		0.02	0.06	<0.02	<0.02	<0.02	0.04		0.05	<0.02	<0.02	<0.02
Se µg/L	<0.5		<0.5	<0.5	<0.5	<0.5	<0.5	<0.5		<0.5	<0.5	<0.5	<0.5
Sr µg/L	21.3		44.9	43.2	13.2	16.3	32.5	31.7		64.7	73.7	31.1	32.2
Th µg/L	<0.02		<0.02	0.03	<0.02	<0.02	<0.02	<0.02		<0.02	<0.02	0.03	0.30
Tl µg/L	<0.02		<0.02	<0.02	<0.02	<0.02	<0.02	<0.02		<0.02	<0.02	<0.02	<0.02
U µg/L	<1	<1	<1	<1	<1	<1	<1	<1	13	<1	42.8	<1	<1
V µg/L	0.15		0.46	0.47	0.16	0.18	0.18	0.19		0.10	0.30	0.43	2.85
Zn µg/L	1.8		20.0	360.0	<20	<20	<20	<20	40.0	112.0	18.3	<20	33.5
Rn Bq/L	17	49	6	43	200	236	200	289	1690	180	774	38	511

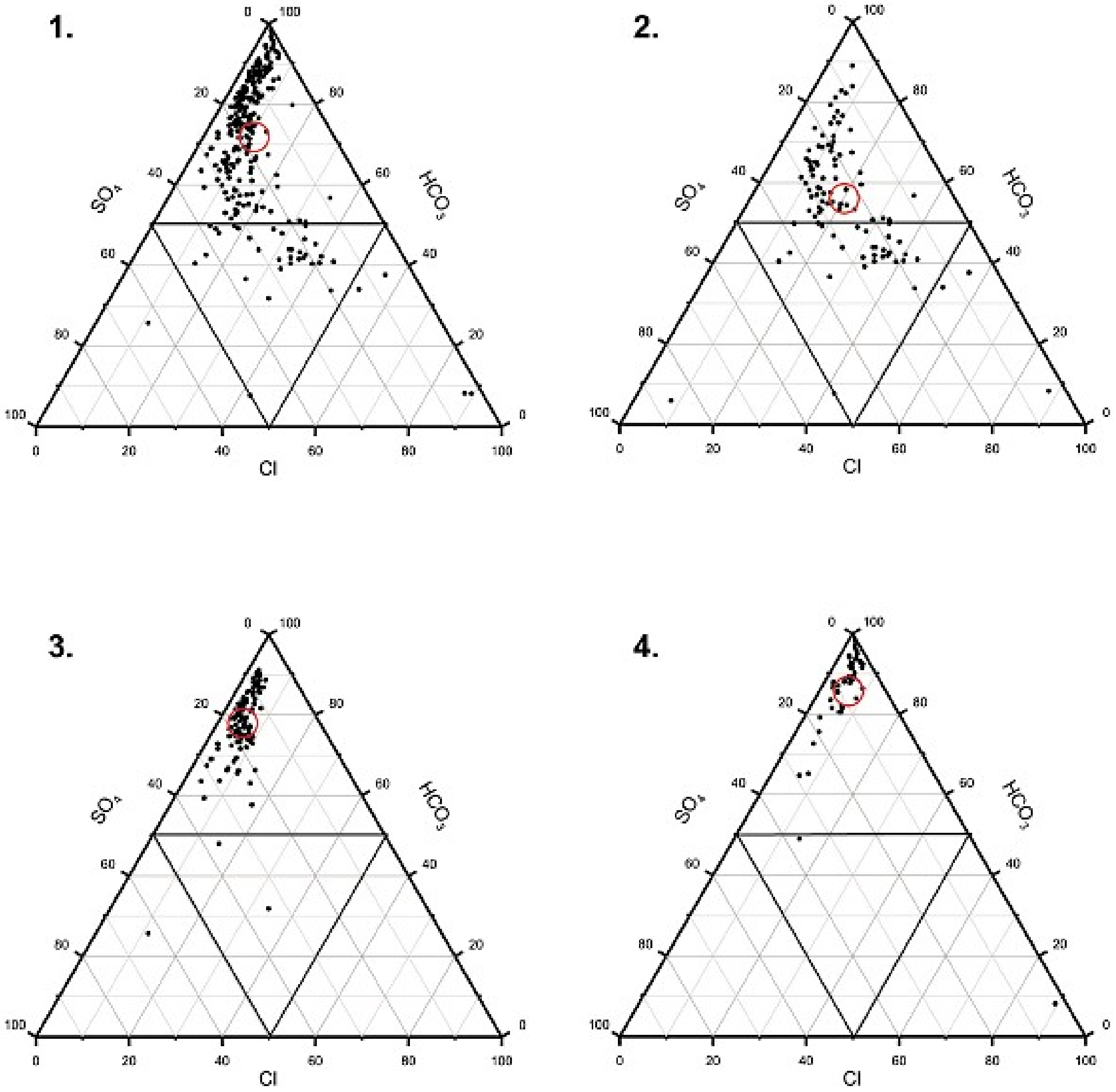


Fig. 15. Triangular diagrams showing the equivalent percentages of bicarbonate, sulphate and chloride for the groundwater samples in the Rovaniemi region. 1. all the samples, 2. the samples in the till deposits, 3. the samples in the sandy deposits, 4. the samples in the bedrock drilled wells and in the groundwater observation wells.

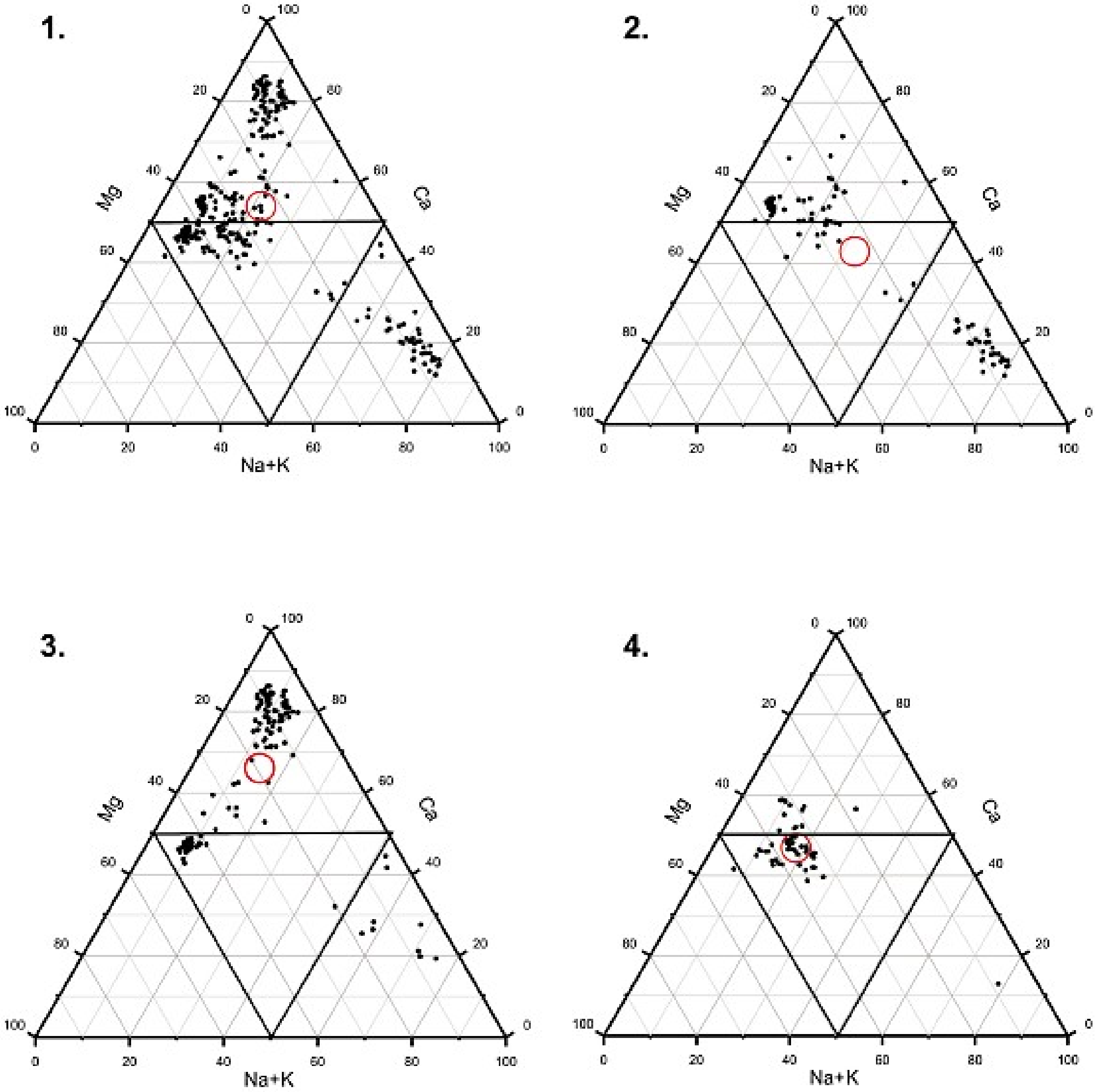


Fig. 16. Triangular diagrams showing the equivalent percentages of calcium, magnesium and sodium and potassium for the groundwater samples in the Rovaniemi region. 1. all the samples, 2. the samples in the till deposits, 3. the samples in the sandy deposits, 4. the samples in the bedrock drilled wells and in the groundwater observation wells.

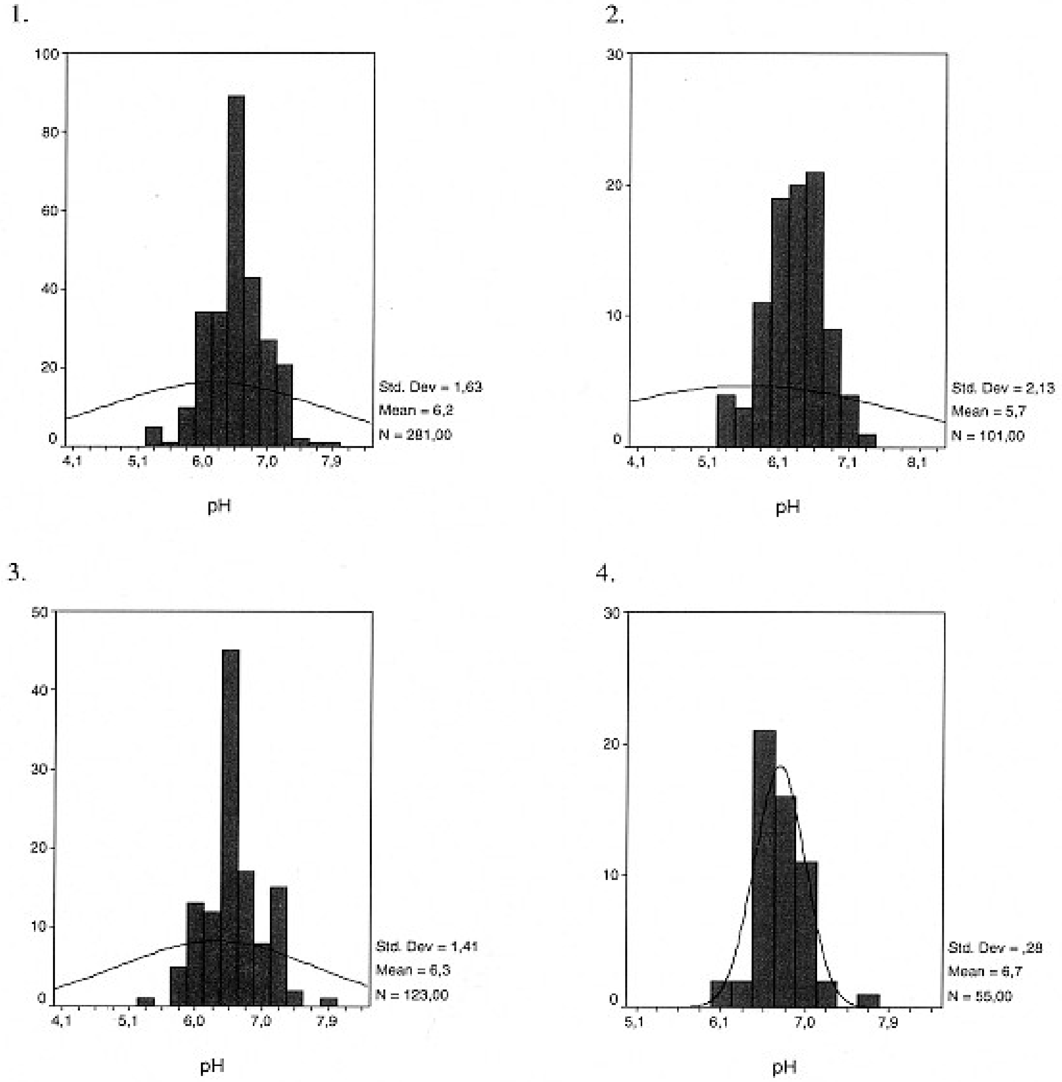


Fig. 17. The frequency distributions of the pH values in the groundwater samples in the Rovaniemi district. 1. distribution of all the samples, 2. distribution in the till deposits, 3. distribution in the sandy deposits, 4. distribution in the bedrock drilled wells and in the groundwater observation wells.

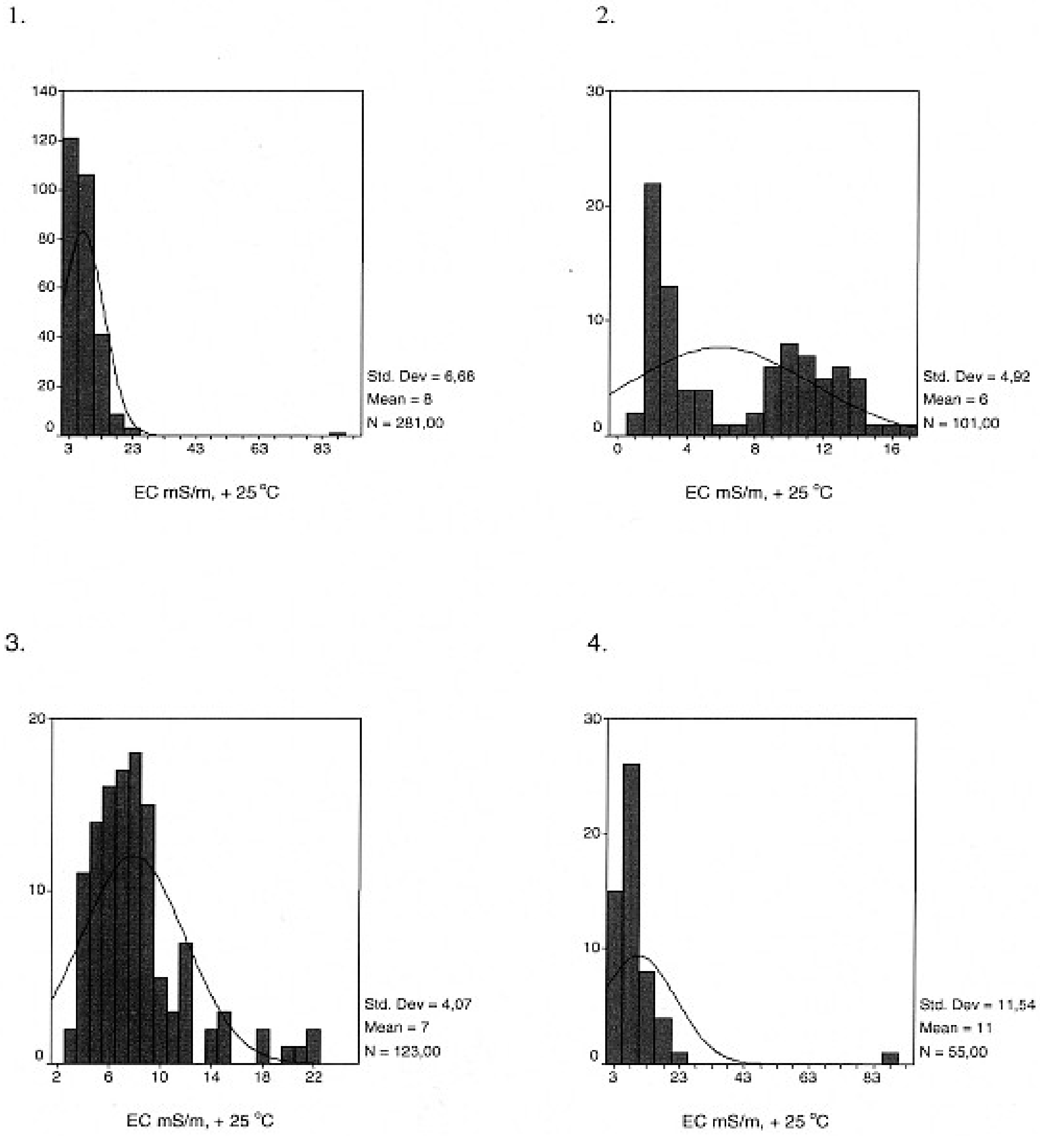


Fig. 18. The frequency distributions of the electrical conductivities in the groundwater samples in the Rovaniemi district. 1. distribution of all the samples, 2. distribution in the till deposits, 3. distribution in the sandy deposits, 4. distribution in the bedrock drilled wells and in the groundwater observation wells.

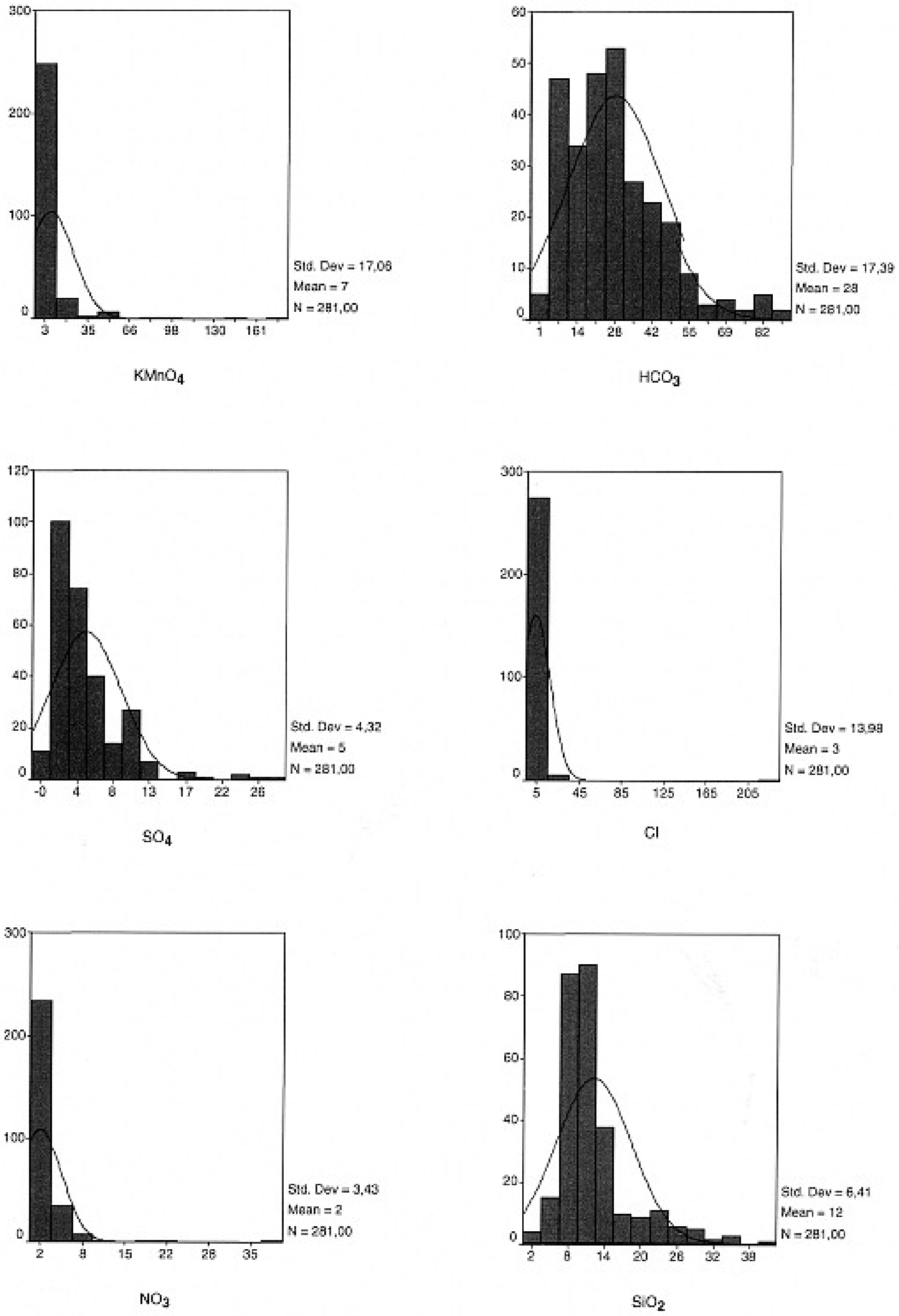


Fig. 19. The frequency distributions of $KMnO_4$ consumption, bicarbonate, sulphate, chloride, nitrate and silica (mg/L) in the groundwater samples in the Rovaniemi district.

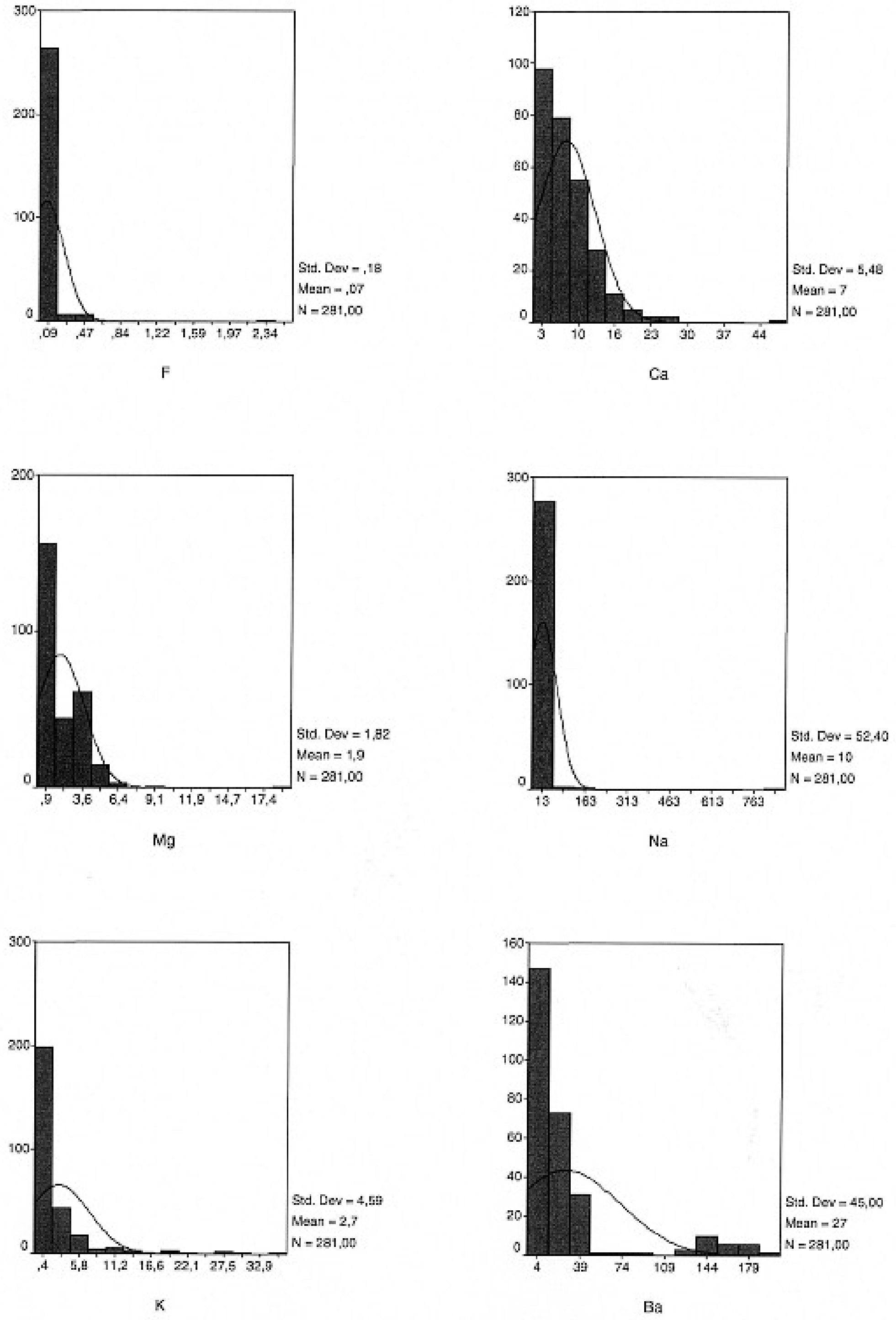


Fig. 20. The frequency distributions of fluoride, calcium, magnesium, sodium, potassium (mg/L) and barium (µg/L) in the groundwater samples in the Rovaniemi district.

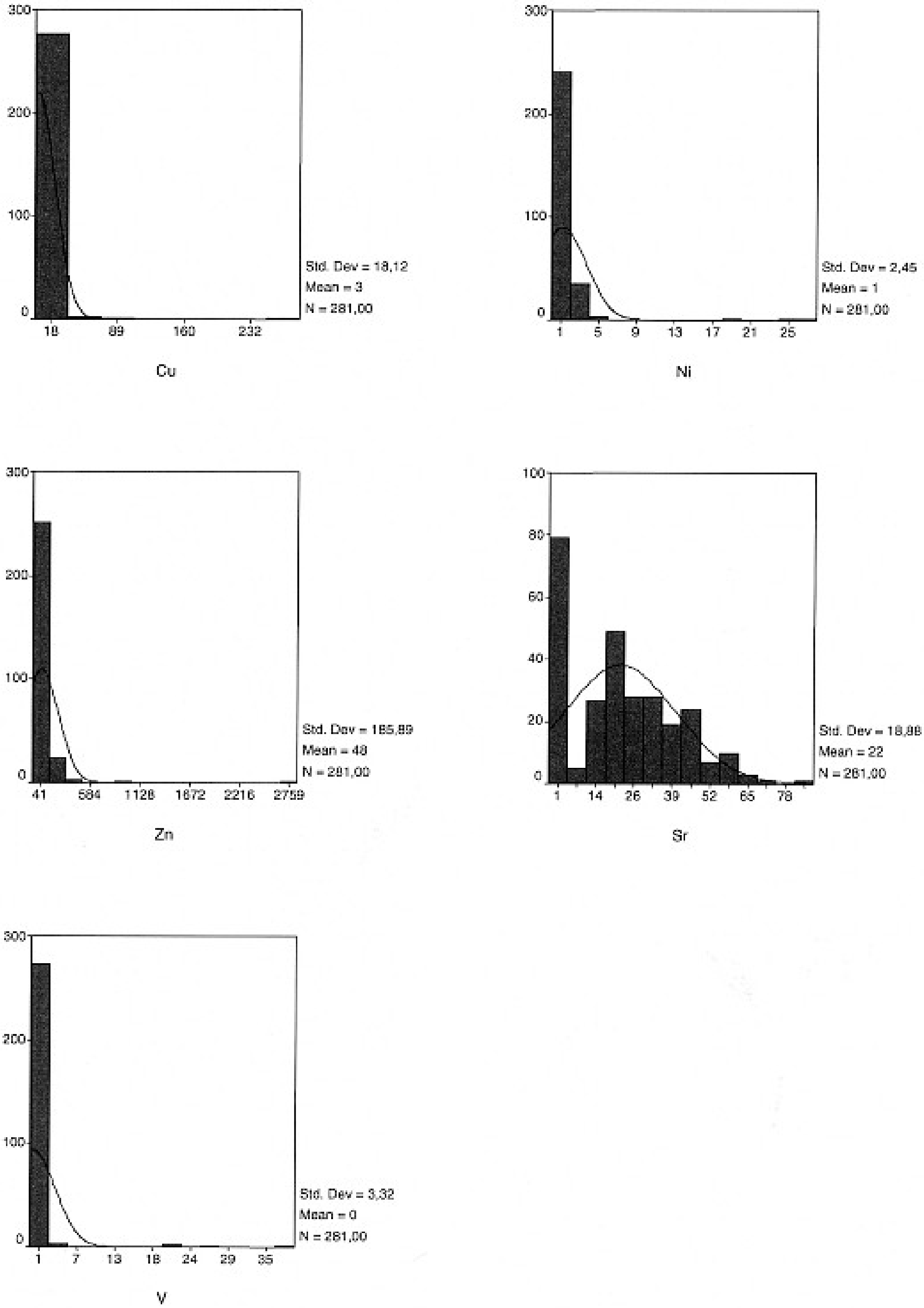


Fig. 21. The frequency distributions of copper, nickel, zinc, strontium and vanadium (μg/L) in the groundwater samples in the Rovaniemi district.

Thus the maximum concentrations of bicarbonate (86 mg/L), sulphate (29 mg/L) and heavy metals as lead (22.4 µg/L) and zinc (2760 µg/L), for instance, were recorded in the wells of these sandy areas.

The high concentration of zinc recorded in one well may be attributed to the presence of a galvanized bucket in the water. The well has now been filled in. There was also one well with a fairly high aluminium content (398 µg/L). Only chloride, sodium, molybdenum and radon showed higher mean concentrations in the till areas than in those of the sandy areas.

In the till areas the bicarbonate, calcium, sodium, boron, copper and rubidium concentrations were on average slightly lower in the spring water than in the dug wells (Table 5), on account of the shorter residence times in the former case, but the springs were marked by the highest concentrations of nitrate (38 mg/L), beryllium (0.26 µg/L) and nickel (27 µg/L). The higher electrical conductivities in the groundwater of bedrock drilled wells showed higher amounts of dissolved substances as bicarbonate, chloride, copper, manganese, zinc, uranium and radon.

The groundwater of till areas around Rovaniemi had lower mean values for electrical conductivity and for main anions, calcium, magnesium, iron, manganese, copper, nickel, lead and zinc concentrations than for Northern Finland as a whole (Table 6), partly on account of the fact that practically all the sampling sites around Rovaniemi were springs, where the more rapid groundwater cycle means that concentrations are generally lower than in wells. The groundwater of the Rovaniemi district in sandy deposits also had a lower mean value for electrical conductivity and lower concentrations of dissolved substances than Northern Finland as a whole (Table 7).

More detailed investigations into the aquifers located in the eskers of the Rovaniemi district and the quality of their water were carried out at Jokkavaara and Palovaara. Groundwater reserves of the eskers of Kolpeneenharju, Mäntyvaara and Mellavaara have been studied earlier by Lapland Regional Environment Centre. In the case of Jokkavaara attention was paid to the level of the groundwater table, the depths and compositions of the Quaternary deposits and the influence of geological factors on groundwater quality. In terms of the RT classification, the material of which these eskers are composed is principally sand and coarse finesand (grain sizes 0.06-2 mm), with interlayers of finer material (grain size <0.06) or gravel in many places. The esker core is usually composed of stone or boulder material (Väisänen 1997), while the surface layers are of fine sand and are at least a few metres thick. The area remained beneath the waters of the Baltic basin for some time after the last deglaciation, which means that the crests of the eskers, including that of Jokkavaara, were levelled off by littoral erosion. These flat tops have an effect on the quantities of water contributing to groundwater recharge.

Although the bedrock of Jokkavaara consists of mica schist and mica gneiss, with pyrite and graphite-bearing mica schist in the west (Väänänen et al. 1997), and iron and manganese are known to be susceptible to leaching out of mica schists and entering the groundwater, the iron and manganese concentrations recorded at the Jokkavaara pumping station are low and the raw water easily meets the criteria set for good domestic water supplies (Sosiaali- ja terveysministeriö 2000). Monitoring of water quality in a well on the sandy margin of Jokkavaara by the Geological Survey since 1993 has shown that it is slightly acid, mostly with electric conductivity values below 10 mS/m, the maximum value being 21.7 mS/m. Concentrations of heavy metals and other dissolved substances are mostly low (Backman et al. 1999), with the exception of lead.

Lead concentrations at the Jokkavaara well have varied greatly over the period 1993-2001 as a whole, being almost 10 µg/L in 1995, i.e. approaching the maximum permissible level

Table 6. Chemical composition of the groundwater of dug wells and springs in till areas in the Rovaniemi district (58 samples), in terms of minimum, median, mean and maximum values, by comparison with the groundwater of similar areas in Northern Finland as a whole (approx. 1700 samples).

	Rovaniemi Min.	Northern Finland	Rovaniemi Med.	Northern Finland	Rovaniemi Mean	Northern Finland	Rovaniemi Max.	Northern Finland
pH	5.3	5.1	6.3	6.5	6.3	6.2	7.3	10.7
Electrical conductivity mS/m, 25^0C	1.8	<1	3.4	6.3	4.5	12.7	15.7	149
$KMnO_4$ consumption mg/L	1.4	<1	3.2	6.0	6.5	14.0	55.0	205
HCO_3 mg/L	<1	<1	11.0	20.1	12.8	43.8	38.4	628
Br mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cl mg/L	<0.5	<0.5	1.0	1.5	2.2	7.6	22.2	246
F mg/L	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.14	1.13
NO_3 mg/L	<1	<1	<1	<1	1.6	<1	38.2	80.6
SO_4 mg/L	<0.5	<0.5	2.7	4.2	3.1	8.7	11.2	650
Al µl/L	<1	<1	7.3	1.9	21.1	25.7	136	780
As µg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	11.5
Ca mg/L	<0.5	<0.5	2.0	5.0	3.2	11.6	12.3	147
Cd µg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.6	8.1
Co µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	14.0
Cr µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.8	10.2
Cu µg/L	<0.5	<0.5	1.0	3.2	2.6	9.9	48.3	850
Fe mg/L	<0.05	<0.05	<0.05	0.05	<0.05	0.14	0.44	29.0
K mg/L	<0.5	<0.5	2.6	<0.5	3.8	4.3	22.0	520
Mg mg/L	<0.05	<0.05	<0.05	1.1	<0.05	2.6	5.7	112
Mn µg/L	<20	<20	<20	20	<20	61.2	30.0	3900
Mo µg/L	<1	<1	<1	<1	<1	<1	<1	631.2
Na mg/L	1.1	<0.5	8.7	2.2	13.6	5.8	147.0	234
Ni µg/L	<0.5	<0.5	<0.5	2.0	0.8	3.7	27.0	890
Pb µg/L	<0.5	<0.5	<0.5	1.0	<0.5	1.3	1.9	500
Sb µg/L	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Sr µg/L	9.9	<1	13.7	11.5	19.9	29.9	47.2	474
U µg/L	<1	<1	<1	<1	<1	<1	2.8	16.7
V µg/L	<1	<1	<1	<1	<1	<1	<1	4.1
Zn µg/L	<20	<20	<20	20	<20	117.4	22.0	12800

Table 7. Chemical composition of the groundwater of dug wells and springs in sand and gravel areas in the Rovaniemi district (12 samples), in terms of minimum, median, mean and maximum values, by comparison with the groundwater of similar areas in Northern Finland as a whole (approx. 500 samples).

	Rovaniemi Min.	Northern Finland	Rovaniemi Med.	Northern Finland	Rovaniemi Mean	Northern Finland	Rovaniemi Max.	Northern Finland
pH	6.0	4.8	6.5	6.5	6.6	6.4	7.1	9.2
Electrical conductivity mS/m, 25^{0}C	2.3	<1	7.4	9.8	9.1	15.5	19.1	131
KMnO$_4$ consumption mg/L	<1	<1	3.2	5.0	7.3	11.6	45.1	111
HCO$_3$ mg/L	9.1	<1	34.2	26.5	38.3	52.0	86.0	440
Br mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	35.0
Cl mg/L	<0.5	<0.5	1.4	2.0	1.8	12.8	5.6	2090
F mg/L	<0.10	<0.10	<0.10	<0.10	<0.10	0.17	0.15	0.95
NO$_3$ mg/L	<1	<1	<1	<1	<1	<1	2.3	109
SO$_4$ mg/L	1.8	<0.5	5.0	6.2	7.7	12.5	26.7	500
Al µg/L	4.1	<1	8.3	0.6	52.6	35.8	398	1000
As µg/L	<0.05	<0.05	0.09	<0.05	0.12	<0.05	0.28	13.4
Ca mg/L	2.5	<0.5	8.3	6.1	10.0	12.7	24.9	120
Cd µg/L	<0.1	<0.1	<0.1	0.5	0.1	0.8	0.5	1.4
Co µg/L	<0.5	<0.5	<0.5	<0.5	0.8	<0.5	5.9	21.0
Cr µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	1.4	7.6
Cu µg/L	<0.5	<0.5	1.0	3.0	26.2	9.2	280.0	280.0
Fe mg/L	<0.05	<0.05	<0.05	0.05	0.10	0.10	0.55	27.0
K mg/L	<0.5	<0.5	2.0	1.2	3.5	4.1	20.0	151
Mg mg/L	<0.05	<0.05	1.10	1.20	1.60	3.00	3.30	41.6
Mn µg/L	<20	<20	<20	<20	23.5	57.8	110.0	2100
Mo µg/L	<1	<1	<1	<1	<1	<1	<1	6.9
Na mg/L	<0.5	<0.5	2.3	2.5	7.7	6.7	54.0	340
Ni µg/L	<0.5	<0.5	1.5	2.0	1.8	4.8	5.0	320
Pb µg/L	<0.5	<0.5	<0.5	<0.5	2.5	1.4	22.4	80.0
Sb µg/L	<0.02	<0.02	<0.02	<0.02	0.05	<0.02	0.27	0.27
Sr µg/L	18.9	<1	35.5	33.4	39.6	50.0	66.4	365
U µg/L	<1	<1	<1	<1	<1	<1	5.0	33.7
V µg/L	<1	<1	<1	<1	<1	<1	1.2	6.1
Zn µg/L	<20	<20	<20	20.0	324.7	133.4	2760	6590

for good domestic water supplies. The maximum concentrations were 19.2 µg/L in 1999 and 22.4 and 18.5 µg/L respectively in the spring and summer samples for the year 2000 (Fig. 22). The figures have declined since that time, however, so that the reading in autumn 2001 was only 0.62 µg/L. The reason for the high lead concentrations and large variations probably lies in the dissolving of substances from the surrounding Quaternary deposits. All the other samples gave low lead concentrations in the Rovaniemi district, however, remaining below 2 µg/L throughout, and for the most part below 0.5 µg/L. The pattern throughout the monitoring period at the Jokkavaara well has been for peak concentrations to occur after the melting of the snow in spring or in the next sample, that representing the summer season. The well concerned is 7 m deep with its water level at 5.4-6 m. The water of this well also has the highest sulphate, arsenic, lithium and rubidium concentrations in the Rovaniemi area, and it is used regularly in a sauna and for watering crops during the summer.

The Mäntyvaara and Mellavaara esker formations, which also belong to the northern esker chain, similarly supply water to the city of Rovaniemi. Mäntyvaara has an area of 58.5 hectares and is said by the Lapland Environmental Centre to be covered by sand and gravel deposits to a thickness of 3-9 metres and to be capable of supplying an estimated 600 m^3 of water per day. The esker has also been used for the extraction of sand and gravel. The bedrock surface is irregular, and the groundwater probably exists in numerous small basins separated by thresholds. Detrimentally high concentrations of iron have been measured in the water from time to time, however, so that it would not be fit for use in domestic supplies without prior treatment. The potential groundwater yield from Mellavaara is estimated to be more than 1000 m^3/day (Britschgi & Gustafsson 1996), and borings have shown that the formation is covered by sand and finesand deposits to a depth of at least 6.5 m, with coarser sand and gravel horizons beneath.

The remaining eskers, Kroopinpalo-Palovaara, Tavivaara and Hietavaara, belong to the southern esker chain (Fig. 5). That of Kroopinpalo-Palovaara is significant as a source of both groundwater and sand and gravel. The thickness of the surficial deposits and the level of the groundwater table were determined by the Geological Survey by means of borings and seismic soundings in connection with the mapping of Quaternary deposits, the seismic results suggesting that these deposits may reach thicknesses of up to 40-50 m, being around 20 m at the esker margins. The groundwater table lies at a depth of some 20 m. Here again the bedrock surface is broken up. Estimates by the Lapland Environmental Centre place the thickness of the aquifer at least 9 m and the potential groundwater yield at around 2400 m^3/day (Britschgi & Gustafsson 1996).

A groundwater pumping station has been functioning on the Kroopinpalo esker since 1994. Large amounts of sand and gravel have also been extracted from the esker, but this has now been discontinued and the area landscaped. A spring located not far away from the pumping station has been used by the Geological Survey for groundwater monitoring purposes, and data on its water quality are available from 1993 onwards. The water emerging from this spring has eroded a gully 6-8 m deep in the esker, revealing coarser, highly permeable horizons beneath the fine, sandy material that forms the surface layer (Kujansuu et al. 1982). The water is slightly acid and has low levels of dissolved substances (Fig. 23). Electrical conductivity and calcium and magnesium concentrations have increased slightly since the pumping station started operating, but aluminium concentrations have diminished, possibly due to the lower rates of groundwater flow, which may allow the aluminium to precipitate out.

The delta-like foreplain of the Tavivaara esker is about 120 hectares in area composing

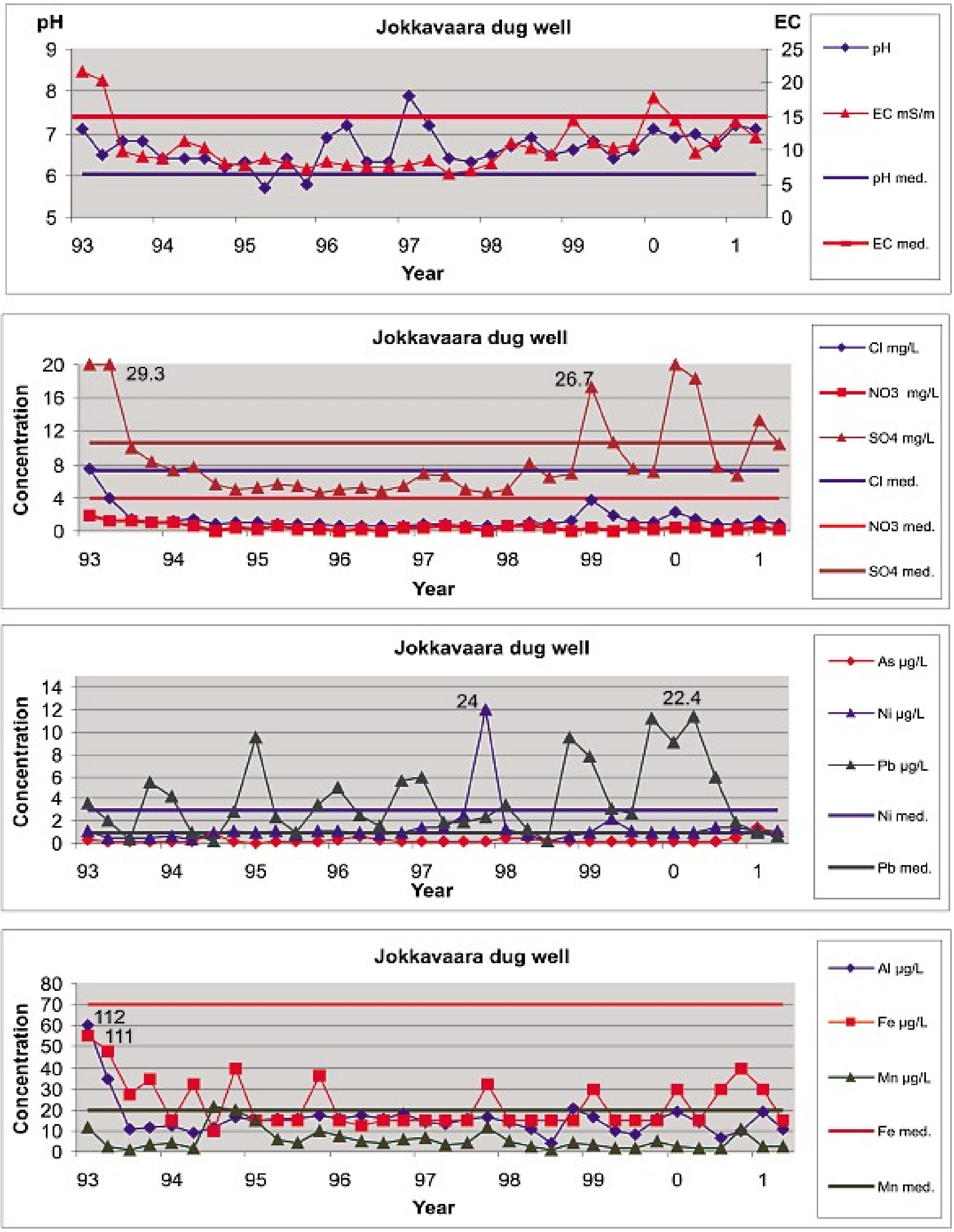


Fig. 22. Measurements of pH and electrical conductivity and anion and element concentrations in the Jokkavaara well in the Rural District of Rovaniemi in 1993-2001. Median values for the whole of Finland according to Lahermo et al. (1990) are presented for comparison.

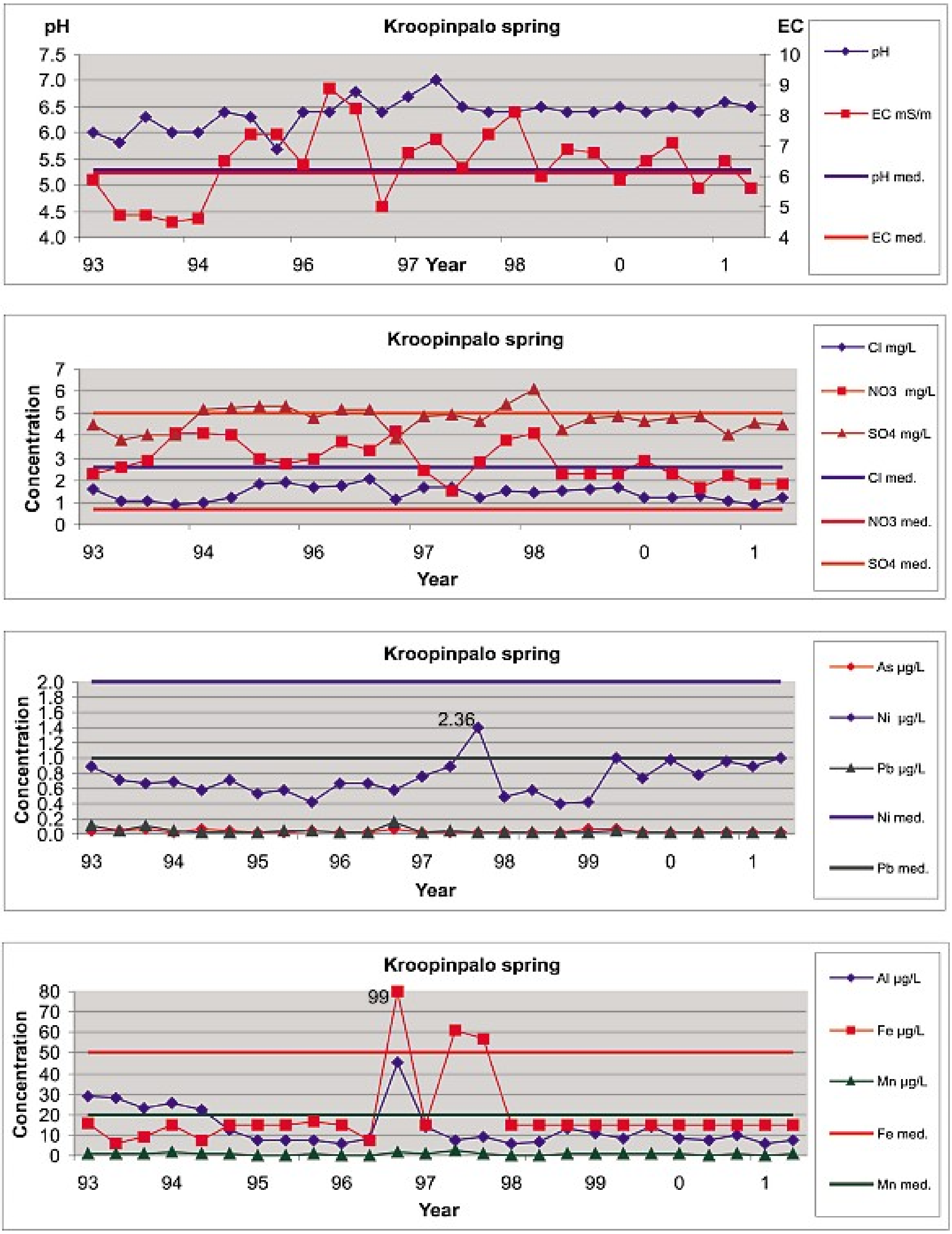


Fig. 23. Measurements of pH and electrical conductivity and anion and element concentrations in the Kroopinpalo spring in the Rural District of Rovaniemi in 1993-2001. Median values for the whole of Finland according to Lahermo et al. (1990) are presented for comparison.

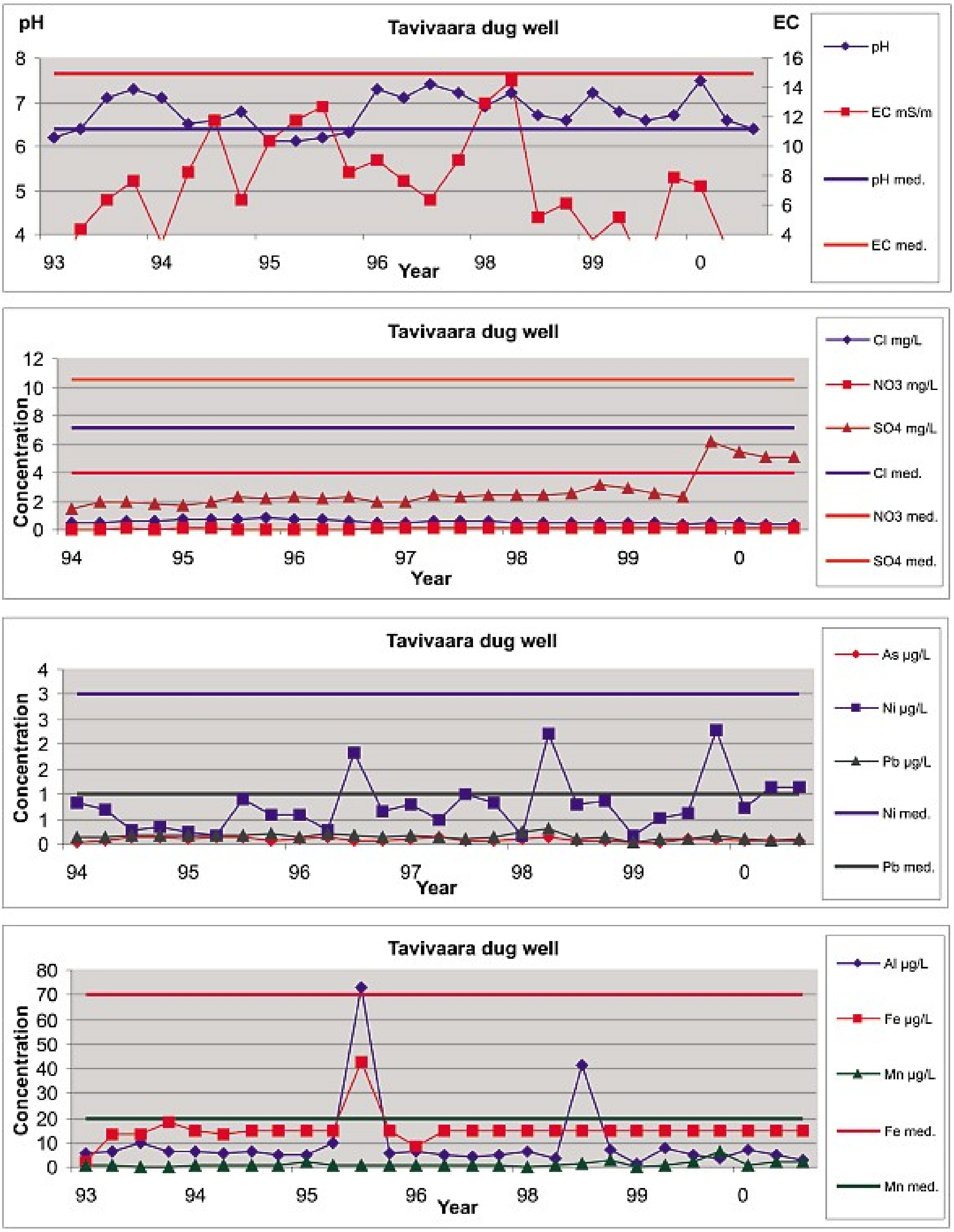


Fig. 24. Measurements of pH and electrical conductivity and anion and element concentrations in the Tavivaara well in the Rural District of Rovaniemi in 1993-2000. Median values for the whole of Finland according to Lahermo et al. (1990) are presented for comparison.

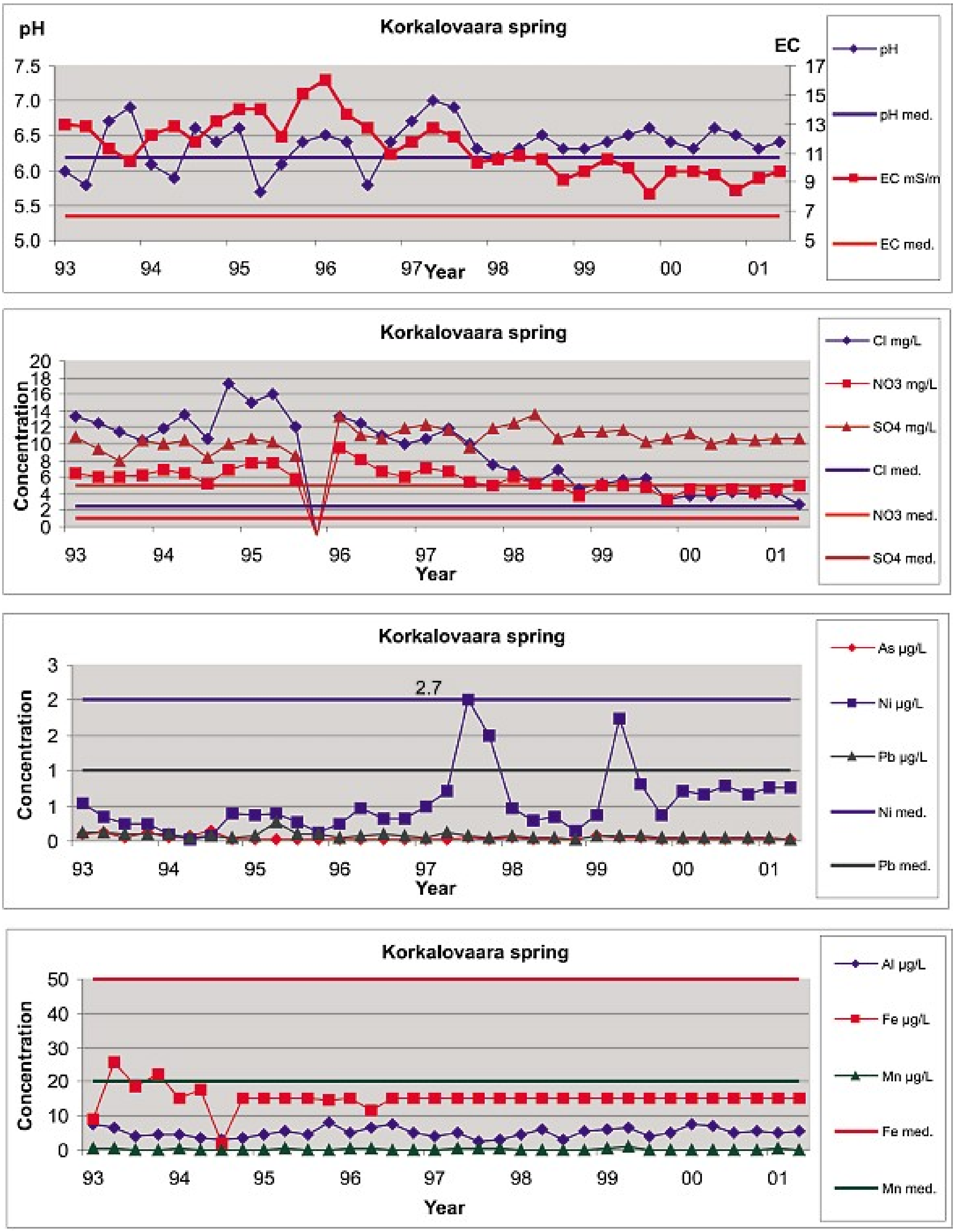


Fig. 25. Measurements of pH and electrical conductivity and anion and element concentrations in the Korkalovaara spring in Rovaniemi in 1993-2001. Median values for the whole of Finland according to Lahermo et al. (1990) are presented for comparison.

predominantly of sand. The quality of the water in a well located on this plain was monitored over the period 1993-2000. Here the groundwater table lies at a depth of only 1.5 m and the water is slightly acid and the concentrations of dissolved substances are low (Fig. 24). Calcium and magnesium concentrations increased slightly over the monitoring period, however, and zinc exceeded 300 µg/L on occasions (Backman et al. 1999).

A spring located in a till area on the hill of Korkalovaara in Rovaniemi that provides many of the nearby inhabitants with their drinking water has also been included in the Geological Survey's water quality monitoring programme since 1993. The water is again slightly acid, but its electrical conductivity has tended to be higher than the average for springs in Northern Finland, and sulphate, chloride and nitrate concentrations have also been above the general level for natural springs in the region, although those of other dissolved substances have remained low (Fig. 25).

Groundwater quality in three bedrock fracture zones was studied by means of the observation wells over the period 1997-2001 (Fig. 6). Wells 1-5, in the Poikajärvi-Latvajärvi fracture zone, and wells 8-10, in the Viiksjärvi fracture zone, are located in granite bedrock, and wells 6 and 7, in the Häkinvaara-Kalliovaara fracture zone, in quartzite-mica schist bedrock (Fig. 3). In the case of observation wells 3 and 4 at Poikajärvi-Latvajärvi and well 9 at Viiksjärvi the groundwater discharged at the surface under its own pressure. An estimated yield of the observation well 3 was about 20 m^3/day and those of the observation wells 4 and 9 were poorer.

Groundwater analyses were performed six times over the period 1997-2001 in the case of wells 1-5 and four times over the period 1998-2001 for wells 6-10. The water was slightly acid or almost neutral, with the mean and median values of 6.7 (Table 5). Electrical conductivity was 3.6-22.7 mS/m. The quality of the groundwater differed somewhat from the mean situation for bedrock groundwater in Northern Finland, with lower values for electrical conductivity, main anions, calcium, magnesium, potassium, copper, nickel, lead and zinc, chiefly on account of the fact that the bedrock groundwater had become mixed with more dilute surficial groundwater in some of the wells. Concentrations that were above average in the Rovaniemi district were those of fluoride, aluminium, iron and molybdenum.

Large amounts of aluminium, iron and manganese were found in the majority of the observation wells (Table 8), e.g. a maximum aluminium concentration of 648 µg/L together with 28.5 mg/L for iron and 669 µg/L for manganese in well 1, whereas the maximum recommended levels are 200 µg/L for aluminium, 0.4 mg/L for iron and 100 µg/L for manganese (Sosiaali- ja terveysministeriö 2000, 2001). Aluminium concentrations were also high in four other observation wells, and iron and manganese concentrations in eight observation wells. The lowest aluminium concentrations were recorded in wells 3, 4 and 9, where the groundwater comes to the surface under its own pressure and the retention time is short. The frequency distributions of aluminium, iron and manganese in the observation wells are presented in Figure 26, together with three bedrock drilled wells studied in the Rovaniemi district. Aluminium, iron and manganese concentrations in the observation wells and in the samples of till deposits from the same sites are presented in Table 8.

Iron, e.g. from the fractured and partially weathered bedrock, readily dissolves in groundwater under anoxic conditions, as shown by the situation in well 3, where the water discharged at the ground surface is clear and colourless but iron is precipitated as oxygenation takes place (Fig. 27).

The highest figures of iron were typically recorded on the first occasion of monitoring (Fig. 28, wells 6 and 7), those for manganese being on subsequent occasions, only a hundredth of the initial value in the case of observation wells 4 and 5. The data nevertheless

Table 8. Aluminium, iron and manganese concentrations in the samples from the groundwater observation wells and the samples of the Quaternary deposits (till) from the same sites (ammonium acetate extraction, method 201P/aqua regia extraction, method 512P).

			Al concentration		Fe concentration		Mn concentration	
Obs. well No.	Depth of obs. well m	Depth of sample of till deposit m	Till deposit mg/kg	Ground-water µg/L	Till deposit mg/kg	Ground-water mg/L	Till deposit mg/kg	Ground-water µg/L
1	14.2	7.5	56/5150	13.0-648	282/15600	0.7-28.1	17/139	47.0-669
2	16.2	17.5	47/3040	2.7-306	182/9400	4.3-9.9	3/93	32.0-243
3	15.0	0.8	218/8160	1.7-5.4	328/23200	4.5-5.3	3/134	149-202
4	15.5	15.5	88/8450	<1-3.7	580/21500	<0.03	22/179	0.04-4.3
5	14.8	9.0	73/5820	5.3-828	201/17400	<0.03-2.6	6/130	1.8-187
6	10.5	9.0	41/11400	4.1-28.0	141/19600	<0.03-2.3	25/162	1.4-366
7	8.5	9.0	21/3330	1.2-250	36/9930	0.03-0.4	3/72	1.2-122
8	8.8	8.0	28/4180	9.1-206	234/13900	23.0-30.4	12/103	153-238
9	8.9	5.0	36/4480	11.0-39.9	222/10900	5.5-5.9	5/75	128-144
10	6.9	7.5	25/3150	173-857	80/14700	35.8-64.2	3/138	196-331

suggest that there is no effective connection between the concentrations in the water and samples of Quaternary deposits, other than the fact that iron concentrations at site 7 are low in both the groundwater and till. Zinc concentration was high (962 µg/L) in the observation well 8. The mean concentrations of other dissolved substances were low in all the groundwater observation wells, those of nitrate, bromide, silver, beryllium, bismuth, cadmium, lead, antimony, selenium, thallium and uranium being below the respective detection limits.

The water in well 3 smelled strongly of hydrogen sulphide, H_2S, evidently on account of the totally or partially anoxic conditions, as these would lead to the reduction of sulphur compounds and the occurrence of sulphur in the form of sulphides.

Radon was determined in the samples from wells 1-5 on three occasions in 1997-1998 and in those from wells 6-10 on one occasion. The highest readings applied to well 3 (1420-1600 Bq/L) and well 4 (1500-1780 Bq/L). Readings in the other wells were considerably lower, well 1 having 6-160 Bq/L radon, well 2 having 3-36 Bq/L and well 5 having 4-18 Bq/L. Radon values in wells 6 and 7 were 39 and 10 Bq/L, while the values in wells 8, 9 and 10 were 16, 410 and 74 Bq/L. The uranium concentrations were mostly less than 1 µg/L. The maximum concentration was in the well 4 (2.68 µg/L).

The water of a well drilled into the bedrock of the Poikajärvi-Latvajärvi crush zone to a depth of 150 m at a point 400 m north-west of the nearest observation well 1 gave analysis results of 774 Bq/L for radon, 42.8 µg/L for uranium and 2.4 mg/L for fluoride, where the maximum recommended level for the latter is 1.5 mg/L (Sosiaali- ja terveysministeriö 2000).

The groundwater circulation in the bedrock at such a depth can be assumed to be slow, and this will explain the high uranium content. Concentrations of the other substances analysed were mostly low (Table 5). The water in this well was slightly alkaline, pH 7.7, which is typical of bedrock groundwater. No pumping data are available from which yields could be determined, but the owner of the well maintains that it provides a plentiful supply of water, which is presumably connected with its location in a crush zone.

The two other drilled wells examined in the Rovaniemi district were 74 and 80 metres deep,

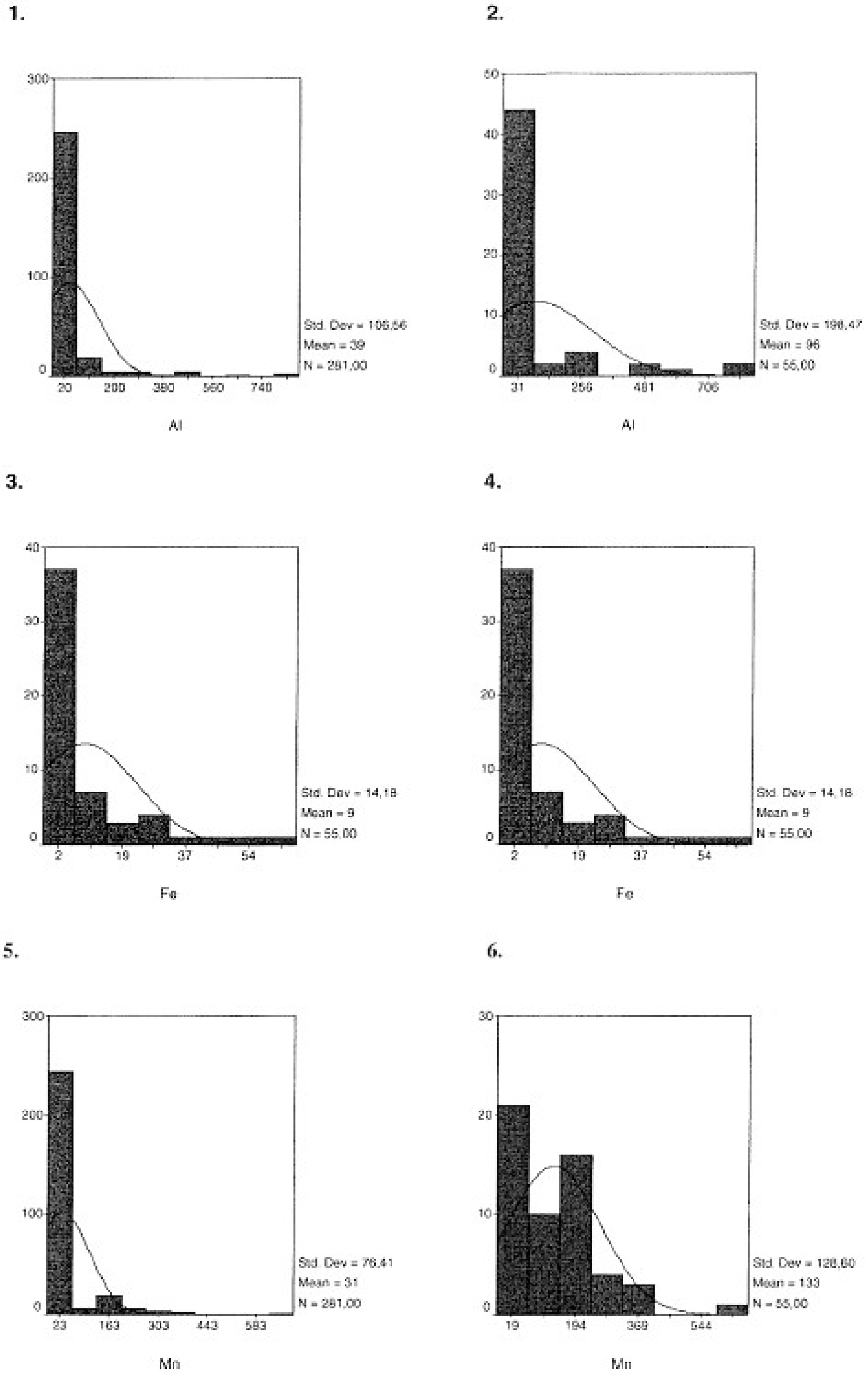


Fig. 26. The frequency distributions of aluminium (µg/L), iron (mg/L) and manganese (µg/L) in the groundwater samples of the Rovaniemi district. 1. aluminium in all the samples, 2. aluminium in the observation wells and bedrock drilled wells, 3. iron in all the samples, 4. iron in the observation wells and drilled wells, 5. manganese in all the samples, 6. manganese in the observation wells and drilled wells.

Fig. 27. The water from observation well 3 is clear and colourless on discharge at the ground surface, but iron is precipitated as oxygenation proceeds near the well.

the former containing the most acid water of all, pH 6.1, and having an electrical conductivity of 87.7 mS/m, which points to a fairly high concentration of dissolved substances. The chloride, sodium, uranium and radon concentrations were especially high (Table 5). The well in question is located at Olkkajärvi, where the bedrock consists of mica schist, black schist, conglomerate and arkosite. Earlier examinations of wells at Apukka, beside Lake Olkkajärvi, in the 1970s also revealed high uranium concentrations. The water in the other drilled well, of depth 80 m, had a pH of 6.3 and concentrations of dissolved substances that were comparable to those in surficial groundwater. This well was located in a granite area.

The mean temperature of the groundwater in sandy deposits in the Rovaniemi district was 5.7°C and in till deposits 4.2°C. The water temperatures from the bedrock drilled wells were not reliable because of measurements from tap water. According to Lahermo et al. (2002) the groundwater temperature is from +4°C to 4.5°C higher than the mean temperature of the year, which is in the Rovaniemi region about 0°C. In wells drilled into the bedrock the temperature is normally higher, probably being due to the minimal contact with air, the retention times involved and the less marked thermal gradient to be found in bedrock (Mälkki 1986).

Geophysical investigations

Three bedrock fracture zones near Rovaniemi were revealed by low-altitude aeromagnetic data and seismic soundings. The Poikajärvi-Latvajärvi and Viiksjärvi fracture zones were also identified on the basis of VLF-R measurements, ground resistivity soundings (Fig. 29), Sampo soundings, gravity and ground magnetic total field methods. The Poikajärvi-Latvajärvi fracture zone is less than 100 m wide and more than 10 km long in the study area and it continues further to the northwest outside the mapsheet area. The Viiksjärvi area belongs to the same Central Lapland granite belt as the Poikajärvi-Latvajärvi area but lies on a NW-SE-oriented low magnetic anomaly that extends for many tens

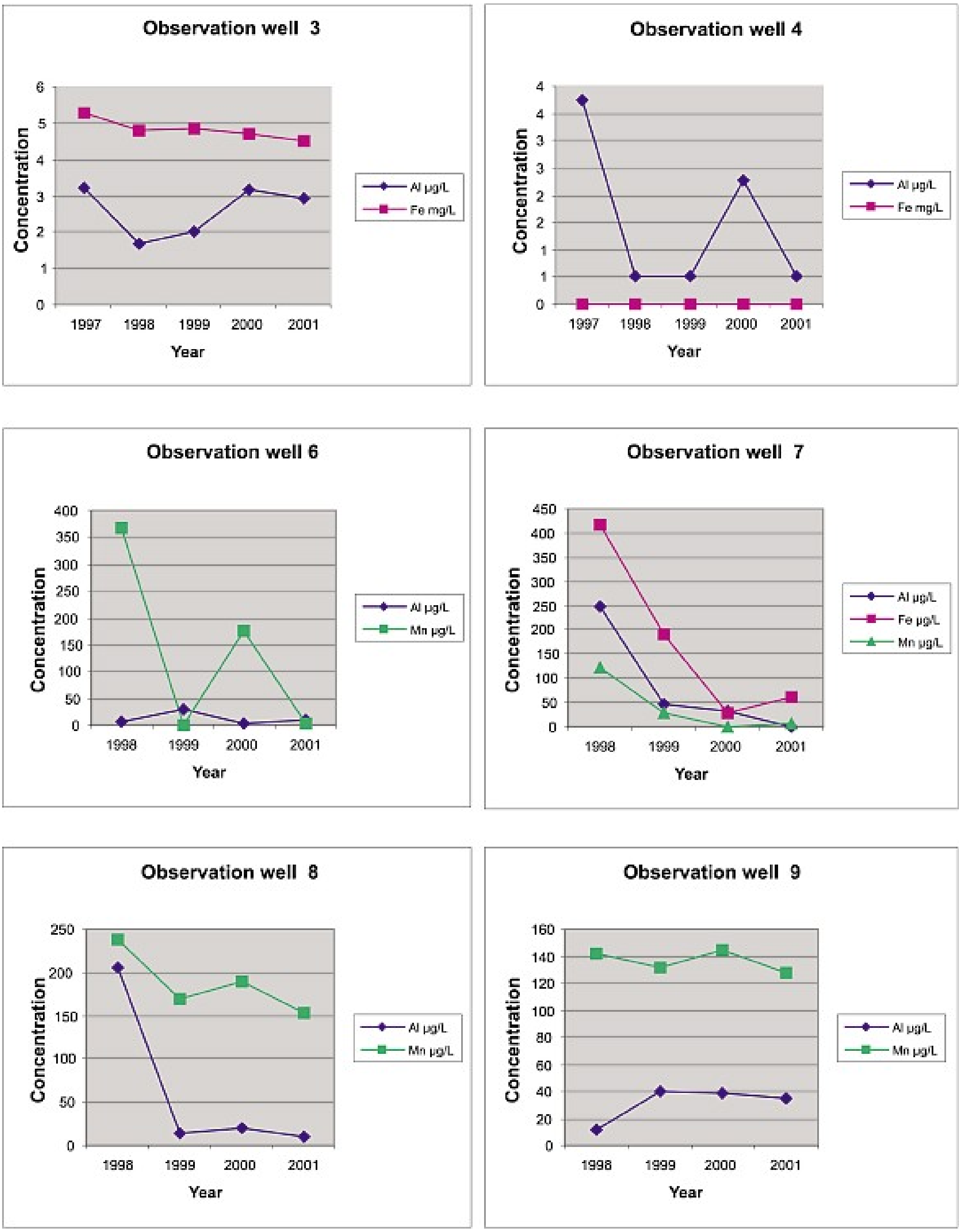


Fig. 28. Concentrations of aluminium, iron and manganese in the groundwater observation wells 3, 4, 6, 7, 8 and 9 in 1997-2001 in the Rovaniemi district.

of kilometres, presumably caused by an ancient fault line and associated crush zone. Similar faults are encountered in other parts of the granite belt. The interpretations of seismic soundings and ground resistivity soundings in the Poikajärvi-Latvajärvi fracture zone are presented in Figure 29.

Seismic soundings carried out in Jokkavaara, at the centre of the esker (Fig. 30, transects I-IV) gave seismic velocities of 300-350 m/s in the surface layers, increasing to 1200 m/s with depth. This reflects increasing density or coarser stony material of the Quaternary deposits with depth, typical values for bedrock being 3500-6000 m/s. The soundings indicated that the groundwater table in the centre of the esker lays at a depth of over 20 m, i.e. at 76-80 m a.s.l. The bedrock surface located at 60-85 m a.s.l., i.e. extending above the groundwater table in places (Fig. 31), to form a threshold that probably divides the esker into two separate aquifers. This means that if a detrimental substance were to escape into the Quaternary deposits and groundwater of the esker, one compartment might well be left unaffected. The present pumping stations at Jokkavaara nevertheless take water from both the northern and southern parts of the esker, i.e. from both sides of this bedrock threshold.

The thickness of the cover material in the central part of the esker was 40-50 m before the extensive extraction of sand and gravel, and that of the marginal areas 20-30 m (Väisänen 1997). Interpretations of ground penetrating radar measurements revealed the overall composition of the esker formation approximately to a depth of 20 metres. Seismic soundings were also carried out in the Palovaara esker. The soundings indicated that the groundwater table in the centre of the esker lays at a depth of over 20 m and the thickness of Quaternary deposits is approx. 40 m.

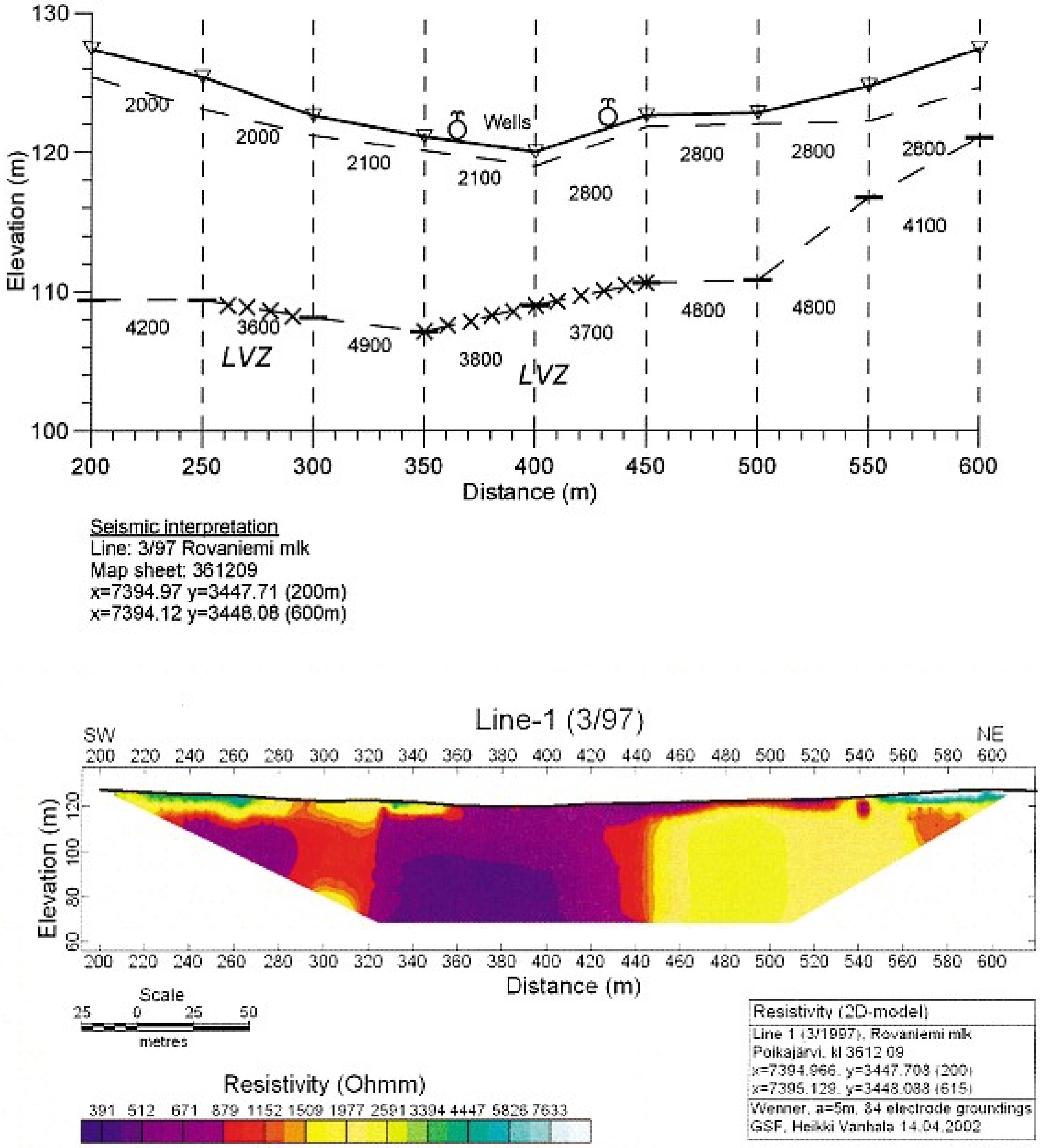


Fig. 29. Interpretation of seismic soundings and ground resistivity soundings across the Poikajärvi-Latvajärvi fracture zone: cross-section through the sites of groundwater observation wells 3 and 4 (Fig. 8). The numbers on the soil horizons and bedrock are excitation wave velocities (m/s).

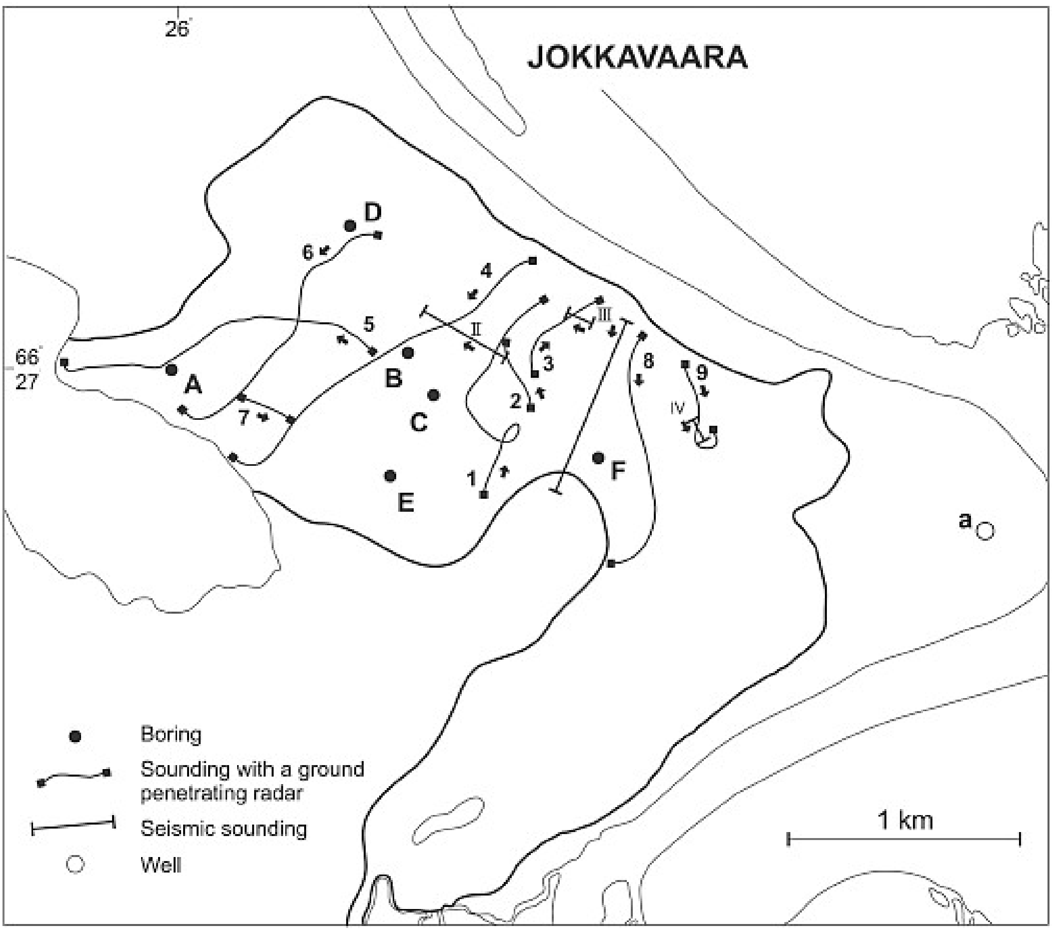


Fig. 30. Seismic soundings (transects I-IV), ground penetrating radar measurements (transects 1-9) and borings (sites A-F) performed on the esker of Jokkavaara. The location of the well on the sandy margin of the esker used for groundwater monitoring is also shown (a). Base map©National Land Survey of Finland, Permission number 516/MYY/03.

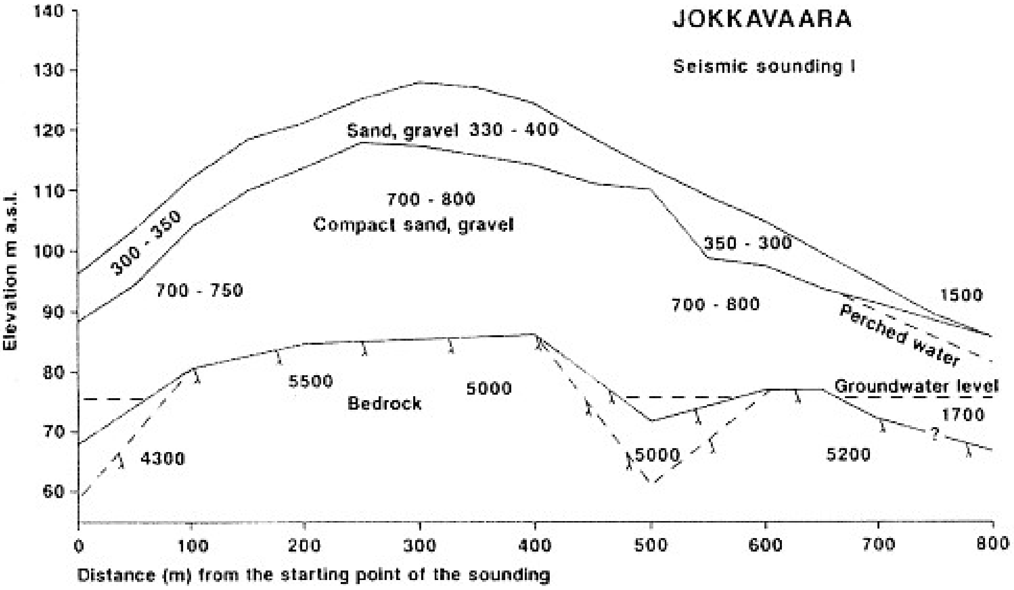


Fig. 31. Cross-section of the esker of Jokkavaara, based on results of seismic soundings along transect I. The numbers on the deposits and bedrock denote excitation wave velocities (m/s).

Composition of the surficial deposits and bedrock at the sites of the groundwater observation wells

An attempt was made to assess the influence of Quaternary deposits on groundwater quality by analysing the coring samples taken in connection with the installation of the groundwater observation wells, including separate analyses of the <2 mm fractions in the E, B and C podzol horizons of the samples corresponding to observation wells 6, 7 and 9. Bedrock samples were also analysed in the case of sites 6-10. The samples were extracted in both ammonium acetate and aqua regia, the results in the latter case being taken to reflect general solubility in the acids occurring in nature, and thereby the tendencies of given elements to dissolve in connection with weathering and their consequent availability as nutrients. Extraction with aqua regia or nitric acid does not reflect the total concentrations of such substances in the surficial deposits, however, except in the case of certain easily soluble substances, the results for which may indeed be close to total concentrations (Koljonen 1992). The fraction extractable in ammonium acetate in turn depicts the situation regarding weakly bound elements, allowing evaluations to be made of the pollutant loading on surficial deposits and sediments, the forms in which certain elements occur and the chemical properties of the surficial deposits. The frequency distributions of some elements in Quaternary deposits from the sites of the groundwater observation wells are presented in Figures 32 and 33. The concentrations are those with aqua regia extraction.

The concentrations of the major elements, aluminium, iron, calcium, magnesium, sodium, potassium and silicon, were mostly higher in bedrock samples than in the corresponding samples from the Quaternary deposits (App. 3). Aluminium and iron had mostly become enriched in the surface layers of these deposits, the B and C horizons, with lower concentrations below them (Fig. 34). The lowest concentrations of iron occurred in the E horizon of the podzol. The occurrence of lower amounts of readily soluble cations such as calcium, magnesium, sodium and potassium in the surface horizons testifies to their mobility in surficial deposits. The concentrations of soluble cations in the groundwater were also low, partly on account of the thick Quaternary deposits, which prevented cations that had leached out of the surface layers from passing into the groundwater.

The smallest amounts of silicon, which was analysed only by ammonium acetate extraction in the samples from sites 6-10, were to be found in the E horizon and the greatest amounts of surficial deposits in the B and C horizons. Phosphorus was also in surficial deposits most abundant in the B and C horizons.

The highest values for sulphur were mostly recorded at greater depths (Fig. 35), while the lowest concentrations occurred in the E, B and C horizons. Sulphur is a highly mobile element under oxidizing, acidic, neutral and also basic conditions, but it is bound in largely insoluble compounds under reducing conditions (Reimann et al. 1998). One indication of the reduction of sulphur compounds in an anoxic environment was the smell of hydrogen sulphide detected in the groundwater obtained from observation well 3. Manganese concentrations mostly increased with depth (Fig. 35). Barium, vanadium, copper and zinc concentrations were low (Fig. 33). Zinc is readily soluble under oxidizing and acidic conditions, but concentrations in the groundwater were almost without exception low.

Beryllium concentrations were in all the samples below 1 mg/kg and cobalt reached no more than a few mg/kg. Chromium concentrations were at the most a few of tens of mg/kg and nickel concentrations were mostly a few mg/kg (App. 3). Strontium concentrations were below 12 mg/kg and silver, arsenic, boron and antimony below the detection limit in all the samples, as were cadmium, molybdenum, lithium and lead in the majority of cases.

Altogether, aluminium, iron, magnesium, sodium, potassium, silicon, manganese, copper, barium, chromium, titanium and vanadium all had their maximum concentrations for bedrock samples at site 7, which also featured the peak concentrations of aluminium, magnesium and copper in samples of Quaternary deposits. The concentrations of these elements in the groundwater at the same site are nevertheless low, the only results of any magnitude being obtained for aluminium and manganese on the first occasion of monitoring (250 and 120 mg/L, respectively).

Thin sections were produced from the bedrock samples for sites 2, 4, 6, 7, 8, 9 and 10, and these were used to determine rock types and minerals under a microscope and minerals by X-ray diffraction. The sample from depth 17.6 m at site 2 in the Poikajärvi-Latvajärvi crush zone proved to consist of granite, the main minerals being quartz, potassium feldspar, plagioclase and a little green biotite, while those from depths of 17.5 and 18 m at site 4 represented amphibolite and granite, the upper sample possessing plagioclase, hornblende, biotite, magnetite and apatite as its main minerals (Fig. 36) and the lower one quartz, potassium feldspar, plagioclase, pyrite and pyrrhotite (interpretations by Vesa Perttunen and Jorma Isomaa). Of the typical uranium-bearing minerals contained in granite, apatite is prone to weathering, whereas zircon and monazite are more resistive (Koljonen 1992). The source of radon at site 4, where the groundwater radon content was highest, is probably uranium released from the apatite by weathering. The bedrock map (Väänänen et al. 1997) shows this to be a granite and granodiorite area, and examination of the till sample from 15.5 m by X-ray diffraction showed the main minerals to be quartz, plagioclase, feldspar, mica and amphibole (interpretation by Pentti Kouri).

The bedrock sample from a depth of 11.9 m at site 6 in the Häkinvaara-Kalliovaara crush zone shows the rock to be a medium and fine-grained, schistose, banded mica gneiss with

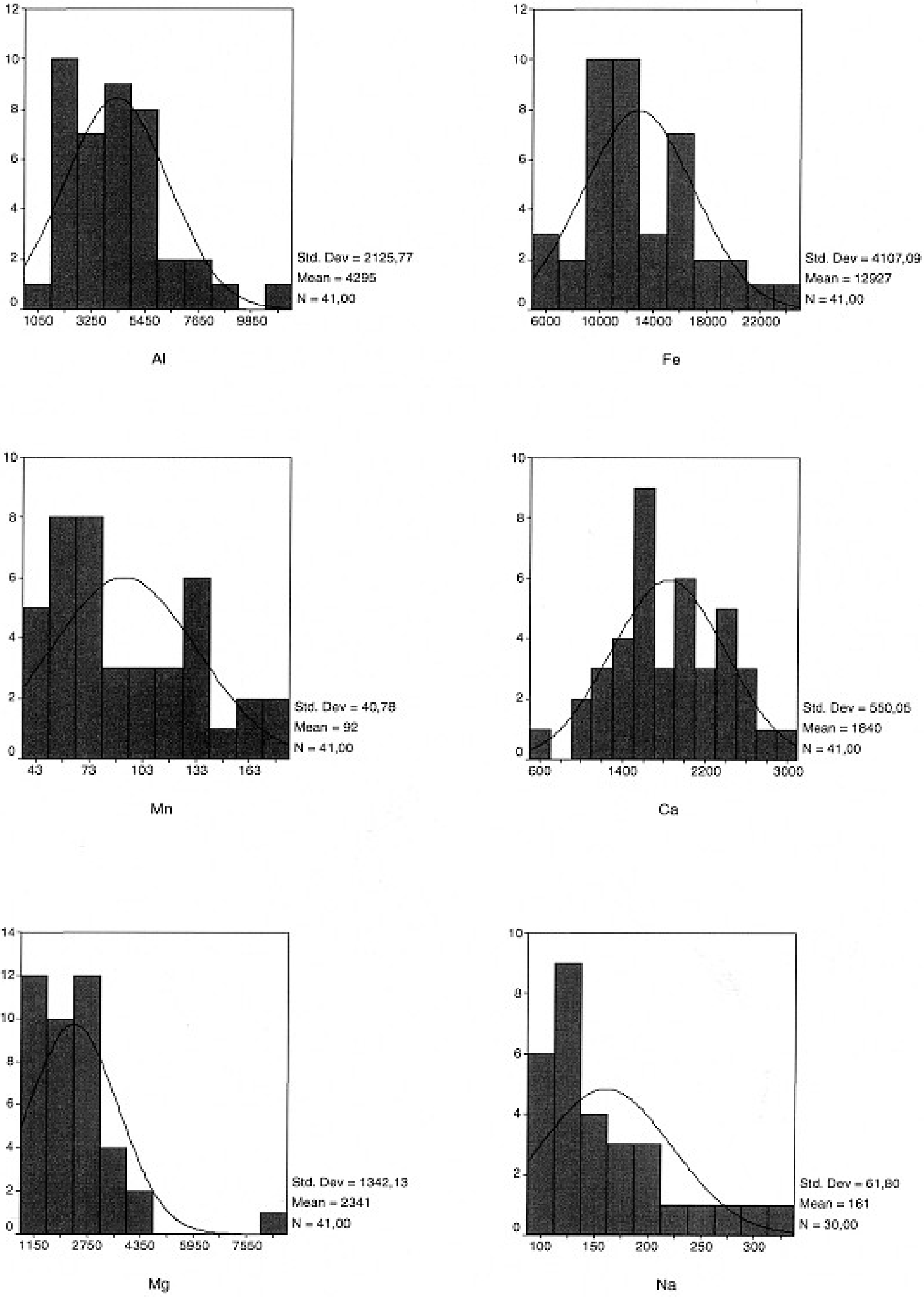


Fig. 32. The frequency distributions of aluminium, iron, manganese, calcium, magnesium and sodium (mg/kg) in the samples of the Quaternary deposits in the Rovaniemi district.

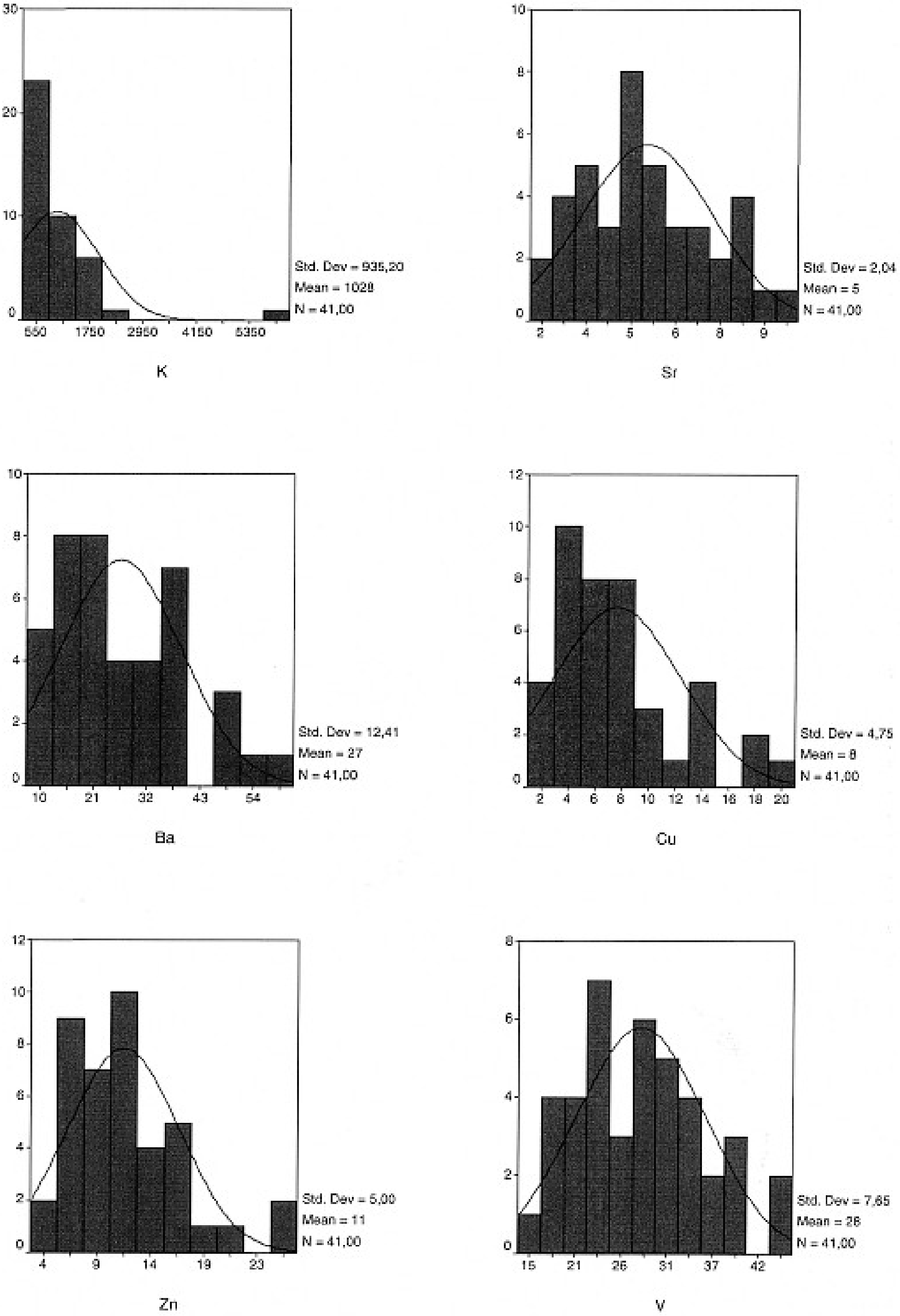
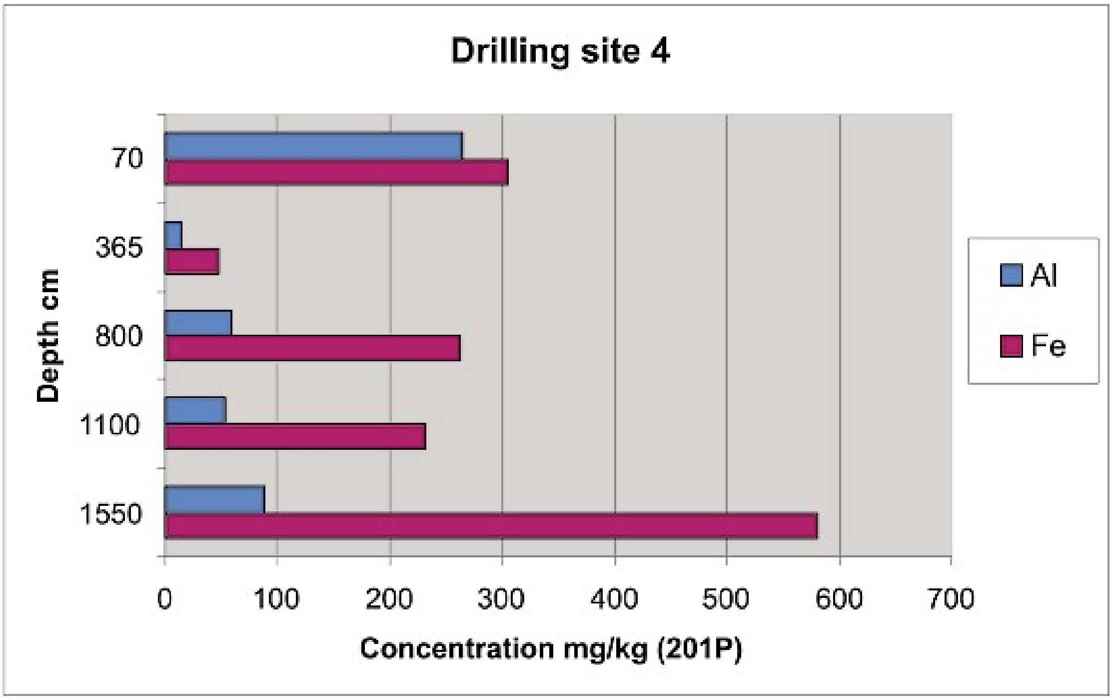


Fig. 33. The frequency distributions of potassium, strontium, barium, copper, zinc and vanadium (mg/kg) in the samples of the Quaternary deposits in the Rovaniemi district.



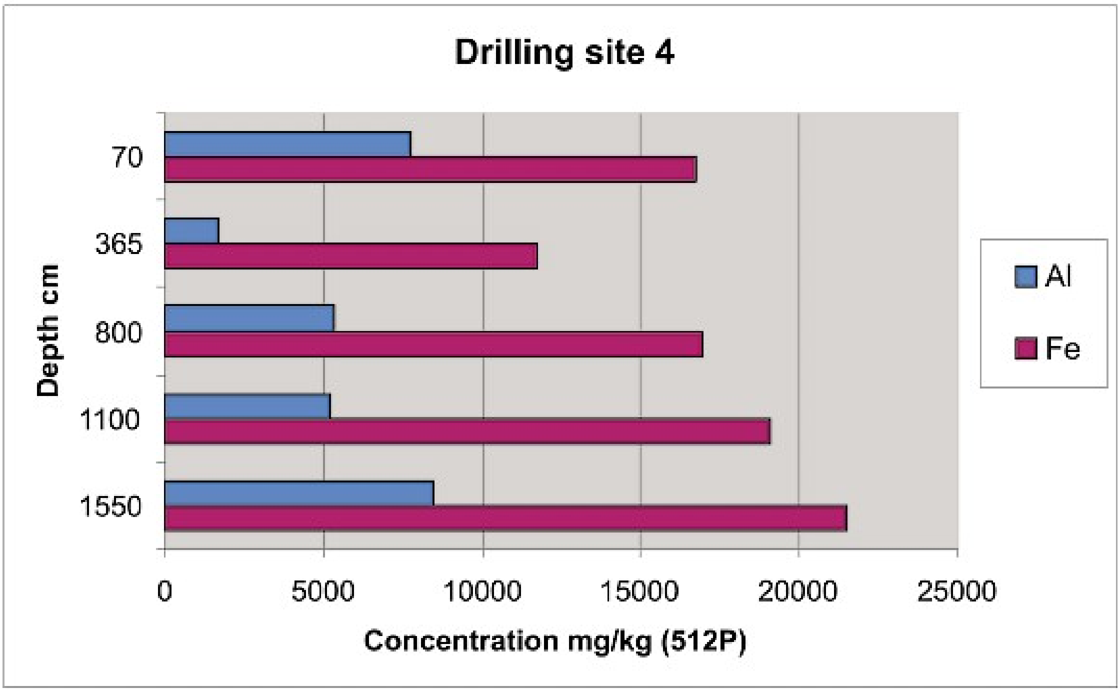
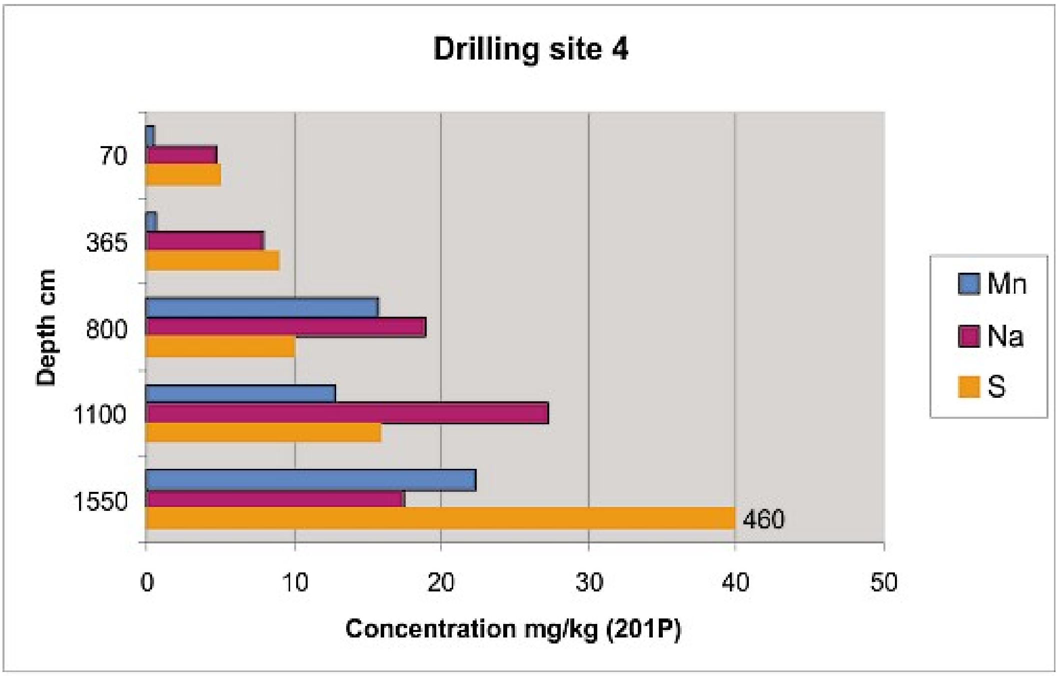


Fig. 34. Trends in aluminium and iron concentrations in samples of Quaternary deposits with depth at site 4 in the Poikajärvi-Latvajärvi fracture zone. Analyses were performed using ammonium acetate extraction (method 201P) and aqua regia extraction (method 512P).



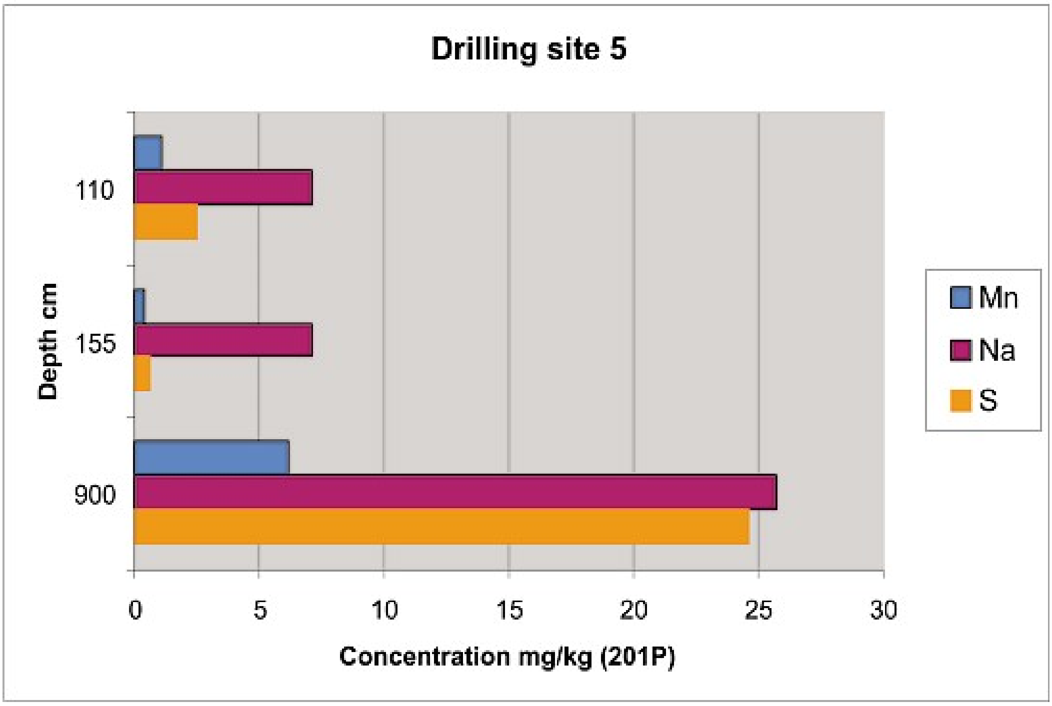


Fig. 35. Trends in manganese, sodium and sulphur concentrations in samples of Quaternary deposits with depth at sites 4 and 5 in the Poikajärvi-Latvajärvi fracture zone. Analyses were performed using ammonium acetate extraction (method 201P).

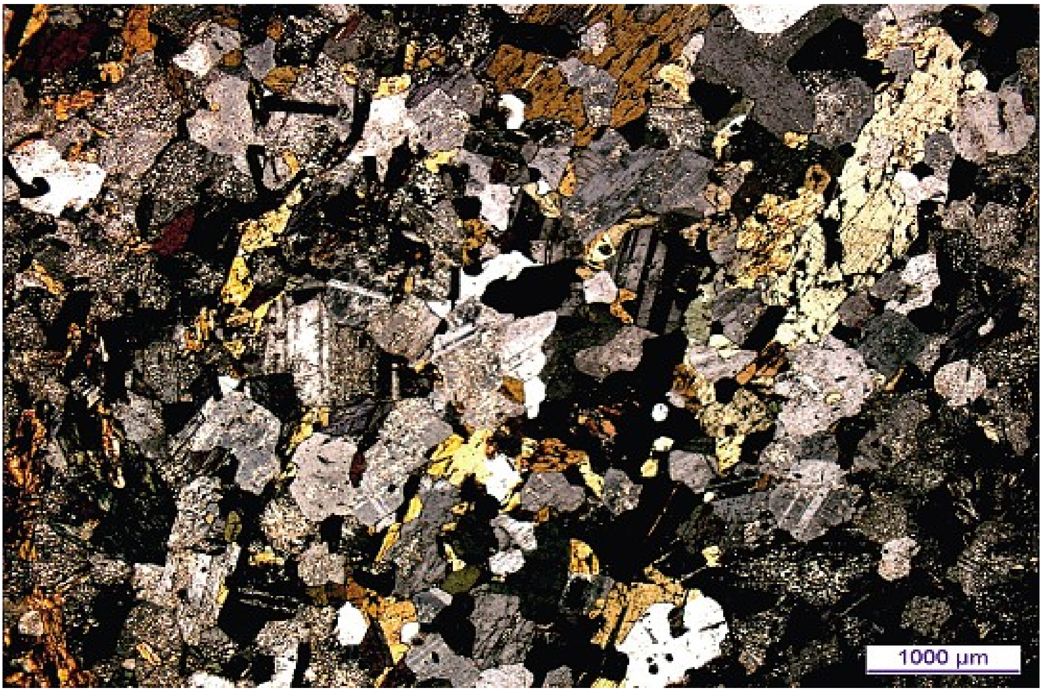


Fig. 36. Microscope image of the thin section for the drilling site 4 at the depth of 17.5 m. Crossed polarizers. The main minerals are plagioclase, hornblende, biotite, magnetite and apatite. Photo by Pentti Kouri.

muscovite, biotite and quartz as its main minerals, together with a little potassium feldspar and plagioclase. The minerals were identified by X-ray diffraction as quartz, mica and plagioclase (interpretation by Pentti Kouri). The bedrock sample taken at a depth of 10.8 m at site 7 was composed of fairly fine-grained schistose mica gneiss (Fig. 37) with quartz, biotite and potassium feldspar as its main minerals and a little accessory plagioclase, slowly weathering ilmenite and grains of zircon and apatite. The bedrock map indicates that this is an area of quartzite, arkosite and mica schist, while the minerals detected by X-ray diffraction were quartz, plagioclase and potassium feldspar.

The bedrock samples taken in the Viiksjärvi crush zone were from depths of 10.8 m, 9.2 m and 9.3 m at sites 8, 9 and 10, respectively. The rock type at site 8 was identified from the thin section as a pegmatitic granite of medium grain size which was rich in potassium feldspar and also contained quartz, plagioclase, a little darkened biotite and some grains of apatite and zircon. The minerals detected by X-ray diffraction were quartz, plagioclase and potassium feldspar.

At site 9 the rock type was a homogeneous, medium or coarse-grained granite with potassium feldspar, quartz and plagioclase as its main minerals and a little green biotite and some grains of zircon, apatite and magnetite. The X-ray diffraction method showed the minerals to be quartz, plagioclase and potassium feldspar. The bedrock at site 10 proved to be a coarse, pegmatitic granite with banded schistose residues, the minerals being potassium feldspar, quartz, plagioclase and biotite, which was in the process of alteration to chlorite, and also some grains of zircon, apatite and magnetite. The minerals identified by X-ray diffraction were quartz, plagioclase and feldspar. The bedrock map shows the area to be composed of granite and granodiorite.

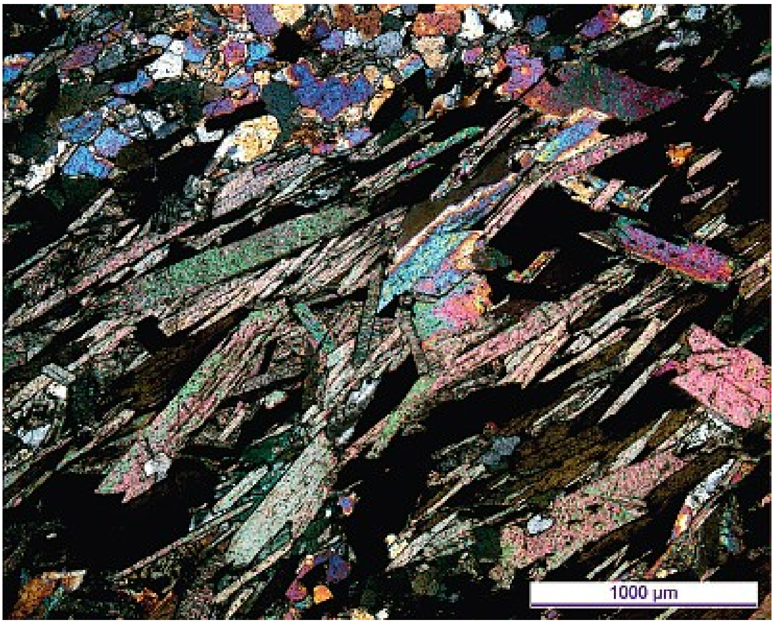


Fig. 37. Microscope image of the thin section for the drilling site 6 at the depth of 11.9 m. Crossed polarizers. The main minerals are muscovite, biotite and quartz. Photo by Pentti Kouri.

Groundwater, surface water and surficial deposits of Nicaragua

Chemical composition of the groundwater

Groundwater in Nicaragua was examined in 32 wells and one spring. One well was examined both in 1994 and 1997. An overall view of the chemical composition of the groundwater in Nicaragua is presented in triangular diagrams for anions (HCO_3^-, SO_4^{2-} and Cl^-) and cations (Ca^{2+}, Mg^{2+} and Na^++K^+) in Figures 38 and 39. The groundwater of all the samples are composed of 81 equivalent percent bicarbonate, 7 equivalent percent sulphate and 12 equivalent percent chloride. The corresponding equivalent percentages are 83, 4 and 13 for the groundwater of the Tisma area (Fig. 38), 79, 12 and 9 in the León-Posoltega area and 83, 3 and 14 in the Santo Tomás-La Libertad area (Fig. 39). The cation equivalent percentages in all the samples are 39 for calcium, 20 for magnesium and 41 for sodium and potassium. The corresponding equivalent percentages are 25, 13 and 62 for the groundwater of Tisma (Fig. 38), 49, 27 and 24 in the León-Posoltega area and 43, 21 and 36 in the Santo Tomás-La Libertad area (Fig. 39).

The groundwater composition is partly calcium-bicarbonate type and partly sodium-potassium-bicarbonate type. In the Tisma area sodium and potassium are dominant cations. The seven groundwater samples of Santo Tomás represent both calcium-bicarbonate type and sodium-potassium-bicarbonate type. The concentrations of the main cations and anions were considerably higher than in the Rovaniemi region, especially bicarbonate concentrations were high, but the differences of sulphate concentrations were smaller. The groundwater in Nicaragua is slightly alkaline on average and electrical conductivities are high compared to those in Rovaniemi. The frequency distributions

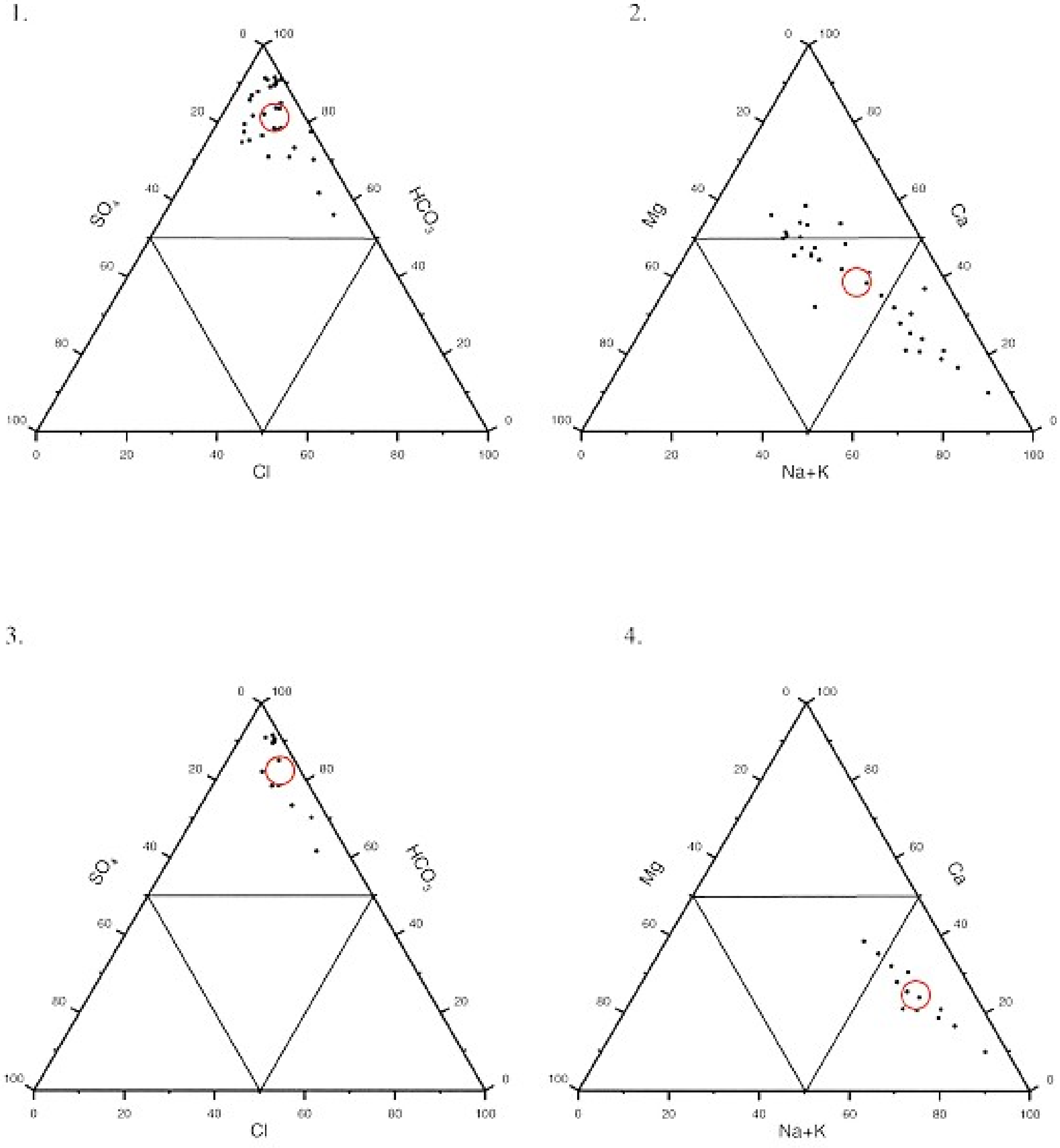


Fig. 38. Triangular diagrams showing the equivalent percentages of the main anions and cations in the groundwater samples in Nicaragua. 1. anions in all the samples, 2. cations in all the samples, 3. anions in the groundwater of the Tisma area, 4. cations in the groundwater of the Tisma area.

of main properties and concentrations in groundwater are presented in Figures 40-43. The histograms show higher concentrations of the most common anions and cations and e.g. those of strontium, barium and vanadium, while those of iron, manganese, zinc and aluminium were smaller than in Rovaniemi (Figs. 19-21 and 40-43).

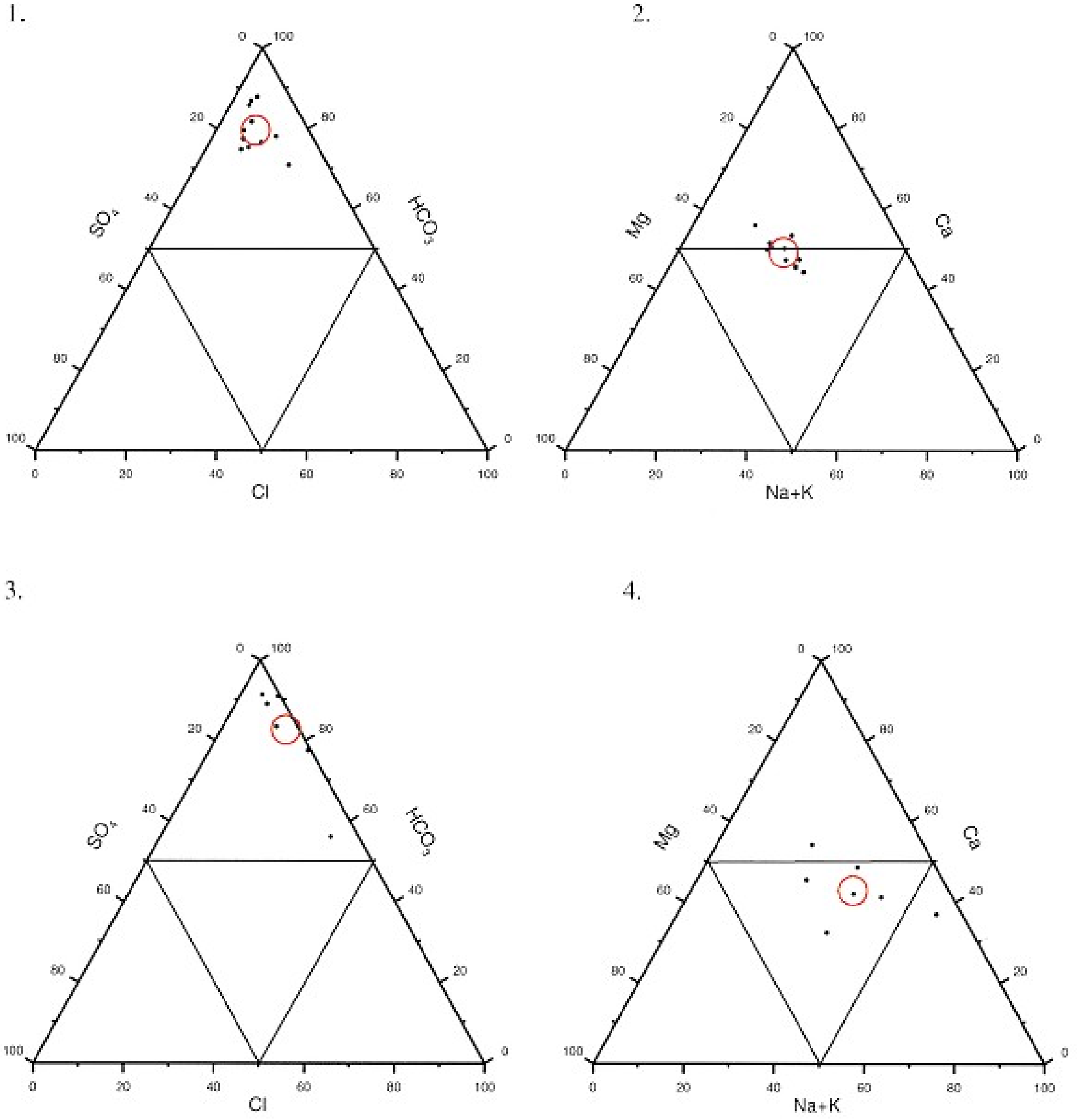


Fig. 39. Triangular diagrams showing the equivalent percentages of the main anions and cations in the groundwater samples in Nicaragua. 1. anions in the groundwater of the León-Posoltega area, 2. cations in the groundwater of the León-Posoltega area, 3. anions in the groundwater of the Santo Tomás-La Libertad area, 4. cations in the groundwater of the Santo Tomás-La Libertad area.

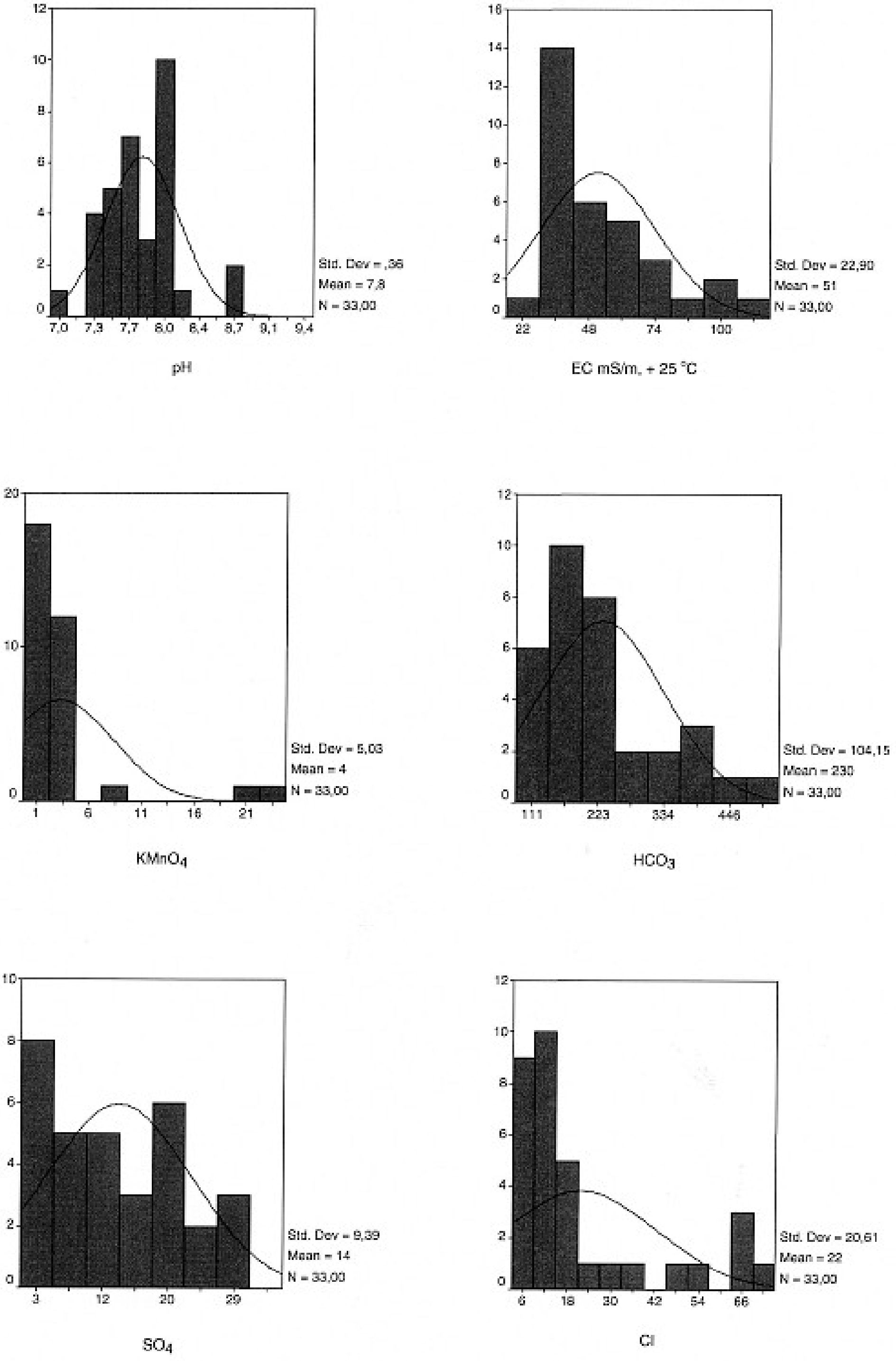


Fig. 40. The frequency distributions of pH, electrical conductivity (mS/m), $KMnO_4$ consumption, bicarbonate, sulphate and chloride (mg/L) in the groundwater samples in Nicaragua.

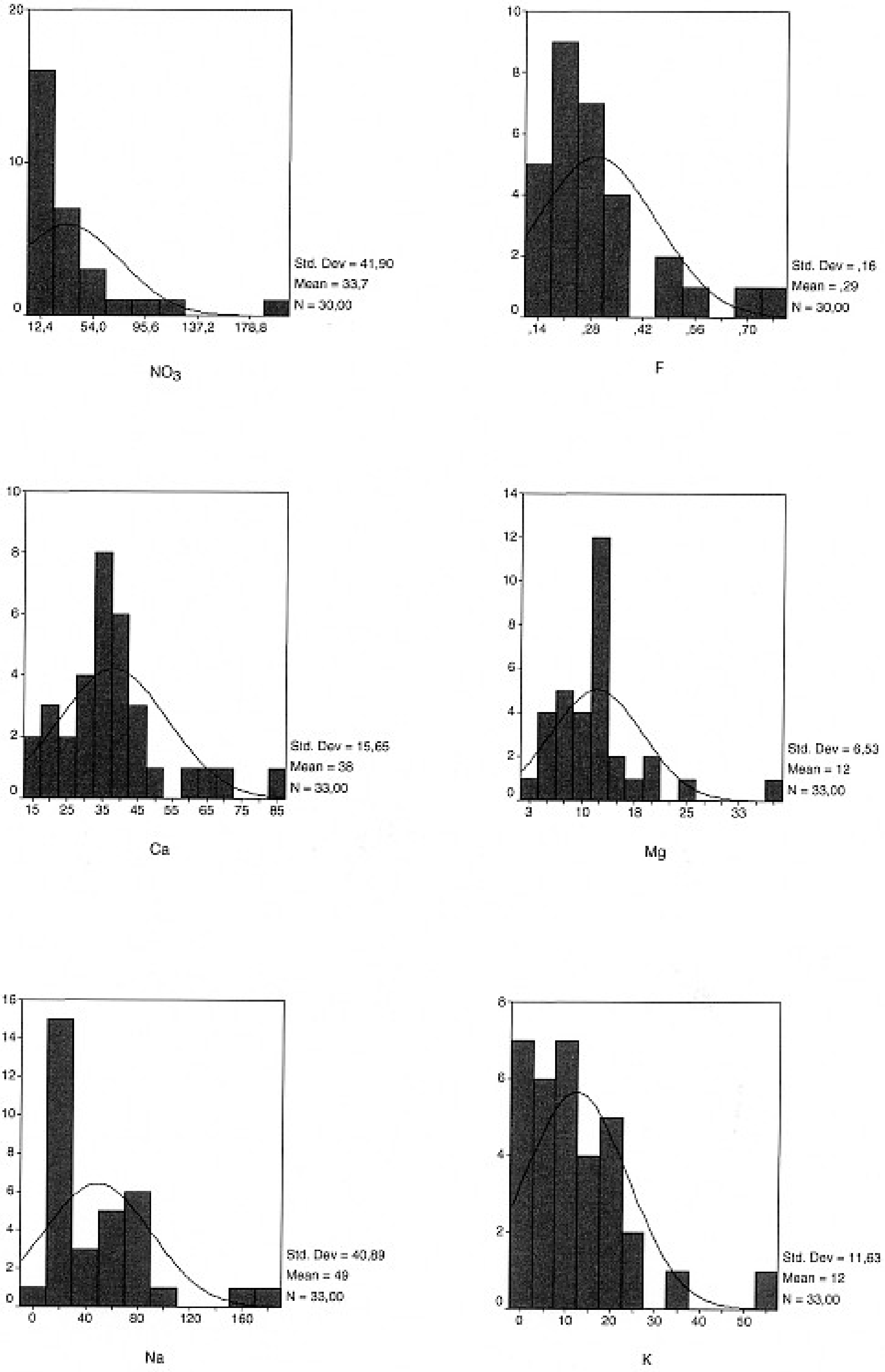


Fig. 41. The frequency distributions of nitrate, fluoride, calcium, magnesium, sodium and potassium (mg/L) in the groundwater samples in Nicaragua.

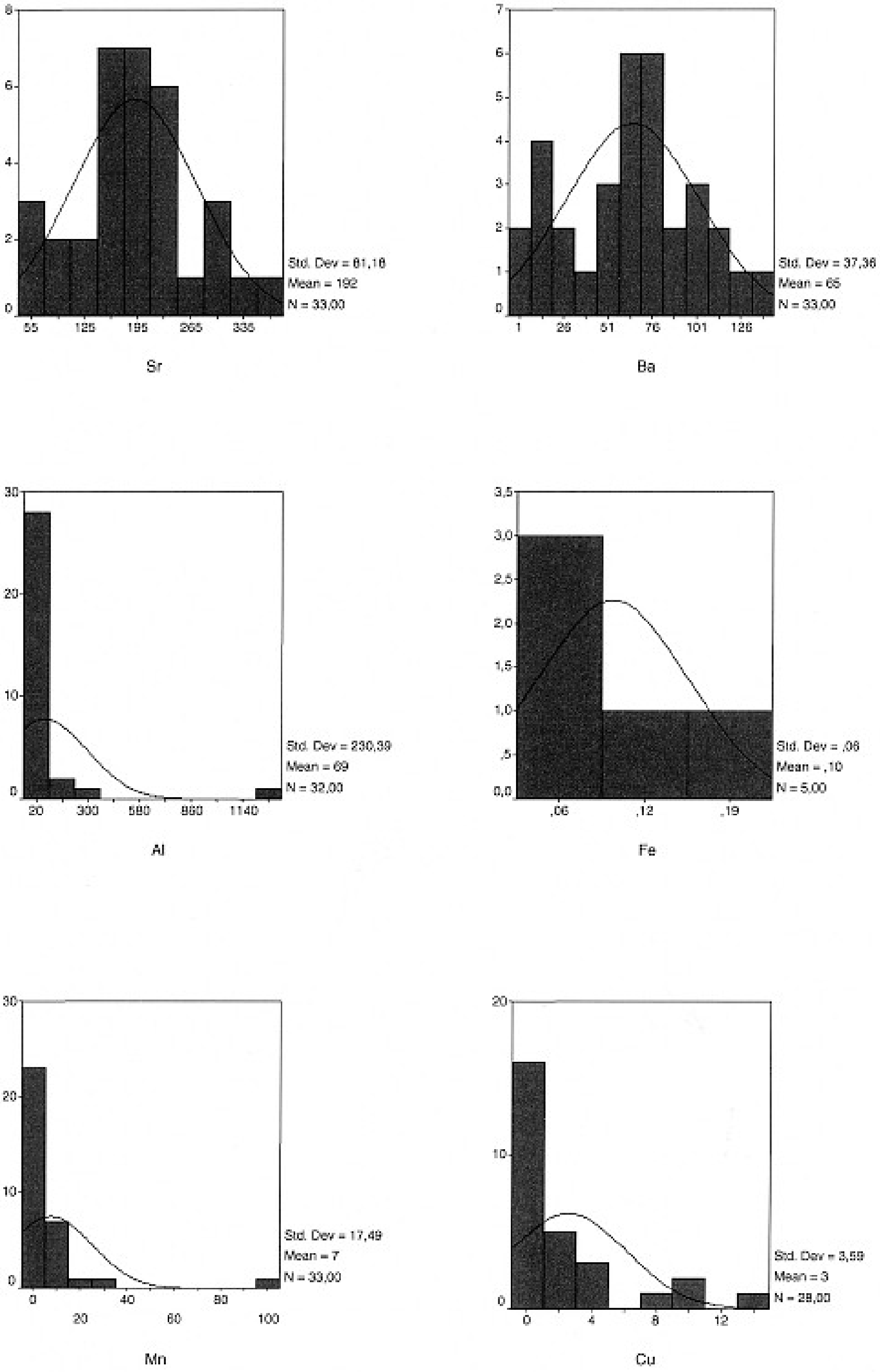


Fig. 42. The frequency distributions of strontium, barium, aluminium (µg/L), iron (mg/L), manganese and copper (µg/L) in the groundwater samples in Nicaragua.

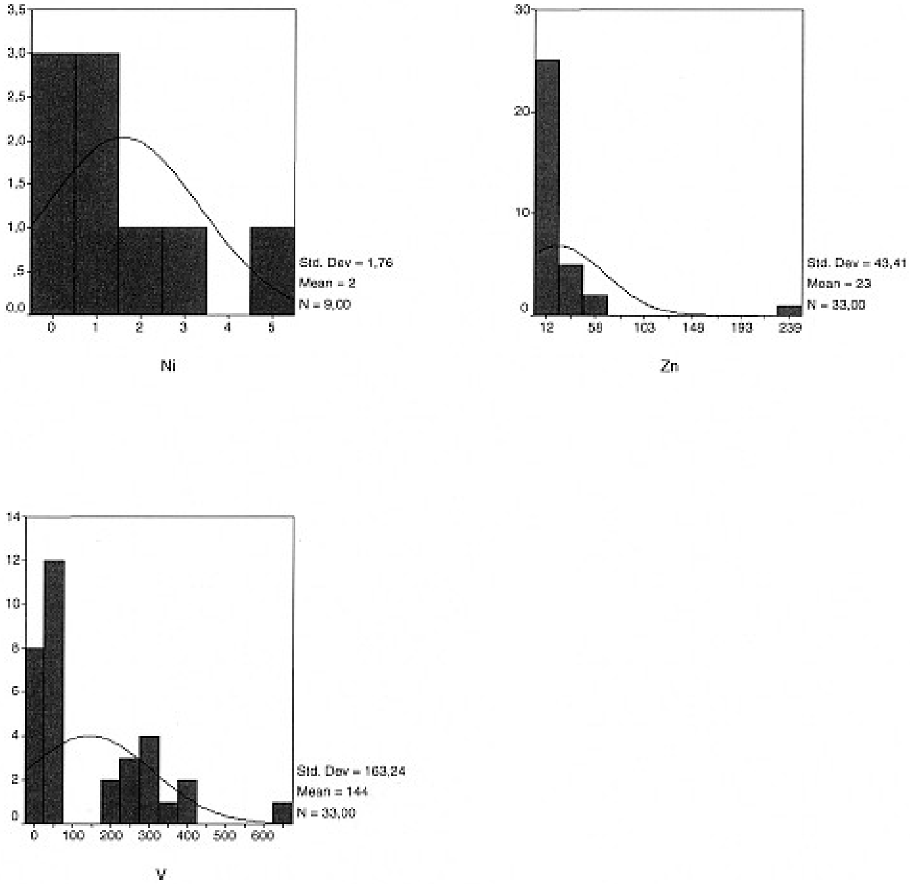


Fig. 43. The frequency distributions of nickel, zinc and vanadium (µg/L) in the groundwater samples in Nicaragua.

Results from the Tisma area

Fourteen groundwater samples, three surface water samples and ten samples of surficial deposits from seven farms were analysed from the Tisma area. In six farms both water samples from wells and samples of surficial deposits were analysed. The groundwater was slightly alkaline on average (Table 9), with pH values of 7.6-8.2 and electrical conductivity readings in the range 40-114 mS/m. Measurements carried out in Tisma showed the groundwater temperatures in wells to be in the range +27 ... +30°C.

The groundwater had higher concentrations of sodium and potassium than in the other study areas (Fig. 39). The impact of human activity is reflected in the relatively high nitrate and manganese concentrations in the water of the shallower wells, the nitrate being derived from polluted surface water and the manganese e.g. from fertilizers and from weathering of the bedrock. Although manganese concentrations in the surficial deposits are also partly attributable to the use of toxic chemicals, the contribution of human activity to the occurrence of this element is usually less marked than that of bedrock weathering (Reimann et al. 1998).

Table 9. Data on groundwater quality in the Tisma area and Finnish recommendations for maximum concentrations of given substances in private wells (Sosiaali- ja terveysministeriö 2000, 2001). The 14 samples analysed in 1994 and 1997 comprised one from a natural spring and 13 from wells, one of which was sampled in both years.

	Min.	Med.	Mean	Max.	Recommendations for maximum concentrations in private wells
Temperature °C	27.0	28.0	28.4	29.7	
pH	7.6	8.0	8.0	8.2	6.5-9.0
Electrical conductivity, mS/m 25°C	41.1	63.3	67.9	114.0	<250
Colour Pt mg/L	<5	5	5	5	<5
$KMnO_4$ consumption mg/L	1.1	2.4	2.4	4.6	20
Alkalinity mmol/L	3.60	4.60	5.00	8.60	
HCO_3 mg/L	219.6	280.6	305.7	524.6	
Br mg/L	<0.1	0.1	0.1	0.3	
Cl mg/L	9.6	17.4	8.4	70.0	100
F mg/L	0.19	0.34	0.43	0.77	1.5
NO_3 mg/L	<0.2	19.5	44.9	206.0	25
PO_4 mg/L	0.04	0.12	0.19	0.55	
SO_4 mg/L	3.1	9.7	14.5	35.3	250
Ag µg/L	0.03	0.32	0.55	1.73	
Al µg/L	3.5	7.5	19.2	105.0	200
As µg/L	4.20	7.20	8.50	16.80	10
B µg/L	125.0	229.0	235.0	461.0	1000
Ba µg/L	17.5	79.5	78.7	139.0	
Be µg/L	<0.1	<0.1	<0.1	<0.1	
Bi µg/L	<0.03	<0.03	<0.03	<0.03	
Ca mg/L	15.7	35.1	35.2	71.4	
Cd µg/L	<0.02	<0.02	<0.02	0.26	5
Co µg/L	<0.02	<0.02	<0.02	0.16	

The concentrations of heavy metals and also other dissolved elements such as beryllium, thorium and thallium were very low and frequently below the detection limit. Vanadium reached levels of several hundred microgrammes per litre. These are high figures by comparison with those recorded in the other study areas or those in Finland. Vanadium enters the surficial deposits through weathering and from traffic (Reimann et al. 1998), the high concentrations in the Tisma area probably being attributable to sources of the former kind. Some wells also gave relatively high results for arsenic and lead, the highest lead concentration, 14 µg/L, being recorded for a well of depth 38 metres that had been constructed in the 1920s (site 14). This same sample also contained toxic residues. Coliform bacteria were quantified in samples from three wells in the Tisma area (Table 12), the highest incidence figures being recorded at site 5, with 22 000 total coliforms and 2200 faecal coliforms per 100 ml. The reasons for these high figures were the shallowness of the well, the poor protection around it and its contamination with polluted surface water. The other two wells had lower incidences of bacteria.

Toxic residues (organochlorine and organophosphorus compounds) were analysed in

Table 9. cont.

	Min.	Med.	Mean	Max.	Recommendations for maximum concentrations in private wells
Cr µg/L	<0.20	0.29	0.57	3.25	50
Cu µg/L	<0.04	1.5	2.6	10.2	2000
Fe mg/L	<0.03	<0.03	<0.03	0.07	0.4
K mg/L	16.3	19.5	22.9	55.8	
Li µg/L	0.6	3.2	3.9	9.4	
Mg mg/L	4.8	9.8	11.4	26.1	
Mn µg/L	0.2	2.9	13.5	97.4	100
Mo µg/L	2.41	4.31	4.79	8.43	
Na mg/L	59.2	79.4	88.2	183.0	
Ni µg/L	<0.06	<0.06	<0.06	0.88	20
Pb µg/L	<0.03	0.1	1.4	14.0	10
Rb µg/L	5.2	8.6	9.3	14.5	
Sb µg/L	0.07	0.11	0.11	0.16	5
Se µg/L	<0.5	1.0	1.4	5.0	10
Si mg/L	22.9	30.1	29.4	36.3	
Sr µg/L	91.3	187.0	189.6	315.0	
Th µg/L	<0.02	<0.02	<0.02	<0.02	
Tl µg/L	<0.02	<0.02	<0.02	<0.02	
U µg/L	1.36	1.73	2.23	5.77	
V µg/L	182.0	323.0	365.0	930.0	
Zn µg/L	3.1	11.4	17.8	67.1	

samples from four wells (sites 3, 5, 12 and 14, App. 5) at the UNI laboratory in Nicaragua. The water at site 5 was found to contain lindane 11 µg/L and oxichlordan 6 µg/L, and that at site 12 similarly lindane 2 µg/L and oxichlordan 4.5 µg/L, while small quantities of the same residues were to be found at the sites 3 and 14. A further analysis performed in Finland showed that the water at site 12 also contained atrazine 0.87 µg/L. The Finnish requirements for domestic water supplies allow a maximum of 0.1 µg/L for any one toxin and 0.5 µg/L for total toxic substances (Vahala et al. 2000).

The topography and groundwater table of the Tisma area vary greatly, so that the groundwater in low-lying areas such as the surroundings of the Laguna de Tisma is located only a few metres below the ground surface, whereas as the terrain rises steeply towards the slopes of the Masaya volcano in the west and southwest, there are places where it is to be found at depths of more than 100 metres. The surficial deposits of volcanic origin contain a high proportion of weathered material. The ploughed horizon of the cultivated land in the Tisma area is underlain by hard talpetate deposits mostly at a depth of 30-40 cm (Fig. 44), which prevent water from percolating into the surficial deposits, increase the surface erosion caused by rainwater and interfere with farming by allowing the surface horizon to be eroded and transported away by the rains (Kukkonen et al. 1999). Element concentra-

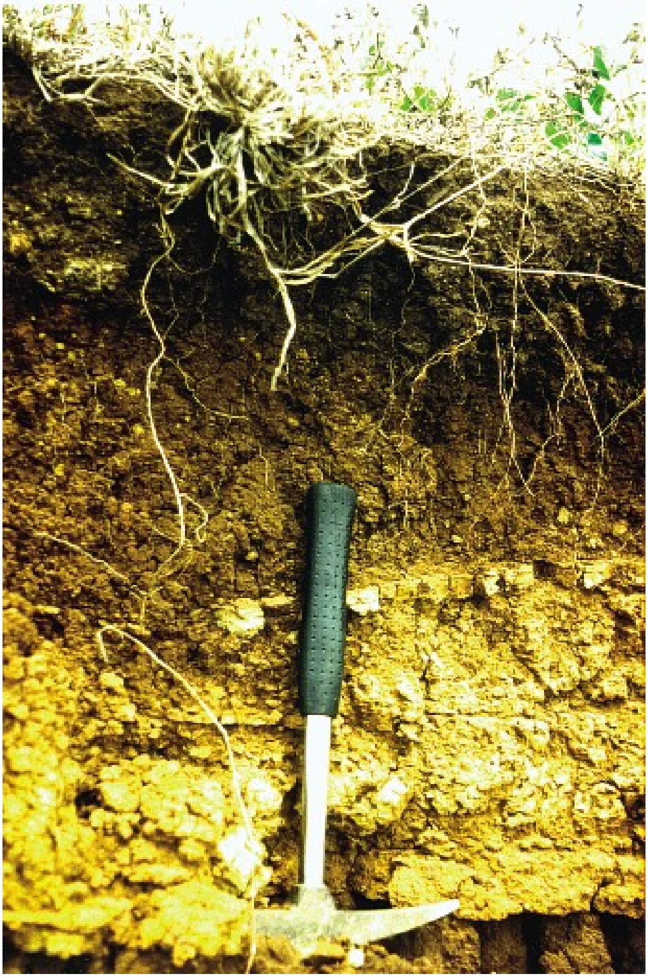


Fig. 44. The hard, calcium-bearing talpetate horizon in the Tisma area, which prevents infiltration of water into the surficial deposits.

tions in the samples of surficial deposits from sites in Nicaragua are presented in Appendix 4, and distributions of the most common elements in Figures 45 and 46, for showing an overall view of the composition of surficial deposits.

Surface water samples were analysed in the Tisma area from the Laguna de Tisma and the Río Tipitapa, and from curiosity the crater lake of Xiloa close to Managua. Although the Laguna de Tisma is known to contain choleragenic bacteria, it continues to be widely used for fishing. The samples contained high concentrations of aluminium, lead and zinc, and fairly high arsenic, cadmium, chromium and iron concentrations (Table 10). Total coliform bacteria in the Laguna de Tisma were 22 000 per 100 ml and faecal coliforms 7800 per 100 ml. The water of the Río Tipitapa contained 14 µg/L arsenic.

Concentrations in the water of the crater lake Xiloa were notably high particularly in the case of chloride, arsenic, boron, lithium, sodium, rubidium and strontium, and the same applied to electrical conductivity (Table 10), and clear anomalies were also observed in potassium, antimony and sulphate. The high concentrations may be attributed to the presence of easily erodible volcanic rocks deposited in the lake by eruptions, allowing large

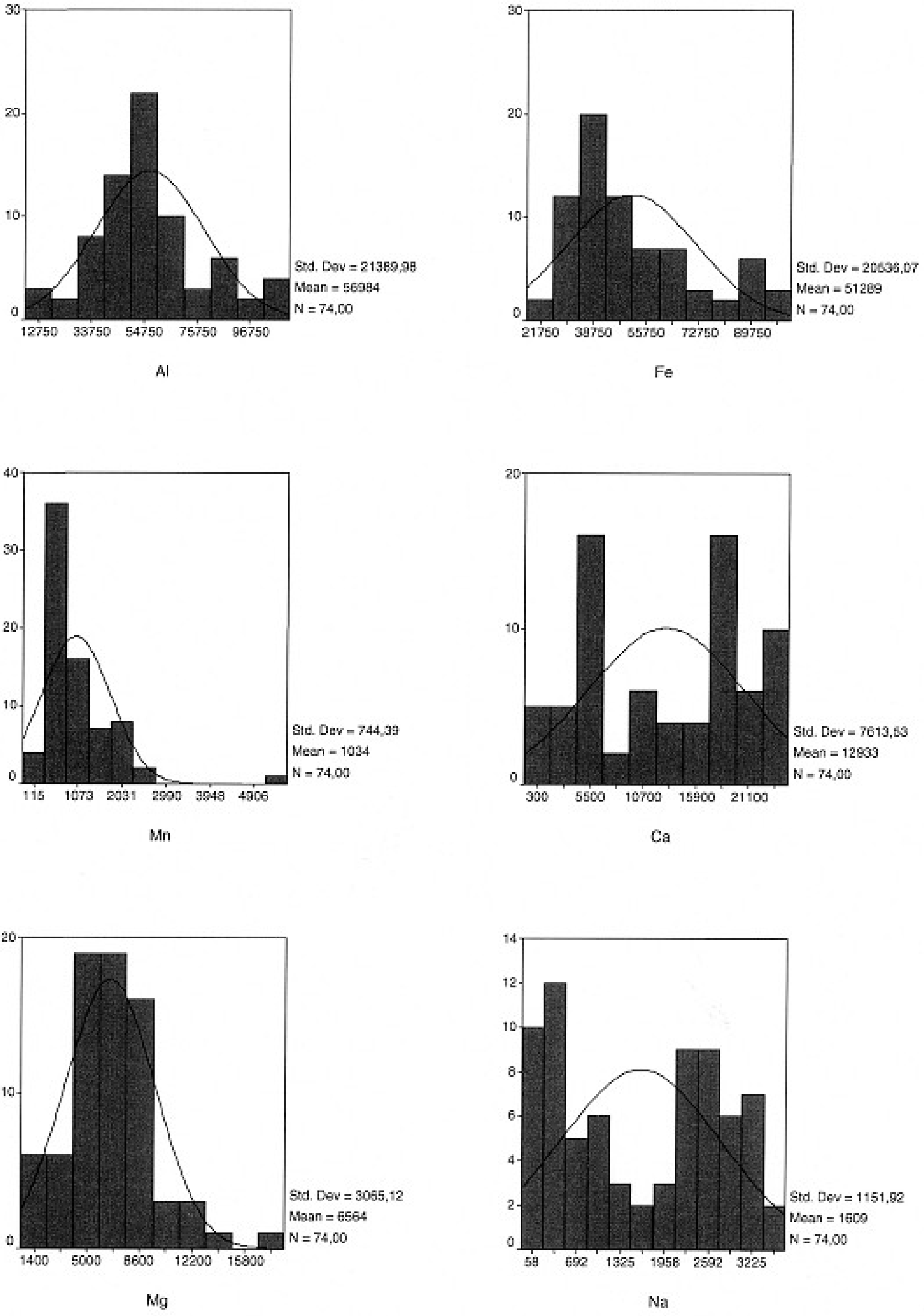


Fig. 45. The frequency distributions of aluminium, iron, manganese, calcium, magnesium and sodium (mg/kg) in the samples of surficial deposits in Nicaragua.

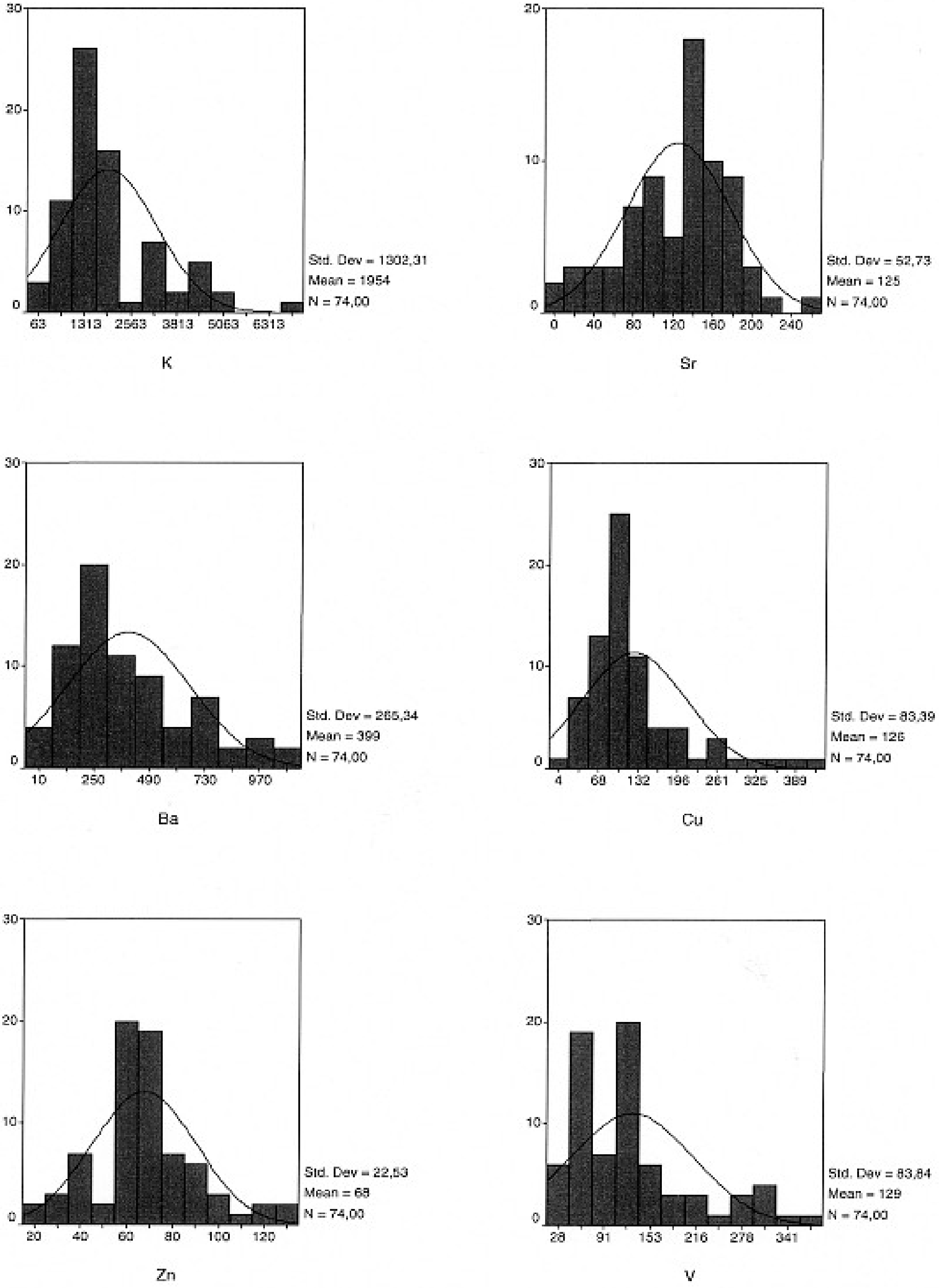


Fig. 46. The frequency distributions of potassium, strontium, barium, copper, zinc and vanadium (mg/kg) in the samples of surficial deposits in Nicaragua.

Table 10. Water quality in Laguna de Tisma, Río Tipitapa and the crater lake Xiloa.

	Laguna de Tisma 1994	Laguna de Tisma 1997	Río Tipitapa 1994	The lake Xiloa 1997
Temperature °C	31.5	35.0	not measured	not measured
pH	7.9	8.3	8.1	8.1
Electrical conductivity mS/m, 25°C	70.6	58.2	84.4	748.0
Colour Pt mg/L	50	70	50	5
Alkalinity mmol/L	5.36	5.00	7.26	6.30
HCO_3 mg/L	327.0	305.0	442.9	384.3
$KMnO_4$ consumption mg/L	19.0	30.0	18.6	18.0
Br mg/L	<0.2	<0.1	<0.2	7.8
Cl mg/L	43.0	27.8	45.0	1930.0
F mg/L	0.70	0.43	0.63	not analyzed
NO_3 mg/L	2.9	<0.2	0.4	not analyzed
PO_4 mg/L	0.61	0.48	1.51	0.84
SO_4 mg/L	17.5	9.2	17.5	304.0
Ag µg/L	0.05	0.53	0.03	0.79
Al µg/L	213.0	665.0	85.2	7.4
As µg/L	16.50	7.50	14.00	757.00
B µg/L	321.0	280.0	564.0	28800.0
Ba µg/L	106.0	128.0	148.0	260.0
Be µg/L	<0.1	<0.1	<0.1	0.1
Bi µg/L	<0.03	<0.03	<0.03	<0.03
Ca mg/L	21.1	28.3	33.5	71.8
Cd µg/L	5.95	0.10	<0.02	<0.02
Co µg/L	0.19	0.41	0.10	<0.02
Cr µg/L	82.10	1.75	0.39	<0.20
Cu µg/L	16.5	8.8	5.8	1.5
Fe mg/L	0.07	0.64	0.06	<0.03
K mg/L	19.1	17.6	18.0	165.0
Li µg/L	2.8	0.9	5.2	2550.0
Mg mg/L	12.1	10.5	12.2	68.1
Mn µg/L	4.6	15.8	2.1	1.8
Mo µg/L	5.16	2.77	7.90	6.96
Na mg/L	120.0	86.7	143.0	1280.0
Ni µg/L	1.99	1.09	<0.06	0.08
Pb µg/L	46.40	3.83	0.08	0.05
Rb µg/L	5.5	3.7	6.2	464.0
Sb µg/L	0.54	0.13	0.26	19.60
Se µg/L	3.7	<0.5	0.6	<0.5
Si mg/L	15.8	17.8	20.3	1.5
Sr µg/L	247.0	233.0	301.0	1200.0
Th µg/L	<0.02	<0.02	<0.02	<0.02
Tl µg/L	0.51	<0.02	<0.02	0.03

Table 10. cont.

	Laguna de Tisma 1994	Laguna de Tisma 1997	Río Tipitapa 1994	The lake Xiloa 1997
U µg/L	2.19	0.70	2.40	1.22
V µg/L	83.20	37.50	91.00	26.20
Zn µg/L	71200.0	11.2	22.1	6.1
Hg µg/L		-		
Coliform bacteria (peaces)	22 000/100 ml			
Faecal coliform bact. (peaces)	7 800/100 ml			

quantities of the substances mentioned to dissolve in the water, together with volcanic gases and hydrothermic solutions accompanying the emissions.

Employing the RT classification normally used for agricultural purposes in Finland, the samples of surficial deposits contained 26-41 % clay (grain sizes less than 0.002 mm), the mean being 33 %, so that this may be taken as the general type of surficial deposits. This combined with the silt fraction (0.002-0.02 mm) accounted for 65-75 % of each sample, the coarser material being mostly finesand (0.02-0.2 mm), with a little sand (0.2-2 mm). The proportions of organic matter were 2.5-4.3 %. The specific surface areas determined for four samples were 62.06-123.91 m²/g (Table 13), measured for the fraction of grain size less than 0.063 mm. The high specific surface areas for the Tisma samples may be attributed to the origin of the material, most of it being either volcanic ash or heavily weathered. The specific surface area of particles is of importance for ion exchange and the binding of chemicals, in that the higher the specific surface area, the greater is the binding capacity. The pH of the surficial deposits was close to neutral (Kukkonen et al. 1999, Table 13) with a mean of 7. The pH of the Tisma samples was evidently raised by the presence of volcanic ash and weathering products.

Ammonium acetate (1 M, pH 7) extraction of the <2 mm grain size fraction was used to analyse soluble and exchangeable cations such as calcium, magnesium, sodium and potassium, and also strontium and barium, which react in the same manner as calcium. The milliequivalent sum of the cations were 24-45 mE/100g. The composition of the clay minerals is important for the binding and transport of cations, as minerals with expanding lattices will readily release substances bound to them as external conditions alter. It is significant in this respect that the Tisma samples (sites 4, 5, 13 and 16) have been found to contain minerals such as smectite, zeolite, quartz and plagioclase (Kristian Lindqvist, pers. comm., based on X-ray diffraction analyses at the Mineralogical Laboratory of the Geological Survey of Finland), as a clay containing large amounts of smectite, for instance, will have a cation exchange capacity of 90 mE/100 g and be particularly apt to bind cations and anions to itself, and also organic molecules such as toxic compounds (Kukkonen et al. 1999).

The analyses carried out in Finland revealed the presence of organochlorine compounds such as DDT and its derivatives DDD and DDE, and also dieldrin. DDE, which is a metabolite of DDT and is even more stable than its parent compound (Berg 1994), reached concentrations of 0.21 mg/kg of sample at site 15, on a cotton field, and 0.52 mg/kg at site 12, a former cotton field that had been left fallow for two years, where a toxaphene level of 8.9 mg/kg was also reported (Kukkonen et al. 1999). Site 11, where tomatoes were being grown, had toxaphene concentrations of 2.2 mg/kg in the surface soil and 2.8 mg/kg at a depth of 60 cm in the undisturbed subsoil (Kukkonen et al.

1995). Site 5 contained evidence of dieldrin and endosulphane, and also p.p'DDE at levels of 0.432 mg/kg in the surface sample and 0.73 mg/kg in the subsoil. The maximum concentration of this latter substance in unpolluted soil, as laid down by the Finnish Ministry of the Environment, is 0.04 mg/kg, and the boundary value for polluted soil is 4 mg/kg (Järvinen et al. 1996). The concentrations obtained for the samples analysed in Nicaragua deviated considerably from the above, presumably due to the different analytical methods employed.

Results from León-Posoltega

The 11 groundwater samples and three surface water samples were analysed from the León-Posoltega area. The samples were almost neutral or slightly alkaline, with pH values in the range 6.8-7.8. This is attributable to the rocks of the area and to the fine grained material in surficial deposits and probable dissolving of weathering products. Electrical conductivity was 29.3-50.5 mS/m. The temperature of the groundwater in the wells was close to 30°C, however, the maximum being 37°C, in a well of depth 38 m on the farm of Los Velásquez (site 18). The reason for this lies in the porous volcanic material making up the soil, which conducts heat exceptionally well. Heavy metal concentrations were in the main low (Table 11). The groundwater was calcium-bicarbonate type. The concentrations of the main anions and cations did not differ much from those in the Tisma area with the exception of sodium and potassium which were higher in Tisma. No measurable amounts of bromide, silver, beryllium, bismuth, iron, nickel or thorium were present in any of the samples, nor cadmium, cobalt, chromium or lithium in the majority. Evidence of pollution through human activity was obtained in the form of relatively high nitrate concentrations in places, especially in shallow wells which were open to contamination by surface water through runoff or infiltration. The maximum nitrate level was 65 mg/L, where the upper limit recommended in Finland is 25 mg/L and 50 mg/L, in those Central American countries which adopted the CAPRE (Comité Coordinador Regional de Instituciones de Agua Potable y Saneamiento de Centroamérica) guidelines in 1994.

High counts were obtained for total and faecal coliform bacteria in most wells (Table 12), water quality being best in the drilled wells serving as sources for municipal water supplies, e.g. sites 20 (drilled well Pp 124), 24 (El Tanque) and 25 (drilled well Pp 122) in Posoltega, where the bacterial counts of less than 2.2 per 100 ml were below the upper limit for good domestic water supplies in Nicaragua.

A rainwater sample taken in the town of León in 1999 had a pH of 5.3, which falls within the range of pH 5-6 quoted by Pleym (1991) for rainwater that does not contain combustion products derived from human activity and is in equilibrium with carbon dioxide of the air. The zinc concentration was markedly high, however, at 377 µg/L as opposed to 1-44 µg/L in the groundwater and surface water samples. The reason for this is not known, especially since concentrations of the other elements were mostly below the detection limit and the sample was collected in a plastic vessel. The electrical conductivity measured *in situ* was only 0.3 mS/m, indicating very small amounts of dissolved substances, and the laboratory result was not much higher.

The physico-chemical properties in the three surface water samples from the León-Posoltega area were broadly similar to those in the well samples, with the exception that aluminium and manganese were somewhat higher.

Analyses of toxic chemical residues performed on samples from eight wells and two rivers at Posoltega led to the identification of such residues in six of the wells and both of the rivers. The highest concentrations were found at site 26, the well of the German Pomares farm, where the combined concentrations of seven toxins analysed amounted to 603.83

Table 11. Chemical composition of the groundwater in the León-Posoltega area in terms of minimum, median, mean and maximum concentrations of dissolved substances (11 samples).

	Min.	Med.	Mean	Max.
Temperature °C	27.8	28.2	30.6	37.0
pH	6.8	7.1	7.0	7.4
Electrical conductivity mS/m, 25°C	25.4	34.2	33.6	43.6
Colour Pt mg/L	<5	5	<5	5
Alkalinity mmol/L	1.37	2.55	2.11	3.11
HCO_3 mg/L	83.6	155.6	151.0	189.7
$KMnO_4$ consumption mg/L	0.6	1.2	1.8	4.6
Br mg/L	<0.1	<0.1	<0.1	<0.1
Cl mg/L	4.2	7.2	9.7	25.5
F mg/L	0.12	0.21	0.22	0.47
NO_3 mg/L	6.4	29.2	31.5	64.5
PO_4 mg/L	<0.02	0.20	0.19	0.43
SO_4 mg/L	10.2	14.9	17.2	27.0
Ag µg/L	<0.01	<0.01	<0.01	<0.01
Al µg/L	<1	2.7	10.1	49.8
As µg/L	0.57	0.97	1.21	2.38
B µg/L	23.0	54.8	105.2	346.0
Ba µg/L	55.9	75.5	79.6	129.0
Be µg/L	<0.1	<0.1	<0.1	<0.1
Bi µg/L	<0.03	<0.03	<0.03	<0.03
Ca mg/L	27.0	37.3	36.3	47.0
Cd µg/L	<0.02	<0.02	<0.02	0.04
Co µg/L	<0.02	0.02	<0.02	0.06
Cr µg/L	<0.2	<0.2	0.6	6.6
Cu µg/L	<0.04	0.41	0.40	1.12
Fe mg/L	<0.03	<0.03	<0.03	<0.03
K mg/L	3.4	7.8	7.6	11.0
Li µg/L	<0.3	<0.3	<0.3	1.4
Mg mg/L	8.4	12.2	12.0	14.1
Mn µg/L	0.1	0.9	2.7	13.0
Mo µg/L	0.24	0.52	0.52	1.00
Na mg/L	9.9	14.5	15.3	23.9
Ni µg/L	<0.06	<0.06	<0.06	<0.06
Pb µg/L	<0.03	0.05	0.07	0.27
Rb µg/L	6.3	12.5	12.3	17.4
Sb µg/L	<0.02	0.05	0.04	0.09
Se µg/L	0.8	1.1	1.1	1.9
Si mg/L	27.0	41.5	41.3	52.8
Sr µg/L	143.0	217.0	200.0	236.0

Table 11. cont.

	Min.	Med.	Mean	Max.
Th µg/L	<0.02	<0.02	<0.02	<0.02
Tl µg/L	<0.02	<0.02	0.02	0.03
U µg/L	0.05	0.30	0.31	0.75
V µg/L	17.20	32.20	33.10	49.80
Zn µg/L	2.3	5.8	11.6	44.0

ng/L. The following toxic residues were found in the wells: DDT 0.001-37.96 ng/L (in 3 wells), DDD 3.39-14.9 ng/L (in 4 wells), DDE 1.41-9.17 ng/L (in 5 wells), endosulphane 1.16 ng/L (in 1 well), aldrin 2.08 ng/L (in 1 well), dieldrin 1.23-5.51 ng/L (in 6 wells) and fenthion 533.05 ng/L (in 1 well).

The surficial deposits of the León area differ between the northern and southern parts. The 19 samples from the north contained 5.3-13.2 % clay, and the same area near the Télica volcano also included the farm of La Hoyada (site 17), which had earlier been good farming land. In 1998 the soil was buried beneath almost half a metre of sandy and gravelly material of low nutrient value that was washed down from the slopes of the volcano and the crater was filled with water to a depth of as much as four metres. This sandy surface layer contained only 2.2 % clay, but the fertile soil beneath it had 16 %. The surficial deposits of the northern area are mostly finesand, with 5.5-28 % silt and clay combined and 0.7-4.3 % organic matter. Their specific surface area was 23.26-38.93 m²/g (Table 13). This well-weathered, fine-grained material has been transport-

Table 12. Bacterial counts for groundwater and surface water samples from the Tisma, León and Diriamba areas (pieces/100 ml).

Site	Location	Total coliform bacteria	Faecal coliform bacteria
3. Dug well	Tisma, Ojo de Agua, San Jerónimo	7000	6800
5. Dug well	Tisma, Las Conchas	22 000	2200
6. Spring	Tisma, Las Conchas	17 000	4500
7. Lake	Tisma, Laguna de Tisma	22 000	7800
18. Dug well	León, Los Velásquez	180	49
19. Dug well	León, San Luis	540	170
20. Drilled well	León, La Trinidad, Pp 124	<2.2	<2.2
21. Dug well	León, La Primavera	14	7.8
22. Dug well	León, Maria de la Concección	>1600	2800
23. Dug well	León, Juan Ramón, Mitapan	1600	140
24. Drilled well	León, Hayde Larios, El Tanque	2	2
25. Drilled well	León, Entre Ríos, Pp 122	2	2
26. Dug well	León, German Pomares	16×10^6	17×10^6
26. River	León, Río Posoltega	9.2×10^6	9.2×10^6
26. River	León, Río San Pablo	16×10^6	116×10^6
26. Dug well	León, La Casa	5400	5400
28. River	Diriamba, Río La Trinidad	9200	540
29. Dug well	Diriamba, San Helén	240	240
30. Dug well	Diriamba, Amayito	170	170
31. River	Diriamba, Río Amayito	3500	3500

Table 13. Electrical conductivity, pH, specific surface area (SSA), cation exchange capacity and humus content of the samples of surficial deposits from the sites in Tisma, León-Posoltega, Diriamba and Santo Tomás-La Libertad.

Sampling site	Depth of the sample cm	EC mS/m	pH	SSA m²/g	Cation exchange capacity mE/100g	Humus %
TISMA						
4. Santa Cruz, corn field	18-24	5.6	6.93	78.04	36.7	
5. Las Conchas, chili field	15-20	15.3	6.95	62.06	38.8	
11. Noel Morales,	10-15				45.4	
corn field	25-30				39.2	
12. El Rodal, fallow field	5-10				25.8	
	20-24				27.5	
	35-40				35.8	
	45-50				38.2	
	70-80				41.3	
13. Quatro Esquinas, corn field	10-30	13.1	6.74	68.50	33.4	
15. 16 de Julio, corn field	10-15				23.6	
16. La Montañita, chili field	20-24	7.8	7.35	123.9	40.7	
LEÓN-POSOLTEGA						
17. La Hoyada, fallow field	10-15	1.9	6.86		3.0	0.69
cross section of a road	240-250	3.3	6.55		5.5	1.90
18. Los Velásquez,	0-5	7.4	6.13		7.8	
corn field	5-15	3.9	6.13	23.36	6.7	4.10
	15-30	3.9	6.29		7.0	
	30-60	3.5	6.45	34.12	9.1	3.49
20a.La Trinidad, Pp124,	0-5	9.3	6.07		9.3	
field-forest plantation	5-15	4.6	6.31		4.9	2.65
	15-30	3.5	6.80		13.4	
	30-60	2.2	6.97		7.7	1.55
20b.La Trinidad, Pp 124,	0-5	10.3	6.39		7.3	
corn field	5-15	4.6	6.31		4.9	
	15-30	3.5	6.80		13.4	2.94
	30-60	2.2	6.97		7.7	
21. La Primavera,	0-5	3.7	6.39		7.4	
peanut field	5-15	3.2	6.38	25.16	7.3	4.28
	15-30	2.8	6.57		8.3	
	30-60	2.7	6.92	38.93	10.0	1.88
24. Hayde Larios,	0-5	2.8	6.70		6.0	1.80
soybean field	5-15	2.3	6.70	39.10	6.5	1.73
	15-30	3.0	6.93		11.2	1.55
	30-60	3.3	6.82	46.34	13.3	3.25
	120	3.1	7.24		14.7	
25. Entre Ríos,	0-5	21.2	6.98		25.7	4.70
pasture	5-15	13.9	7.09		21.1	2.85
	15-30	10.8	7.34	72.91	23.6	2.24
	30-60	6.0	7.13		20.2	1.80
26a.German Pomares,	0-5	5.2	6.81	53.96	16.9	4.18
sugar cane plantation	5-15	6.3	6.63	45.75	13.7	4.75
	15-30	3.8	6.82	57.34	14.0	3.09
	30-60	2.6	7.10	82.08	15.0	2.26
26b.German Pomares,	0-5	12.8	6.53		14.8	
banana plantation	5-15	6.7	6.72	40.87	14.5	2.71
	15-30	6.5	6.90		15.4	
	30-60	6.5	7.32	61.69	13.7	1.59

Table 13. cont.

Sampling site	Depth of the sample cm	EC mS/m	pH	SSA m²/g	Cation exchange capacity mE/100g	Humus %
DIRIAMBA						
28. Río la Trinidad, fluvial deposit	25-30	4.7	7.22	57.36	38.0	0.43
29a. San Helén, corn field	5-15	13.0	6.94	31.2	3.70	
29b. San Helén, fallow field	5-15	6.1	6.35	30.0	2.80	
31. Río Amayito, fluvial deposit	25-30	5.0	7.03	46.06	40.0	0.49
SANTO TOMÁS-LA LIBERTAD						
42a. San Juan, La Libertad, fluvial deposit		3.5	6.17	17.19	3.7	1.18
43a. Río Mico, La Libertad, fluvial deposit		5.6	5.87	14.81	5.1	1.73
44a. Río Mico, San Pedro de Lóvago, fluvial deposit		2.4	6.54	27.67	22.4	1.30
45. Río Mico, Santo Tomás, fluvial deposit		17.8	7.68	32.00	27.5	2.13

ed from the slopes of the volcano as a result of erosion.

The surficial deposits of the southern part of the area contained 17.2-27.9 % clay and a total of 37-53 % silt and clay combined, the principal fraction being finesand. The organic content was in the range 1.6-4.8 % and the specific surface areas were 39.1-82.08 m²/g. The highest humus content of the ploughed soil was recorded at site 26, which is affected by annual flooding, and the specific surface area was also highest here (Table 13).

These specific surface areas in León-Posoltega are fairly large when one bears in mind the small proportion of clay material in the soil. The reason for this is the presence of humus-rich flood horizons, as humus has the effect of increasing the specific surface area of soil particles.

The samples of surficial deposits in the northern area (sites 17-21, Table 13) had pH values some lower than the southern area. The milliequivalent sum of soluble and exchangeable cations were also lower in the northern part (Table 13). The contributions of barium, sodium and strontium to the exchangeable cations were very low, from 0.1 to 3 %, whereas the contribution of calcium was 47-83 %, that of magnesium 10-25 % and that of potassium 1-32 %. Analysis of samples of surficial deposits taken at metre intervals down to a depth of 9 m from a section in the bed of the Río Télica showed the composition of the material to vary irregularly throughout, with higher concentrations of easily soluble cations such as calcium, potassium, sodium and magnesium at all depths than were to be found in the coring samples from the Rovaniemi district (App. 3 and 4).

Organochlorine residues in surficial deposits were found in nine out of the 15 samples from the León area, representing five farms. Three samples contained DDT (0.01-0.04 mg/kg), all nine DDE (0.01-0.04 mg/kg) and toxaphene (0.25-10.5 mg/kg) and two deltamethrin (0.02 and 0.03 mg/kg). There were two farms on which no toxic residues were found at all in the analyses. Only deltamethrin among the toxins identified is still in use in the area, the interviews with farmers indicating that applications of DDT and toxaphene were discontinued at the same time as cotton growing came to an end, in the later 1980s in the León area.

Results from Diriamba

The groundwater of two wells and surface water of two rivers and four samples of surficial deposits were analysed from the Diriamba and La Trinidad areas. The pH values of water samples were 7.4-8.1 and electrical conductivities in the range 33-69 mS/m. The concentrations of main anions and cations did not differ much from those in Tisma, but bicarbonate and calcium concentrations were higher than in León-Posoltega. Silica concentrations were high compared to those in Tisma and León-Posoltega. Heavy metal concentrations were low and frequently below the detection limit (Table 14), but turbidity caused by suspended solids detracts from the quality of the surface water. Again toxic residues were to be found in the surficial deposits and water samples and high coliform bacteria counts in the water samples (Table 12).

Two soil samples taken in a field in Diriamba yielded clay contents of 51 and 62 %, combined silt and clay 84 and 90 % and organic matter 2.8 and 4.6 %, while two samples from river sediments contained 12 % and 18 % clay. The relatively high specific surface areas of 46 and 57 m^2/g may be attributed to the humus content of the flood horizons and the fines contained in the samples. The pH values were 6.4-7.2 and the cation exchange capacity was 30-40 mE/100 g (Table 13). Of the detrimental substances, cadmium reached 1.6 mg/kg on a fallow field, whereas only small amounts of mercury, cadmium and lead were present in the river sediments. It was evident from interviews that large amounts of chemicals were used at that time and that these were sprayed on the land from the air with no concern for the location of dwellings. Toxic residues were found in the form of 0.005 mg/kg DDT in the cultivated area and 0.05 mg/kg DDT, 0.32 mg/kg DDE and 0.9 mg/kg toxaphene in the fallow area. The interview data indicated that the use of both DDT and toxaphene had come to an end with the cessation of cotton growing in the area in 1972.

Results from Santo Tomás-La Libertad

Groundwater quality was analysed for seven wells located within an area of 5x20 km in the environs of Santo Tomás, and surface water quality from five sites from the rivers, four of which were analysed both in 1997 and 1999. Water quality was analysed also from the reservoir, which is getting its water partly from rivers and partly from wells.

The pH range of groundwater was 7.9-8.7 and the electrical conductivity of the water 34-86 mS/m. The groundwater was calcium-bicarbonate type with lower sulphate and potassium concentrations compared to the other study areas (Figs. 38 and 39, Table 15). The physicochemical properties of the groundwater were mostly good, as although some of the wells had deficient protection, they were sufficiently deep that pollutants would not easily penetrate as far as the groundwater. There were no high nitrate concentrations, for instance, but a few samples had high aluminium and arsenic concentrations. There is little agriculture in the region, and therefore toxic chemicals do not present the same threat to the environment. The groundwater table in the mountainous uplands of Santo Tomás lies mostly at depths of 40-80 m, while in the valleys it may be at a depth of a few metres. The rocks of the area are of low permeability, but the faults occurring in them and the fractures brought about by weathering mean that they conduct water very efficiently in places. The interview data suggest that considerable variations in yields can be observed even between wells located close together.

The drilled well constituting site 33, located in the village of Puertas de Paris between Santo Tomás and La Libertad, is used jointly by ten homes, and its water level is reported to be at a depth of 48 m. Water quality was good except for a high concentration of arsenic,

Table 14. Chemical composition of the water samples in Diriamba-La Trinidad.

	Río Amayito Dug well	Finca Amable Dug well	La Trinidad River	Río Amayito River
Temperature °C	29.5	29.0	27.5	27.5
pH	8.0	7.4	8.1	8.0
Electrical conductivity mS/m, 25°C	68.5	33.3	47.3	49.7
Colour Pt mg/L	5	20	10	10
Alkalinity mmol/L	6.15	2.15	3.74	4.20
HCO_3 mg/L	375.2	131.2	228.1	256.2
$KMnO_4$ consumption mg/L	3.2	4.4	5.6	5.6
Suspended material mg/L			40	20
Br mg/L	<0.1	<0.1	<0.1	<0.1
Cl mg/L	28.1	16.6	13.0	16.8
F mg/L	0.23	0.13	0.23	0.18
NO_3 mg/L	2.5	14.8	2.2	0.8
PO_4 mg/L	0.35	0.21	0.21	0.1
SO_4 mg/L	18.8	19.2	35.4	23.8
Ag µg/L	<0.01	0.01	<0.01	<0.01
Al µg/L	12.5	135.0	20.4	16.3
As µg/L	1.50	0.31	0.64	0.47
B µg/L	30.5	16.3	41.9	31.8
Ba µg/L	56.9	17.4	137.0	169.0
Be µg/L	<0.1	<0.1	<0.1	<0.1
Bi µg/L	<0.03	<0.03	<0.03	<0.03
Ca mg/L	87.4	35.8	58.7	64.0
Cd µg/L	<0.02	0.02	<0.02	<0.02
Co µg/L	<0.02	0.05	0.05	0.02
Cr µg/L	<0.2	0.3	<0.2	<0.2
Cu µg/L	0.5	0.9	1.8	1.5
Fe mg/L	<0.03	0.05	<0.03	<0.03
K mg/L	4.7	1.0	8.5	6.0
Li µg/L	6.7	5.8	<0.3	<0.3
Mg mg/L	19.1	6.3	12.9	13.3
Mn µg/L	1.3	1.0	17.6	5.0
Mo µg/L	1.27	0.12	1.10	0.60
Na mg/L	32.0	22.5	18.3	18.4
Ni µg/L	<0.06	<0.06	<0.06	<0.06
Pb µg/L	0.04	0.03	<0.03	<0.03
Rb µg/L	3.7	0.2	2.9	1.0
Sb µg/L	0.04	0.02	0.05	0.05
Se µg/L	1.1	0.6	0.7	<0.5
Si mg/L	375.0	186.0	296.0	358.0
Th µg/L	<0.02	<0.02	<0.02	<0.02
Tl µg/L	<0.02	<0.02	<0.02	<0.02
U µg/L	0.87	0.04	0.64	0.63
V µg/L	46.50	4.63	29.80	14.70
Zn µg/L	3.5	3.3	0.4	0.9

Table 15. Chemical composition of the groundwater of the Santo Tomás-La Libertad area in terms of minimum, median, mean and maximum concentrations of dissolved substances, and the water quality in the Quipor reservoir, from which Santo Tomás receives most of its water supply.

	Min.	Wells Med.	Mean	Max.	Quipor reservoir
Temperature °C	25.0	26.2	26.2	27.2	26.1
pH	7.4	7.9	8.0	8.7	7.8
Electrical conductivity mS/m, 25°C	24.0	33.6	43.8	85.8	23.3
Colour Pt mg/L	5	5	19	50	40
Alkalinity mmol/L	2.20	2.90	3.40	6.70	2.20
HCO_3 mg/L	134.2	176.9	210.0	408.7	134.2
$KMnO_4$ consumption mg/L	0.9	2.8	8.5	23.0	17.0
Br mg/L	<0.1	<0.1	<0.1	0.1	<0.1
Cl mg/L	5.3	11.9	25.5	66.1	6.9
F mg/L	<0.1	0.17	0.12	0.36	<0.1
NO_3 mg/L	<0.2	1.5	9.0	43.4	<0.2
PO_4 mg/L	0.03	0.13	0.18	0.43	0.04
SO_4 mg/L	0.4	4.5	5.1	14.9	0.5
Ag µg/L	0.19	2.76	2.30	3.83	0.93
Al µg/L	3.8	19.9	242.5	1280.0	165.0
As µg/L	0.46	2.60	6.70	35.90	0.50
B µg/L	8.3	15.2	16.1	22.7	10.6
Ba µg/L	0.9	13.4	24.2	99.4	19.0
Be µg/L	<0.1	<0.1	<0.1	<0.1	<0.1
Bi µg/L	<0.03	<0.03	<0.03	0.04	<0.03
Ca mg/L	19.1	33.4	39.2	65.5	21.4
Cd µg/L	<0.02	<0.02	<0.02	0.26	<0.02
Co µg/L	<0.02	0.05	0.15	0.72	0.21
Cr µg/L	0.26	0.75	1.23	3.39	0.54
Cu µg/L	<0.04	1.7	4.6	14.4	1.8
Fe mg/L	<0.03	<0.03	0.05	0.20	0.17
K mg/L	0.3	1.2	1.4	4.5	1.2
Li µg/L	0.7	1.4	6.8	34.0	<0.3
Mg mg/L	1.8	9.0	13.3	36.3	10.9
Mn µg/L	0.6	1.1	5.0	13.6	29.8
Mo µg/L	0.04	0.09	0.27	0.84	0.03
Na mg/L	20.2	29.1	35.9	75.8	11.4
Ni µg/L	<0.06	1.29	1.76	5.35	0.87
Pb µg/L	<0.03	0.14	0.39	1.87	0.11
Rb µg/L	0.3	0.8	1.1	3.4	1.0
Sb µg/L	<0.02	0.04	0.05	0.13	<0.02
Se µg/L	<0.5	<0.5	<0.5	<0.5	<0.5
Si mg/L	14.9	25.8	22.2	28.1	17.1
Sr µg/L	39.8	120.0	156.1	351.0	78.5
Th µg/L	<0.02	<0.02	<0.02	<0.02	<0.02

Table 15. cont.

	Wells Min.	Med.	Mean	Max.	Quipor reservoir
Tl µg/L	<0.02	<0.02	<0.02	<0.02	<0.02
U µg/L	0.05	0.24	0.36	0.92	0.04
V µg/L	7.23	23.30	19.90	32.00	7.62
Zn µg/L	8.3	29.7	59.1	246.0	11.4

35.9 µg/L, probably associated with the high gold content of the bedrock, as the gold-producing area of La Libertad is only about 10 km away. Arsenic is to be found in abundance in hydrothermal ores, in conjunction with these and precious metals, and its concentrations may also be thought of in general as being high in areas with rocks of volcanic origin that contain volatile substances (Lahermo et al. 1996).

Wells 34 and 35 serve as sources of water for a small brickworks in the village of Santo Tomás. Here the groundwater table lies at a depth of only 30 cm, so that the wells can easily be contaminated with surface water. The newer one, well 34, was made in 1997 and is 18 metres deep. Its water was alkaline (pH 8.7) probably on account of the new concrete rings with which it is lined, and had an aluminium content of 347 µg/L. The older one, which is dilapidated and no longer used for water supplies, contained water of pH 7.7 with an aluminium concentration of 1280 µg/L and the highest lead content to be found in the Santo Tomás area, 1.87 µg/L.

Well 37, of depth 5.6 m, is located in a valley, next to a new disposal site for biological waste. The groundwater table at this point lies at a depth of 1.6 metres. About a kilometre away, on the other side of the valley, is well 38, of depth 60 m, from which water is pumped into the piped water supply of Santo Tomás. Well 40, of depth 16 m, is also situated close to Santo Tomás, in the valley of the Río Lóvago. The water level in this well was said by its owner to vary as much as 4 metres between the rainy season and the dry season, and at the time of visiting, in the rainy season, it stood at 6.5 m from the ground surface. One danger as far as pollution is concerned arises from the cattle that are allowed to wander about freely in the area. Well 46, of depth 18 m, is located in the Río Mico valley and has its water level at 4 m. The owner explained that it had been drilled down as far as the bedrock surface.

The population centre of Santo Tomás receives its water from the Quipor reservoir, which retains water from a number of streams and rivers flowing down from the mountains. The water of the reservoir is chlorinated regularly. Additional water is obtained from four wells. Three surface water samples from the Río Mico were analysed, together with one sample in each year, 1997 and 1999, taken from its tributary, the Río San Juan, at a point close to the La Libertad gold mining area. The water of the Río Mico was of good physico-chemical quality, but problems are caused by suspended solids, which amounted to 210 mg/L at their highest. The water was practically neutral and had a lower electrical conductivity than the surface water at either Diriamba or León, and heavy metal concentrations were low, as also were those of calcium, magnesium, potassium and sulphate, and similarly nitrate. Suspended solids and humus content increased towards the lower reaches of the river, however, as reflected in the colour and turbidity of the water. The high humus content was also reflected in a fairly high potassium permanganate consumption, which also increased downstream. The same pattern was similarly followed by aluminium, but manganese concentrations diminished towards the lower course of the river (Table 16). The values

Table 16. Chemical composition of the water in the Río San Juan and Río Mico in the La Libertad and Santo Tomás areas in 1997 and 1999. A single figure is quoted if the concentration was the same in both years. Suspended material was determined only in 1999.

	San Juan La Libertad 1997/1999	Río Mico La Libertad 1997/1999	Río Mico S.P. de Lóvago 1997/1999	Río Mico Santo Tomás 1997/1999
Temperature °C	26.8/27.2	26.8/24.0	26.0/23.7	24.9/26.2
pH	7.2/7.5	7.3/7.7	7.5	7.5/7.7
Electrical conductivity mS/m, 25°C	7.2/6.8	8.0/7.9	9.8/5.8	12.2/11.0
Colour Pt mg/L	10	15/60	20/250	60/50
Alkalinity mmol/L	0.37	0.53/0.41	0.74/0.42	0.96/0.93
HCO_3 mg/L	22.6	32.3/25.0	45.1/25.6	58.6/56.7
$KMnO_4$ consumption mg/L	3.0/2.5	3.8/6.0	5.0/21.0	16.0/11.0
Suspended material mg/L	20	90	210	30
Br mg/L	<0.1	<0.1	<0.1	<0.1
Cl mg/L	5.8/5.2	5.6/6.4	5.8/4.0	6.4/5.8
F mg/L	<0.10	<0.10	<0.10	<0.10
NO_3 mg/L	0.8/<0.2	<0.2/1.5	<0.2	0.2
PO_4 mg/L	<0.02	<0.02	0.02	0.04/0.02
SO_4 mg/L	4.2/3.9	2.4/4.4	2.0/1.6	1.2/1.5
Ag µg/L	0.19/0.01	0.39/0.01	0.28/<0.01	1.92/0.01
Al µg/L	4.2/7.1	17.6/56.6	112.0/303.0	178.0/320.0
As µg/L	0.16/0.17	0.22	0.45/0.36	0.60/0.77
B µg/L	15.0/28.8	11.8/14.1	12.1/14.5	12.9/14.4
Ba µg/L	55.1/58.5	26.3/28.3	25.6/20.4	32.2/30.9
Be µg/L	<0.1	<0.1	<0.1	<0.1
Bi µg/L	<0.03	<0.03	<0.03	<0.03
Ca mg/L	4.4/3.7	5.4/4.2	7.7/3.8	11.0/9.1
Cd µg/L	<0.02	<0.02	<0.02	<0.02
Co µg/L	0.76/0.95	0.17/0.99	0.09/0.12	0.10/0.18
Cr µg/L	<0.20	<0.20	0.28/0.25	0.32/0.21
Cu µg/L	0.5/0.7	0.3/0.9	1.1/2.2	1.1/1.3
Fe mg/L	0.20/0.16	0.22/0.10	0.21/0.16	0.27/0.19
K mg/L	0.8	1.4	1.4/1.7	1.9/1.5
Li µg/L	1.3/1.4	0.9/0.6	1.1/0.5	0.9/0.7
Mg mg/L	2.4/2.2	2.4/2.0	3.1/1.7	3.4
Mn µg/L	260.0/387.0	80.8/96.2	16.0/6.2	12.6/27.6
Mo µg/L	0.09/0.10	0.08/0.42	0.09/0.12	0.08/0.15
Na mg/L	5.3/4.9	5.9/7.1	7.7/5.0	9.4/9.2
Ni µg/L	0.18/0.08	0.15/0.27	0.24/0.18	0.29/0.21
Pb µg/L	0.08/0.18	0.06/0.05	0.54/0.07	0.08/0.06
Rb µg/L	0.9	1.8	1.6	1.7
Sb µg/L	0.02	0.02/<0.02	0.03/0.02	0.03/0.02
Se µg/L	<0.5	<0.5	<0.5	<0.5
Si mg/L	6.9/7.1	9.6/8.9	9.8/8.2	10.3/12.7
Sr µg/L	24.0/21.0	32.0/24.0	43.0/25.0	52.0/49.0

Table 16. cont.

	San Juan La Libertad 1997/1999	Río Mico La Libertad 1997/1999	Río Mico S.P. de Lóvago 1997/1999	Río Mico Santo Tomás 1997/1999
Th µg/L	<0.02	<0.02	<0.02	<0.02
Tl µg/L	0.03/0.05	<0.02/0.04	<0.02/0.03	<0.02/0.02
U µg/L	<0.01	<0.01	0.06/0.01	0.03/0.02
V µg/L	0.24/0.35	0.66/0.83	1.44/2.22	2.48/2.99
Zn µg/L	3.3/1.2	4.8/1.0	7.8/1.4	27.4/1.3

in 1999 were in general similar to those obtained in 1997, calcium, iron, strontium and zinc concentrations being slightly lower, probably as a consequence of the diluting effect of the heavy rains that prevailed at the time of sampling.

Iron-rich laterites are to be found in the area, and the samples from the gold-mining area of La Libertad and the sediments of the Río Mico contained more aluminium, iron, manganese, vanadium and also titanium than those representing Finland and weathering in a cooler climate (Figs. 32, 33, 42 and 45, App. 3 and 4). The maximum aluminium concentration, 9.2 %, was recorded for a sample from a former gold-mining site beside the Río San Juan. High aluminium, iron, manganese and titanium concentrations were also found in the samples of Tisma, León and Diriamba.

Concentrations of silver, gold, mercury and lead in the parallel samples taken from San Tomás-La Libertad in 1997 and 1999 are presented in Table 17. The gold concentration was also analysed in the sandy bed of the Río Mico at San Pedro de Lóvago, which the local inhabitants use for making cement. The 1999 samples were taken at the same sites as in 1997, but there may have been dicrepancies of a few tens of metres in some cases. The differences in mercury concentrations between the analyses performed by the Geological Survey of Finland and those carried out in Nicaragua may be due to differences in sample pre-treatment and analytical techniques.

The minerals contained in the samples of surficial deposits, in descending order of quantity (as estimated by Kristian Lindqvist at the Mineralogy Laboratory of the Geological Survey of Finland), were: 42. San Juan: quartz, smectite, hematite and chlorite; 43. Río Mico, La Libertad: quartz, smectite and plagioclase; 44. Río Mico, San Pedro de Lóvago: quartz, plagioclase, smectite and heulandite (= zeolite); 45. Río Mico, Santo Tomás: quartz, plagioclase, smectite and heulandite.

The highest amounts of mercury in the river sediments (1.32 mg/kg and 0.914 mg/kg) were to be found at site 43, two kilometres away from the mining area, and the concentration was considerably lower at site 44 on the lower reaches of the river, 10 km from the mining area. The directive boundary value for mercury pollution in surficial deposits in Finland is 0.2 mg/kg and the limit 5 mg/kg (Järvinen et al. 1996). The sample from site 43 consisted of finesand, but although fine-grained material is generally more effective in retaining mercury than coarser-grained material, it should be noted that the sample 43 that contained most mercury also had the lowest clay fraction, so that in this case the situation must have been influenced by the location of the site close to the mining area as well as by the composition of surficial deposits. Mercury readily forms compounds with soil particles and substances dissolved in water. It also readily evaporates, but is returned to the surficial deposits by subsequent rains.

Table 17. Silver, gold, mercury and lead concentrations in the river sediments of the Santo Tomás-La Libertad area in 1997 and 1999 and in the sand of the river bed in 1999. Silver, gold and lead were analysed at the Geological Survey laboratories in Finland after aqua regia extraction and mercury after nitric acid extraction. Mercury was also analysed in parallel samples at the UNI laboratory in Nicaragua in 1997.

Site	Mean composition of surficial deposits	Clay % 1997/99	Ag mg/kg 1999	Au µg/kg 1997/99	Hg mg/kg 1997/99	Hg mg/kg UNI 1997	Pb mg/kg 1997/99
42. San Juan	Sand	12/22	2.5	154/1930	0.035/0.27	0.110	35/45.7
43. Río Mico, La Libertad	Fine sand	9/22	5.2	1250/1630	0.914/1.32	0.200	43/40.1
44. Río Mico, S.P. Lóvago	Sand	13.5/27	1.0	790/109	0.285/0.10	0.002	17/<5
45. Río Mico, Santo Tomás	Silt	44.5/29	1.0	9/149	0.037/0.12	0.002	5/<5
Río Mico, sand of the river bed				1850	0.10		7.4

DISCUSSION AND CONCLUSIONS

Surveys covering the whole of Finland have shown the water of wells drilled into the bedrock to possess fluoride, sodium, manganese, chloride and radon concentrations that are higher on average than those found in wells located in unconsolidated sediments, and electrical conductivity, alkalinity and the concentrations of arsenic and a number of heavy metals are also higher (Lahermo et al. 1990, Backman et al. 1999, Korkka-Niemi 2001, Tarvainen et al. 2001, Lahermo et al. 2002). The main reasons for the greater concentrations of dissolved substances in bedrock groundwater lie in its slower cycle and the influence of the bedrock itself on water quality. Thus bedrock groundwater frequently contains e.g. large amounts of dissolved iron and manganese, which easily dissolve in water in anoxic conditions, and also sulphur in the form of sulphides. A further factor at greater depths may also be the geothermal conditions, which cause minerals to dissolve more readily. Local changes in bedrock groundwater quality, e.g. acidification, can be brought about by the weathering of sulphide minerals, as a result of released sulphuric acid (Backman 1993), and weathering is known to be accentuated under circumstances in which a drop in the groundwater table takes place. The most serious consequence of groundwater acidification is intensification of its corrosive properties for the water pipes, leading to an increase in the concentrations of many heavy metals. Acidification problems have shown signs of abating in recent times, however, partly in response to the decrease in acid emissions into the air.

The mineral composition of the bedrock affects the water chemistry, the effects being greater the more local and finer-grained the till is and the longer the time over which the minerals have been able to react with the water. It has been shown by Koljonen (1992) that the fines (grain size less than 0.063 mm) in till usually serve well to reflect the mean composition of the bedrock and that elements with similar geochemical properties tend to appear in combination in tills. The fine fraction of till frequently represents the longest transport distances and maximum level of homogenization of the material (Gillberg 1977, Perttunen 1977, Saarnisto et al. 1980, 1981, Taipale et al. 1986), being in effect a mixture of material from different stages in the glaciation, as erosion has affected both the bedrock and the unconsolidated sediments and the latest till bed is their mixture (Lintinen 1995). The till material can be derived from bedrock that located anywhere from a few tens of metres to several kilometres away from the site of the till. Small bedrock units will have little impact on till composition, with the exception of limestone and ore mineralizations, even small occurrences effect on the quality of the groundwater (Lahermo et al. 1996).

Under Finnish conditions the eluvial and illuvial horizons of podzol soils have effects of their own on the quality of the groundwater. The pH values of acidic rainwater also affect the geochemical reactions in the soil. The mean pH of rainwater in Finland is around 4.5, measurements made in Southern and Central Lapland giving figures of 5.8-5.9 in 1971 and 4.5 in 1980 (Järvinen & Haapala 1980, Soveri 1982). The median pH of rainwater in Lapland in 1997 (measured at six stations) was 4.87-5.76, the lowest pH 4.87 being at Juotas measuring station, approx. 50 km to the east of Rovaniemi. The electrical conductivity of rainwater was in Finland in 1997 2.6 mS/m on the south coast and diminishes northwards to approximately 1 mS/m in Northern Finland (Vuorenmaa et al. 1999). A survey by the Instituto Nicaragüense de Estudios Territoriales in 1989 reported the pH of rainwater in León to be 6.58 and its electrical conductivity 5 mS/m, and the measurements made in León in 1999 gave the results of 5.3 for pH and 0.3 mS/m for electrical conductivity.

Soluble cations in the soil are transported with rainwater deeper into the ground in the gravitational water and enter the groundwater, especially in areas with thin Quaternary deposits, while the illuvial horizon prevents certain elements such as iron and manganese from being transported from the ground surface to such depths. The rain water nevertheless alters in quality as it infiltrates into the groundwater as a result of reactions with minerals. Besides easily soluble cations e.g. sulphur is also a highly mobile element, but tends to occur in poorly soluble compounds under reducing conditions.

The groundwaters studied in the Rovaniemi district are mostly calcium-bicarbonate type and slightly acid. A part of the samples in till deposits have high equivalent percentages of sodium and potassium. Anomalously high sodium and potassium concentrations in some shallow wells are due to human impact, but in some springs of natural state the source may be granitic bedrock which has high sodium contents and relatively high potassium contents (Reimann et al. 1998). The anomalously high concentrations of sodium and potassium were also found in sandy deposits in some shallow wells.

The groundwater composition in Nicaragua is also generally calcium-bicarbonate type, but sodium and potassium are dominant cations in the Tisma area. High sodium concentrations in shallow wells are mainly due to human impact and contamination. Weathered bedrock, sea spray and fertilizers are also possible sources of sodium and potassium (Reimann et al. 1998). In coastal areas brackish and saline groundwater is another reason for high sodium and potassium concentrations (Lahermo et al. 1990). The groundwater of Santo Tomás represent both calcium-bicarbonate type and sodium-potassium-bicarbonate type. The concentrations of the main anions and cations are generally higher in Nicaragua than in the Rovaniemi district. The groundwater is neutral or slightly alkaline on average and electrical conductivities high compared to those in the Rovaniemi region.

The Pearson correlation matrix was computed for the variables of the groundwater samples in the Rovaniemi district (Table 18) and in Nicaragua together with the surface water samples (Table 19). The matrix is presented for all the samples both in Rovaniemi and in Nicaragua for the overall picture of the correlations. The data of the matrix of the Rovaniemi district include all the analyses of the monitoring sites since 1993.

Electrical conductivity indicates the amount of dissolved electrolytes in water and for this reason it is correlated with many constituents.

Table 18. The Pearson correlation matrix for the properties and concentrations of dissolved constituents in the groundwater samples in the Rovaniemi district (N=284). Only correlation coefficients of the levels of P<0.01 (in bold) and P<0.05 are presented.

	EC	pH	O_2	Colour	$KMnO_4$	HCO_3	SO_4	Cl	F	SiO_2	NO_3	Ca	Mg	Na	K	Fe	Mn
EC																	
pH	**0.296**																
O_2		**0.356**															
Colour	**0.211**		-0.146														
$KMnO_4$			**-0.160**	**0.761**													
HCO_3	**0.520**	**0.234**	-0.126														
SO_4	**0.395**		0.178	-0.167		**0.348**											
Cl	**0.763**						**0.168**										
F	**0.178**					**0.295**											
SiO_2	**0.299**	**0.158**	**-0.267**	**0.364**	0.135	**0.451**	**-0.157**		**0.293**								
NO_3	**0.319**	**-0.165**					**0.292**	**0.389**									
Ca	**0.768**					**0.721**	**0.624**	**0.504**			**0.279**						
Mg	**0.752**					**0.399**	**0.336**	**0.643**	**0.202**	**0.355**	**0.562**	**0.523**					
Na	**0.710**							**0.946**	0.124		**0.274**	**0.435**	**0.535**				
K	**0.370**						0.122	**0.433**				**0.273**	**0.246**	**0.591**			
Fe	**0.265**		**-0.193**	**0.834**	**0.662**	0.145	**-0.239**		0.131	**0.604**							
Mn	**0.286**		**-0.268**	**0.550**	**0.290**	**0.339**	**-0.264**		**0.274**	**0.752**			**0.281**			**0.694**	
Zn						**0.203**						**0.179**					
Al			**-0.156**	**0.638**	**0.585**		-0.134			**0.251**						**0.454**	**0.398**
U	**0.268**							**0.288**	**0.713**		0.149	**0.187**	**0.304**	**0.272**	**0.175**		

Table 19. The Pearson correlation matrix for the properties and concentrations of dissolved constituents in the groundwater and surface water samples in Nicaragua (N=52). Only correlation coefficients of the levels of P<0.01 (in bold) and P<0.05 are presented.

	EC	pH	Colour	$KMnO_4$	HCO_3	SO_4	Cl	F	NO_3	Ca	Mg	Na	K	Fe	Mn	Zn	Cd
EC																	
pH	**0.562**																
Colour	-0.318	**0.382**															
$KMnO_4$			**0.677**														
HCO_3	**0.912**	**0.638**															
SO_4	**0.541**				**0.447**												
Cl	**0.823**	0.305			**0.643**	0.351											
F	**0.615**				**0.667**		**0.491**										
NO_3	**0.456**						**0.442**										
Ca	**0.637**	**0.443**	**-0.421**	-0.301	**0.525**	**0.520**	**0.481**		0.376								
Mg	**0.692**	**0.361**	-0.354		**0.610**	**0.458**	**0.583**			**0.805**							
Na	**0.838**	**0.468**			**0.847**	0.308	**0.708**	**0.793**			0.276						
K	**0.709**	**0.367**			**0.652**	**0.477**	**0.441**	**0.546**	0.334			**0.731**					
Fe				0.509													
Mn	-0.311	**-0.445**			-0.310					**-0.394**	-0.296						
Zn								0.320									
Cd							0.648	0.731								**0.999**	
Al			**0.432**	**0.731**													
U	**0.789**	0.346			**0.777**	0.362	**0.626**	**0.681**				**0.908**	**0.684**		0.350		0.658

In the groundwater samples of the Rovaniemi district electrical conductivity is strongly correlated (>0.6) with calcium, chloride, magnesium and sodium. Chloride is strongly correlated with sodium and magnesium (Table 18, Fig. 47). Sulphate, sodium, potassium and nitrate concentrations mostly indicate the effects of human activity. Chloride is a main component in salty waters and it correlates with other electrolytes typical in salty waters as bromide and iodide (Lahermo et al. 2002). Bicarbonate is strongly correlated with calcium. Bicarbonate is the most common anion in groundwater and calcium and magnesium the most common cations which is a natural reason for correlations between them. Sulphate is strongly correlated with calcium. Fluoride is strongly correlated with uranium, even though the concentrations of uranium were mostly very low. Silica is strongly correlated with manganese and iron. Iron is strongly correlated with $KMnO_4$ consumption and manganese (Fig. 48), which is geochemically similar to iron. Colour and $KMnO_4$ consumption are strongly correlated since dissolved humus is the main contributor to colour and to the chemically consumable material in water (Lahermo et al. 1990). Colour is also strongly correlated with iron and aluminium.

Nitrate has a weak negative correlation with pH, which was also the situation in the study of the whole country (Lahermo et al. 2002). Sulphate has a slight negative correlation with manganese, iron, silica, aluminium and colour. In anoxic conditions sulphate is reduced and sulphur may occur as hydrogen sulphide (H_2S), for instance, while iron and manganese dissolve in water. In oxidizing conditions e.g. iron and manganese precipitate, thus dissolved oxygen has a negative correlation with iron and manganese. Oxygen has a negative correlation also with silica, aluminium, $KMnO_4$ consumption, colour and bicarbonate.

In Nicaraguan water samples electrical conductivity is strongly correlated with bicarbonate, chloride, with the main cations (Table 19, Fig. 49) and with fluoride and uranium. Bicarbonate is strongly correlated with pH, chloride, magnesium, sodium, potassium, uranium (Fig. 50) and fluoride. Chloride is strongly correlated with sodium, uranium and cadmium. High concentrations of these elements in shallow wells may indicate human impact except uranium which mainly enters the environment from the bedrock. Fluoride is strongly correlated with sodium, uranium and cadmium. Fluoride enters the environment from the bedrock and from fertilizers, for instance. Calcium is strongly correlated with magnesium, while sodium correlates with potassium (Fig. 51) and uranium. Potassium is strongly correlated with uranium, which is strongly correlated with cadmium.

Colour is naturally strongly correlated with $KMnO_4$ consumption. Zinc is strongly correlated with cadmium. The cadmium concentrations of groundwater samples were however very low. Zinc is highly mobile in the environment and it indicates human impact. Aluminium is strongly correlated with $KMnO_4$ consumption. Dissolved aluminium may be derived from molecules bound to organic matter in the soil (Näpänkangas 1995).

In Nicaraguan water samples manganese and colour have a negative correlation with pH and electrical conductivity. Colour has also a negative correlation with calcium and magnesium. Calcium has furthermore a negative correlation with manganese and $KMnO_4$ consumption, and manganese with bicarbonate and magnesium (Table 19).

It has been shown that a correlation exists between soluble aluminium and beryllium in acidic groundwater (Hrkal 2001), and it was indeed the case that the highest beryllium concentrations in the observation wells in the Rovaniemi area occurred in conjunction with the highest aluminium concentrations, but they were still less than 1 µg/L. In practically all the other samples concentrations of beryllium were below the detection limit of 0.01 µg/L. As

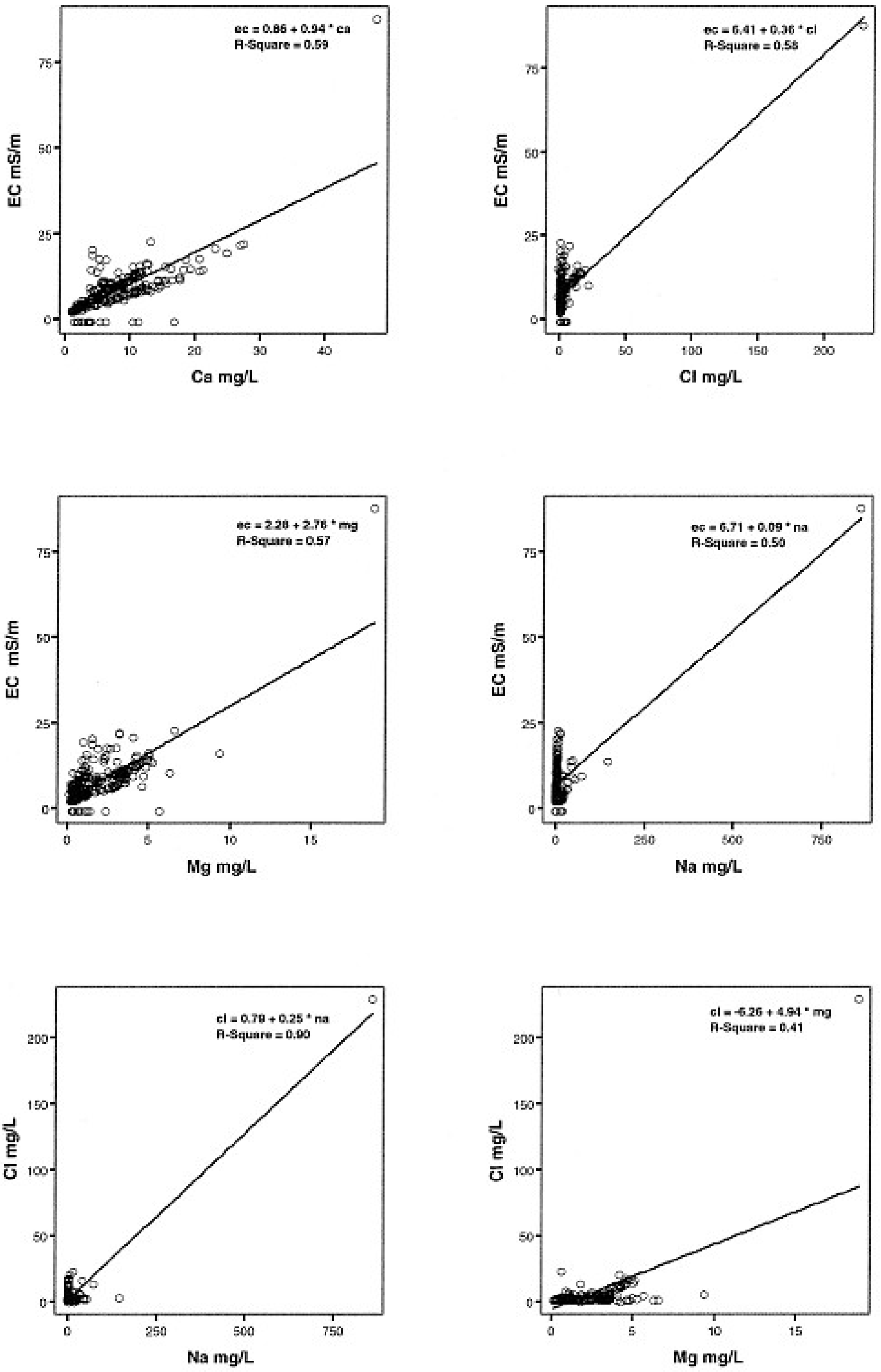


Fig. 47. Scatter diagrams of electrical conductivity and dissolved elements in the groundwater in the Rovaniemi district. Correlations of electrical conductivity with calcium, chloride, magnesium and sodium and correlations of chloride with sodium and magnesium.

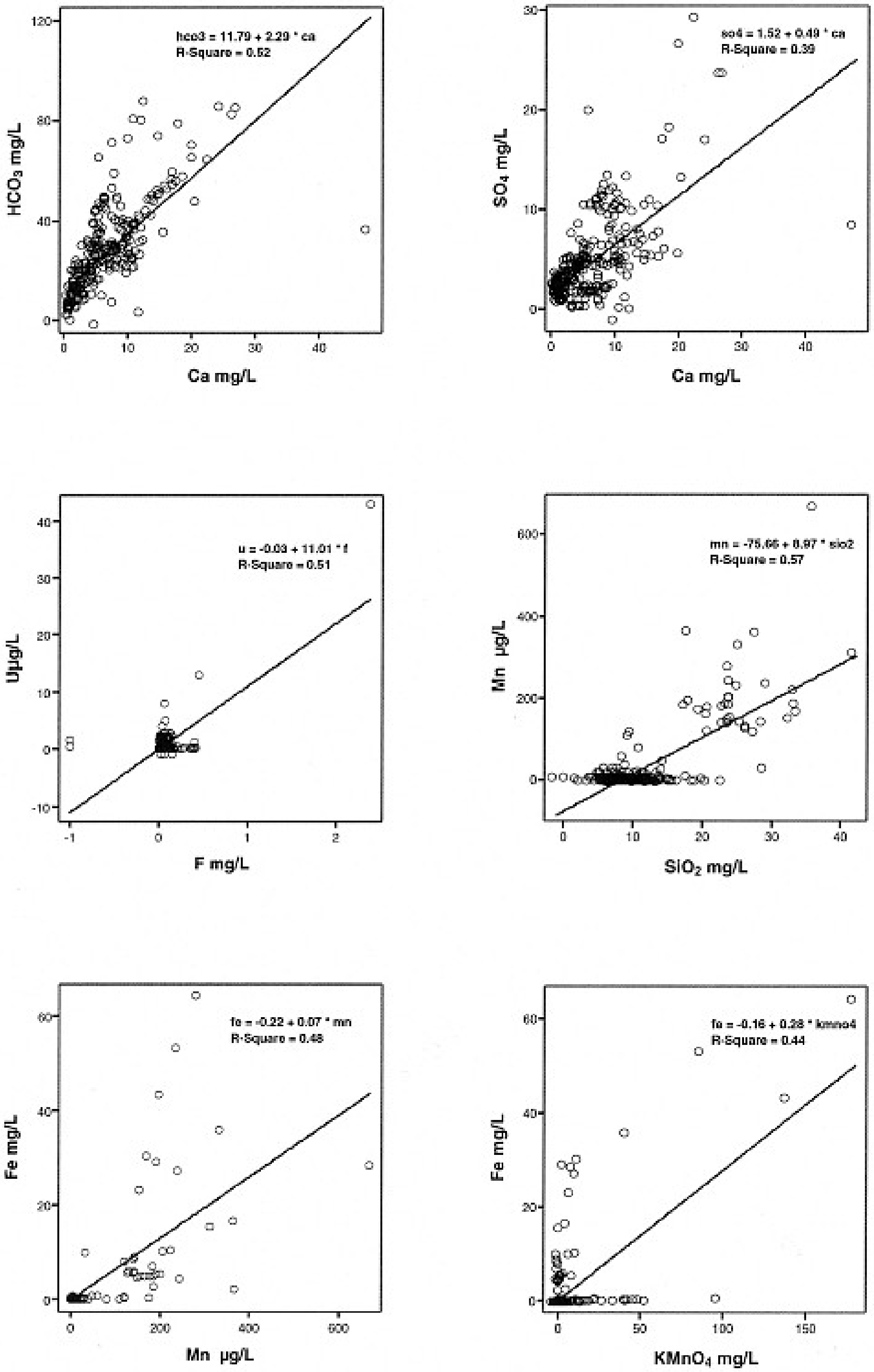


Fig. 48. Scatter diagrams of some properties and dissolved elements in the groundwater in the Rovaniemi district. Correlations of bicarbonate with calcium, sulphate with calcium, uranium with fluoride, manganese with silica and iron with manganese and KMnO$_4$ consumption.

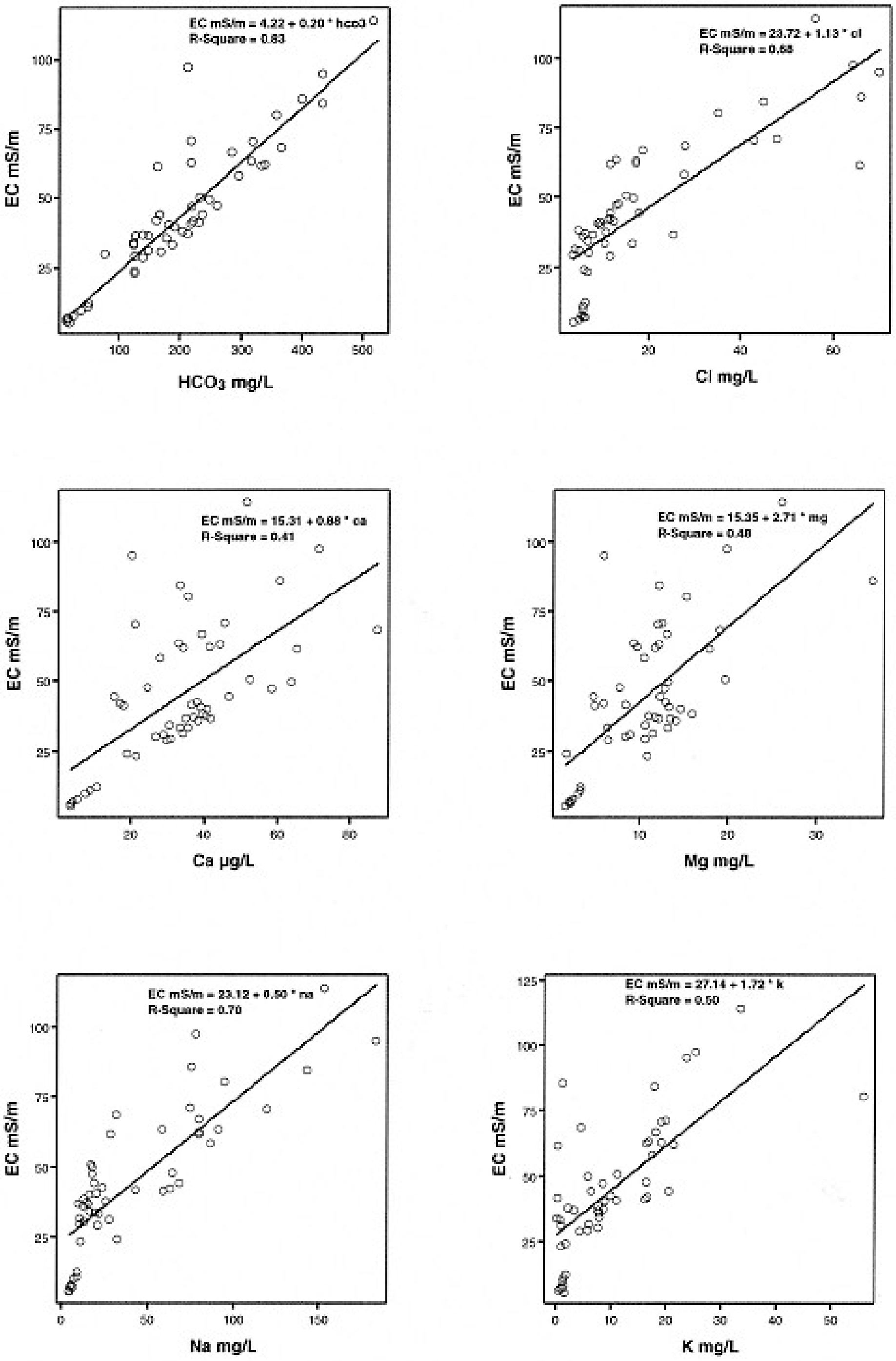


Fig. 49. Scatter diagrams of some properties and dissolved elements in the groundwater in Nicaragua. Correlations of electrical conductivity with bicarbonate, chloride, calcium, magnesium, sodium and potassium.

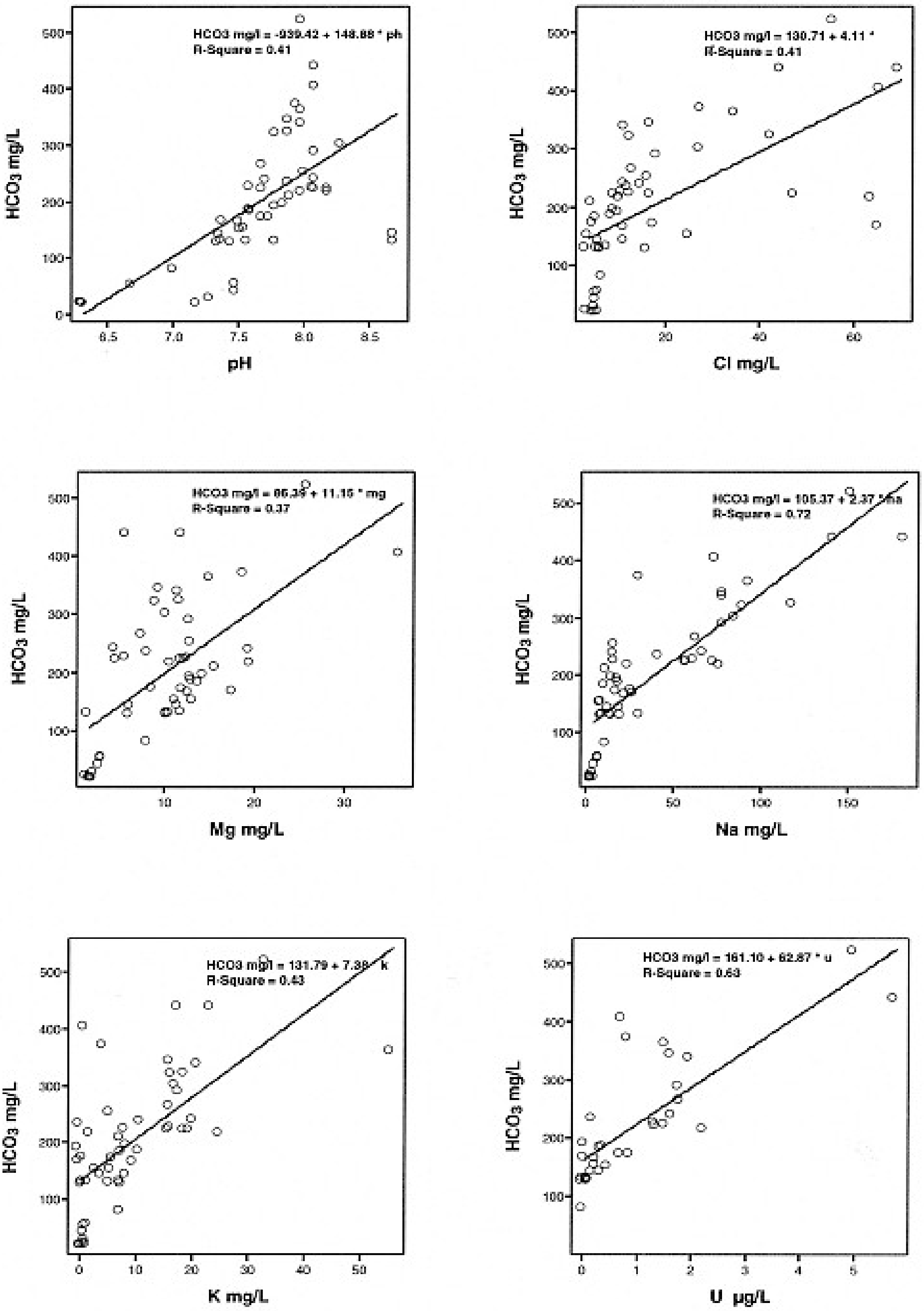


Fig. 50. Scatter diagrams of some properties and dissolved elements in the groundwater in Nicaragua. Correlations of bicarbonate with pH, chloride, magnesium, sodium, potassium and uranium.

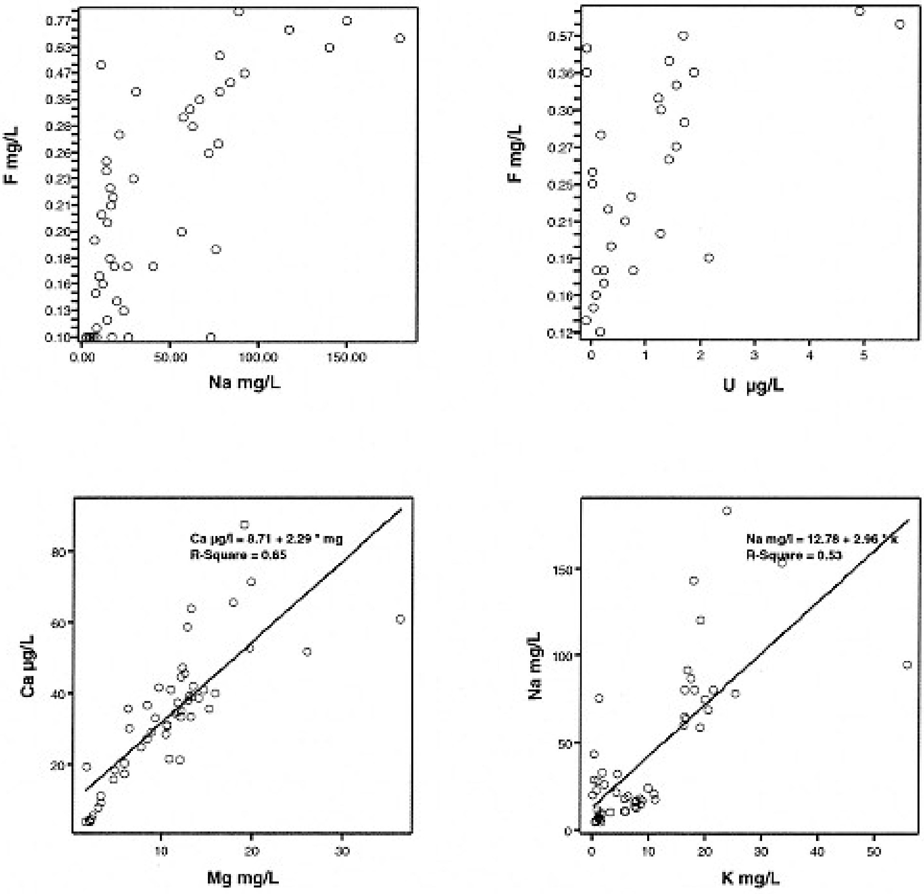


Fig. 51. Scatter diagrams of some dissolved elements in the groundwater in Nicaragua. Correlations of fluoride with sodium and uranium, calcium with magnesium and sodium with potassium.

one of the alkaline earths, beryllium bears a closer resemblance to aluminium than does any other element (Lytle et al. 1992, Edmunds & Trafford 1993). In some cases the strong correlations in Table 18 and 19 are based only on a few samples with anomalously high concentrations, as the strong correlation between fluoride and uranium in the Rovaniemi district.

Comparison between the results for Finland and Nicaragua

Geographical, climatic and geological distinctions, physical and chemical properties of the surficial deposits, differences in land use and in the environmental impacts of human activity can all be expected to give rise to variations in both groundwater and surface water quality between the Rovaniemi district of Finland and Nicaragua. The biggest differences were those of anions (bicarbonate, nitrate, sulphate and chloride) and the soluble cations calcium, magnesium, sodium and potassium. The cations occurred in greater abundance partly on account of geological factors and partly because of human activity. Calcium concentrations in the drilled wells near Rovaniemi were however approximately similar to those in the groundwater of Nicaragua. The main reason for the higher chloride, nitrate and sulphate concentrations in Nicaragua lies in the infiltration of polluted surface water into the shallow wells. These same wells also had the highest counts of coliform bacteria. Bromide, fluoride and phosphate concentrations were for the most part low in the groundwater of both Nicaragua and the Rovaniemi district. Concentrations of strontium were in Nicaragua considerably higher than in Finland both in waters and in surficial deposits. Strontium is geochemically similar to calcium and it enters the environment from weathered material and as sea spray (Reimann et al. 1998). Vanadium concentrations were also higher in Nicaragua. Vanadium bearing mafic minerals weather easily (Koljonen 1992) and its mobility is high under oxidising and acid conditions, and very high under neutral to alkaline conditions (Reimann et al. 1998).

Aluminium, iron and manganese, elements that are characteristic of volcanic areas and of the weathering products and laterite soils to be found in tropical areas, are present in lesser quantities in the groundwater of Nicaragua than in the Rovaniemi district of Finland. Aluminium concentrations were frequently below the detection limit, but two exceptionally high figures of 347 µg/L and 1280 µg/L were recorded for two wells in the Santo Tomás area. Elsewhere all the concentrations were in the range <1-105 µg/L. Some relatively high concentrations were also measured in surface water samples, e.g. 213 and 665 µg/L in the Laguna de Tisma in 1994 and 1997 and 303 and 320 µg/L in two sites of the Río Mico at Santo Tomás. Iron concentrations were below the limit of detection (0.03 mg/L) in most of the groundwater samples. This indicates than these elements tend to occur in poorly soluble compounds under the neutral conditions prevailing in Nicaragua. The highest iron concentrations in the groundwater of the Rovaniemi district were to be found in the bedrock fracture zones in anoxic conditions.

Copper concentrations were in all the Nicaraguan groundwater samples mostly below the limit of detection (0.04 µg/L). The concentrations in the Rovaniemi district were low for the most part, the highest concentrations being found in the observation well 8 (962 µg/L) and in two bedrock drilled wells (51.8 and 94.2 µg/L). Zinc concentrations were generally low in both sets of data, below 20 µg/L on average, but slightly higher levels were found in Santo Tomás than in other study areas of Nicaragua the maximum being 246 µg/L.

Barium and boron concentrations were more prevalent in the groundwater of Nicaragua on average than in Rovaniemi boron reaching a maximum concentration of 461 µg/L in Tisma, where the mean boron concentrations were considerably higher than in the other study areas in Nicaragua. The figures in the León and Diriamba areas were a few tens of µg per litre at most, but they reached several hundred µg at Tisma. Concentrations in Rovaniemi were usually a few µg per litre, the maximum being 33.8 µg/L. Boron finds its way into the environment as sea spray, through fertilizers, sewage and weathering and dissolving especially from marine sediments. Boron is adsorbed on clay minerals (Reimann et al. 1998).

Beryllium was below the detection limit (0.1 µg/L) at all the sites in Nicaragua and almost all those near Rovaniemi, while bismuth was below the detection limit (0.03 µg/L) in the both countries except for one well in Nicaragua. Cobalt, chromium and cadmium concentrations were also very low in Nicaragua and in the Rovaniemi area, the majority being below the detection limit (0.02 µg/L for cobalt and cadmium and 0.2 µg/L for chromium). Nickel was similarly very low around Rovaniemi, no more than a few µg per litre, and mostly below the detection limit (0.06 µg/L) in Nicaragua.

Arsenic concentrations in Nicaragua were higher than in Finland on average. There were six groundwater samples in which the reading was over 10 µg/L, which is the upper limit for good domestic water supplies in Finland. The groundwater of Nicaragua contained considerably more vanadium and also strontium than that of the Rovaniemi district, where vanadium was below 1 µg/L on average and strontium just a few tens of µg per litre. The vanadium concentrations recorded here for Nicaragua were at most a few tens or hundreds of µg per litre, the highest figures, over 300 µg/L on average, being reached at Tisma. These two metals find their way into the environment partly through weathering of the bedrock and partly in connection with volcanic eruptions. The anomalously high arsenic concentrations in Tisma were probably due to fertilizers and pesticides.

Concentrations of molybdenum, lead, rubidium, antimony, selenium, thorium, thallium and uranium were low in all the groundwater samples from Nicaragua and Rovaniemi, reaching a few µg per litre at most. The only exception was uranium in two drilled wells in the Rovaniemi district, where figures of 13 and 42.8 µg/L were recorded. Groundwater pH, electrical conductivity and concentrations of some anions and elements are quoted for selected sites in Nicaragua and around Rovaniemi in Figures 52-54.

Elements can become dissolved in the groundwater more easily from the surficial deposits of Nicaragua, which contain large amounts of heavily weathered material, than in those of Finland, although their solubility may be reduced somewhat by the neutral pH. Chemical and biological weathering are the main mechanisms of release from the bedrock under tropical conditions, whereas slow physical weathering is more powerful in cold and humid climatic situations in Finland. The result of chemical weathering is a clay that is rich in aluminium and iron, insoluble quartz or silicon and mostly calcium, magnesium, sodium and potassium in soluble form. In practice all the potassium remains in the weathered horizon, whereas calcium, magnesium and sodium are more mobile (Driscoll 1986).

There are many old, thick horizons of weathering products in Nicaragua which have a far higher buffer capacity than those in Finland.

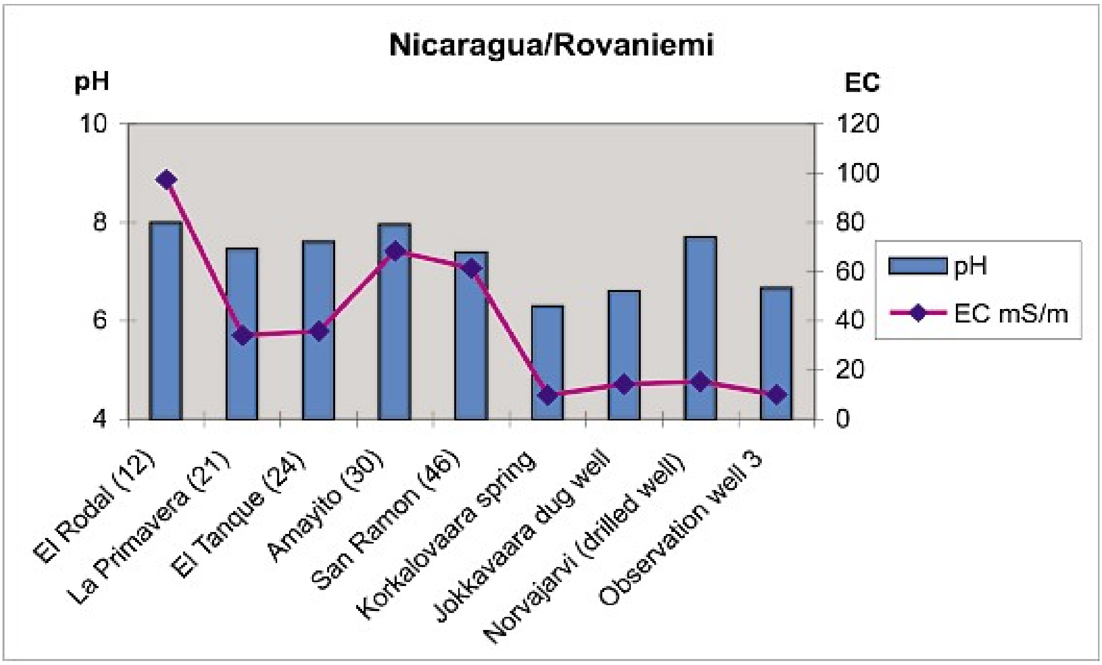
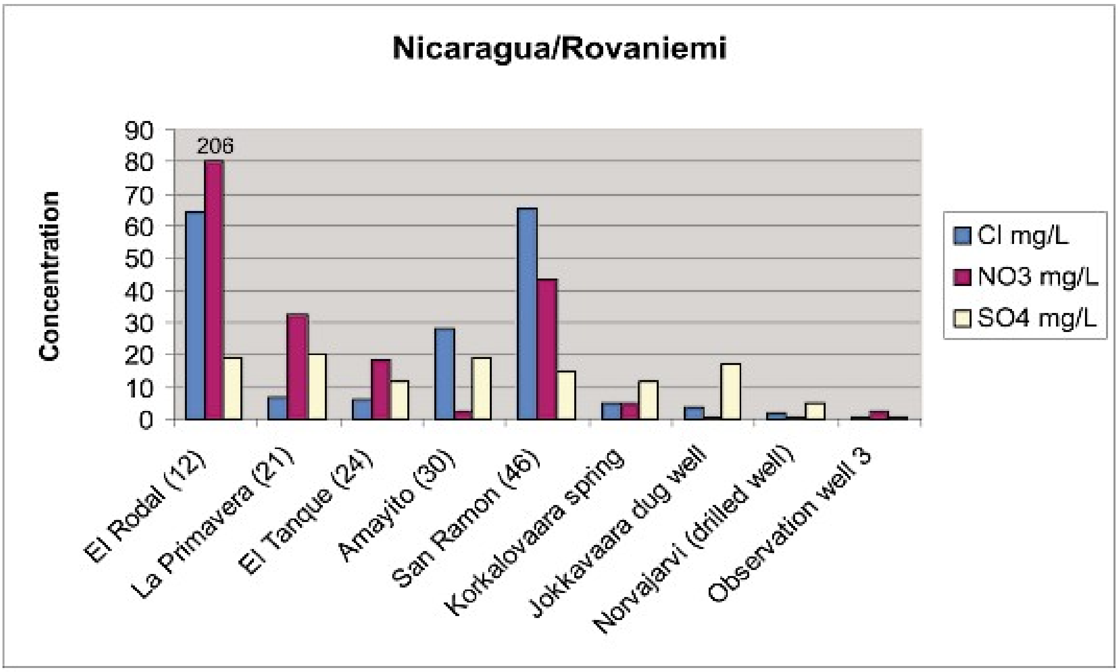


Fig. 52. The pH values and electrical conductivities at selected sites in Nicaragua and in the Rovaniemi district.



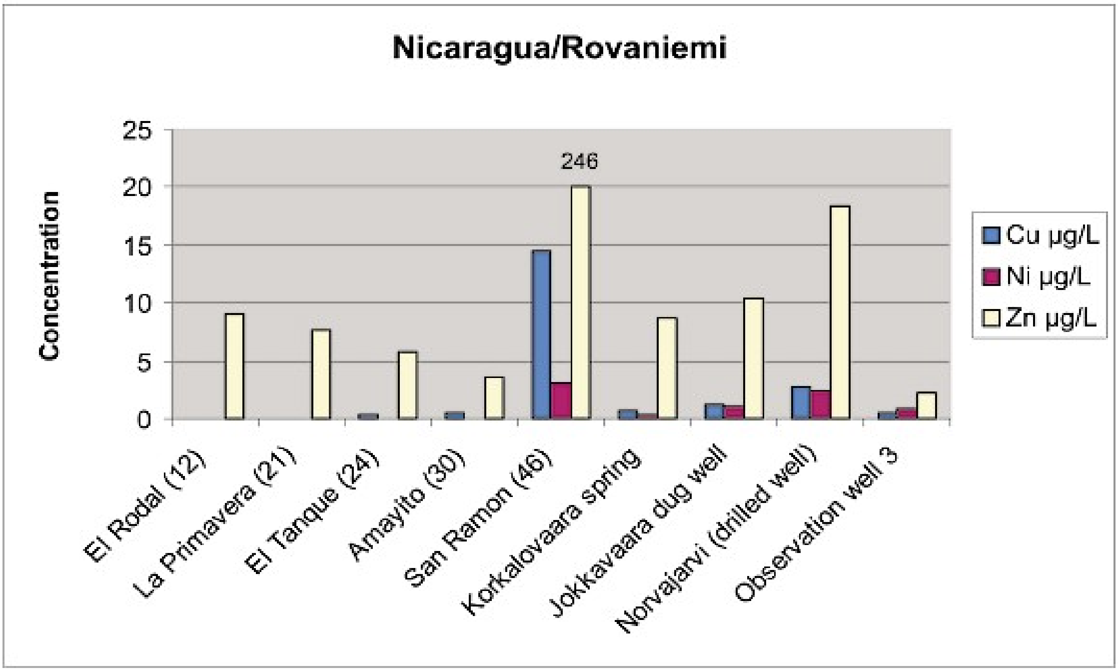
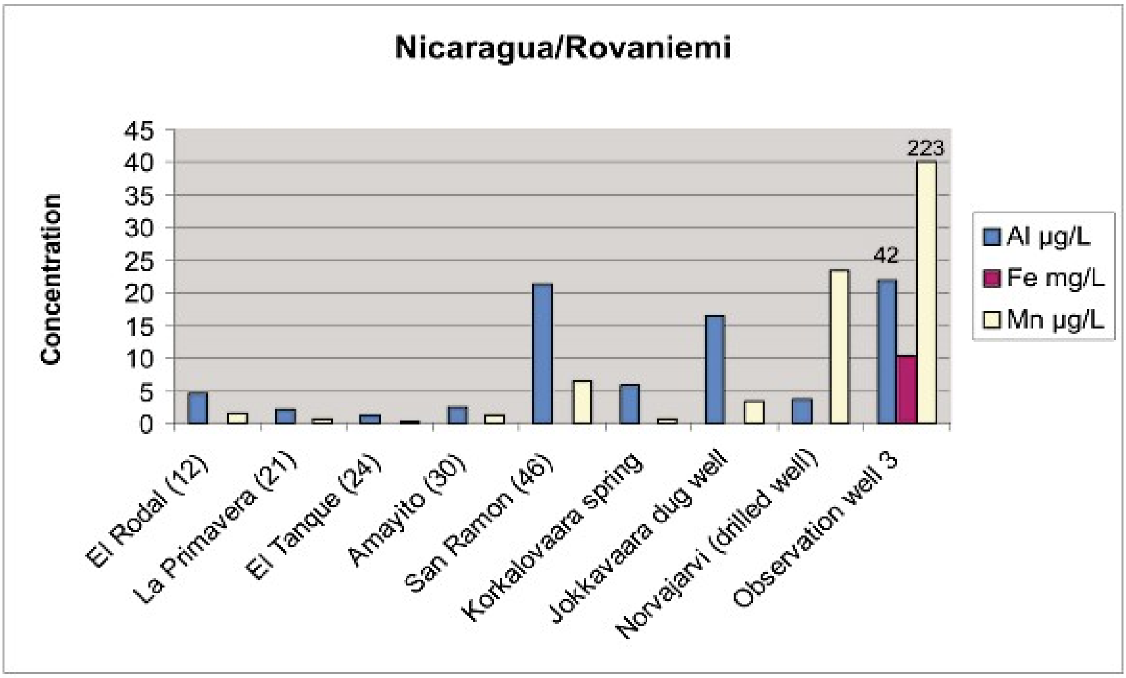


Fig. 53. Concentrations of chloride, nitrate, sulphate, copper, nickel and zinc in groundwater at selected sites in Nicaragua and in the Rovaniemi district.



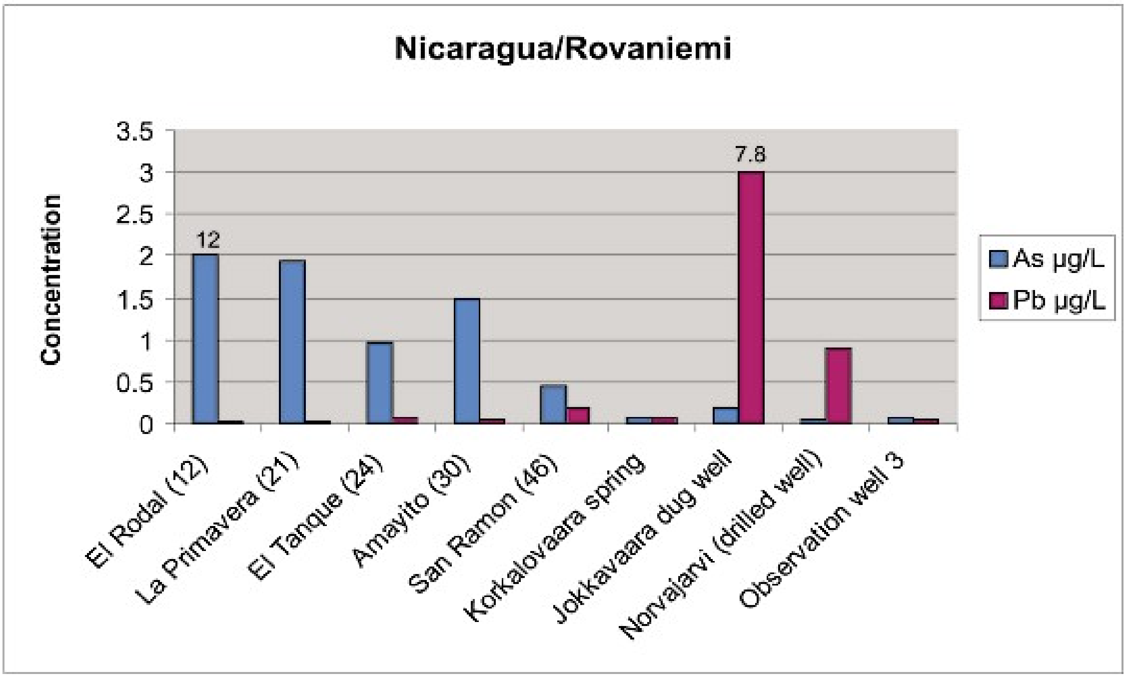


Fig. 54. Concentrations of aluminium, iron, manganese, arsenic and lead in groundwater at selected sites in Nicaragua and in the Rovaniemi district.

The accumulations of weathering products to be seen in Nicaragua mostly represent the local bedrock, whereas the Rovaniemi district does not possess any old deposits of this kind, as they were eroded and transported away during the last glaciation. Ancient deposits of weathering products frequently contain expanding lattice clay minerals that are efficient binders of cations and toxic chemicals. The possibilities for using smectite and the other clay minerals for treating polluted water or soil have been explored to some extent, and it has been proposed that smectite clay could be used as an alternative to activated charcoal in cases of dioxin pollution, for instance, on account of its weak ion bonds (Andrews et al. 1996). Thus the mineral composition of the clays is important from the point of view of the binding and transport of exogenous substances.

The cation exchange capacities of the illites, for instance, increase as they are further weathered to vermiculite or smectite (Moore & Reynolds 1989). The cation exchange capacities in Tisma and Diriamba were 24-45 mE/100 g, while in León-Posoltega and Santo Tomás they were smaller (Table 14). Birkeland (1974) places the cation exchange capacity of smectite at 80-100 mE/100 g (dry wt.). The zeolites are also efficient at adsorbing ions and organic molecules. The clays found in Finland have cation exchange capacities in the range 10-30 mE/100 g (Soveri 1950), on account of the fact that the weathering of their minerals has not yet advanced to the expanding lattice stage. Most investigations show that a substantial proportion of the minerals in Finnish Quaternary clays belong to the mica or hydromica group, the latter comprising illite and mixed lattice minerals formed by micas and hydromicas (Romu 1980).

Cation exchange on the surfaces of soil particles is the principal buffering process in the humus and eluvial horizons (Boyle & Voigt 1973, Petersen 1976, Evans 1980, Brady 1984, Andersson 1988), and exchangeable cations are of significance because these reactions lead to the formation of other substances. Cation exchange is most pronounced in the organic soil horizon, from which basic cations are transported to the lower deposits and into the groundwater (Räisänen 1989b). The cation exchange capacity is influenced by pH, grain size, moisture content and organic matter content of surficial deposits, and the mobility of exchangeable cations is also affected by the amounts of clay minerals and their properties, the degree of weathering of the silicate minerals and the amounts of organic compounds and their adsorption properties (Melkerud 1983). Cation exchange in a mineral soil takes place chiefly in the fine fraction, where the specific surface area is high, and it is less pronounced overall in coarse-grained deposits, although it may be promoted by the presence of organic matter (Rose et al. 1979).

Toxic substances can be bound efficiently by a soil with a large specific surface area. The humus horizon can have a specific surface area as large as 800 m^2/g, giving it a high binding capacity. The binding of elements in soils can alter, however, if the soil undergoes physical or chemical changes, e.g. as a consequence of forest ploughing, ditching, acidification or liming (Lodenius 1993). Specific surface areas for the fine fraction of till in Finland are small compared to those in Nicaragua varying in the range 3.75-34.06 m^2/g, with a mean of 10 m^2/g (Vallius 1994). The tills of the Rovaniemi district contain a moderate fines fraction, but its specific surface area is low and the clay content minimal (Lintinen 1995). The specific surface areas in Nicaragua varied in the range 15-124 m^2/g.

Almost all the samples of surficial deposits from Nicaragua had been taken from the depths of 5-60 cm, where nutrients are present in abundance, whereas the surficial deposits in the northern part of the León area are depleted in nutrients on the slopes of the volcano Télica, e.g. on the farm of La Hoyada, on account of erosion by floodwater and coarse material slipping down from the upper slopes to bury the fertile cultivated horizon. Considerable alterations brought about by erosion are also to be seen in many other areas in Nicaragua.

The surficial deposits of Nicaragua contain an abundance of soluble cations, e.g. calcium was also more abundant in the samples in Tisma, León and Diriamba than in the Rovaniemi district, often by a factor of ten (after aqua regia or nitric acid extraction), while the concentrations at Santo Tomás were of the same magnitude as in Finland. Concentrations of soluble cations in Nicaragua vary somewhat with depth, but no impoverishment of the surface horizon is found that is comparable to the situation in Finland. This was observed in the section examined in the bed of the Río Télica, for example. Analyses from Nicaragua showed the pH of surficial deposits in Nicaragua to differ from the situation in Finland, where the surficial deposits are predominantly acidic, pH 4-5 in the humus and eluvial horizons and usually increasing with depth (Räisänen 1996).

Under Finnish conditions the surface soils easily become depleted in soluble nutrients, whereas aluminium, iron and manganese have accumulated in the illuvial horizon. Aluminium concentrations in Nicaragua were notably high relative to those recorded in the Rovaniemi district, reaching several percent in places (aqua regia and nitric acid extractions), where the latter were no more than a few hundredths of a percent. In general aluminium can be regarded as a poorly soluble element under tropical conditions and one that becomes enriched in clayey weathering products such as laterites and bauxites (Koljonen 1992). The majority of the aluminium that is mobile in surficial deposits or finds its way into water will have leached out of soil horizons, river bed sediments or aluminium precipitations that have become attached to the surfaces of aquatic plants (Nilsson & Bergkvist 1983, Henriksen et al. 1988, Driscoll 1989). The clays of the Santo Tomás area are rich in aluminium and the clay-rich deposit of weathering products is used for making bricks. The Nicaraguan samples also showed high iron and manganese concentrations.

Titanium, which is also characteristic of laterite, is present in greater abundance in Nicaragua than in Finland. After ammonium acetate extraction, however, the concentrations of aluminium, iron and titanium were lower in Nicaragua than in Finland, on account of the pH levels used, a neutral solution, pH 7, in Nicaragua, as this corresponded best to the neutral trophic status of the soil, and pH 4.5 for the Finnish samples.

Outstanding features of the Rovaniemi district

The northern part of the Rovaniemi district belongs to the acid granitoid region, where till is poor in most of the main nutrient elements, and their concentrations are for this reason low in the groundwater. These rock types in northern part frequently have small molybdenum mineralizations associated with them (Koljonen 1992), and it is also known that areas with molybdenum anomalies characteristically have high fluoride concentrations (Lahermo et al. 1996). The groundwater in the bedrock drilled wells and in the observation wells had higher molybdenum concentrations than the other sampling sites and the maximum fluoride concentration was also in a drilled well. The southern part also consists of acid rocks, mostly of schists and mica schists, which are resistant to weathering. The composition of the unconsolidated sediments can be generalized to provide an indication of the composition of the bedrock, particularly in areas with easily weathered rocks.

The Quaternary deposits of the Rovaniemi district are largely composed of a sandy basal till which is relatively easily permeable to meltwater and rainwater. The amounts of elements dissolved in the groundwater of till areas can be affected in some extent by the amounts and composition of the fine fraction of the till that has been derived from the bedrock by weathering. The fine till fraction in Finland characteristically contains quartz, feldspar, amphibole, chlorite, illite, vermiculite and other clay minerals (Soveri & Hyyppä 1966, Räisänen et al. 1992) and represents a mixture of interstadial and interglacial weathering products (Soveri & Hyyppä 1966).

The tills of the Rovaniemi district contain less fines fraction than those of the ice divide area of Central Lapland, where the highest proportions of this fine material to be found anywhere in the north of the country is just under 40 % (Lintinen 1995). The low proportion of fines in the till in Rovaniemi is due to the minimal amounts of weathering products contained in it. These fines have little effect on the quality of the groundwater, however, for the concentrations of dissolved substances in samples from Tankavaara, north of Vuotso in Sodankylä, are low, e.g. calcium 2.6 mg/L, magnesium less than 0.02 mg/L, sodium 1.8 mg/L and potassium less than 0.5 mg/L. Concentrations in the water of wells in the till and sand areas of Vuotso are similarly low. A more significant factor from the point of view of solubility at this area would seem to be the groundwater flow velocity.

The groundwater of the Rovaniemi district is slightly acidic, representing the average situation in Finland as a whole, and the rainwater is likewise acidic and the pH lower than in Nicaragua. This will affect the acidity of the water recharging the aquifers to some extent, although this gravitational water will in any case mix with the pore water before infiltrating the groundwater reserves. Other reasons for groundwater acidity are the resistance of the acidic rocks against to weathering and acidifying airborne sulphur and nitrogen depositions. Element concentrations in the groundwater of the Rovaniemi district are for the most part lower than the average for Northern Finland or for the country as a whole, also on account of the mainly acidic bedrock and its resistance to weathering, and little influence of the composition of either the bedrock or the unconsolidated sediments on water quality can be detected. Also, some elements exist in the area principally in the form of poorly soluble compounds.

Another reason for the low concentrations reported here lies in the fact that the majority of the samples represent springs, where the groundwater residence time is short. Little impact of human activity is to be seen in the quality of the groundwater, although sulphate, chloride and nitrate concentrations in the water of a spring on the hill of Korkalovaara in Rovaniemi are higher than is normal for springs in a natural state in Northern Finland. Although the spring is located on the lower slope of a densely populated hill, the anomalously high concentrations may equally well be attributable to discharge of the water through fractures in the bedrock.

An exception to low concentrations concerns the high aluminium, iron, manganese and radon concentrations in the bedrock fracture zones. They are not caused, however, directly by the composition of bedrock and surficial deposits, but rather by the composition of the aquifer. The high concentrations observed at a few points may be attributed in the case of iron and manganese, at least, to the prevailing redox conditions (Lahermo 1991b). The high concentrations of dissolved iron in anoxic conditions were shown in the observation well 3, where the water discharged at the ground surface is clear and colourless but iron is precipitated as oxygenation takes place (Fig. 27). The reducing conditions in the same well were revealed by smell of hydrogen sulphide in the water. Even quantities of 0.5 mg/L of hydrogen sulphide can be distinguished in cold water by their smell (Driscoll 1986). Hydrogen sulphide is a toxic gas that is formed upon the reduction of sulphates, which can in turn enter groundwater through the oxidation of pyrite, FeS_2, leaching from gypsum, deposition in acid rain or distribution in fertilizers. Ancient sedimentary rocks are frequently rich in pyrite (Appelo &

Postma 1996).

The solubility of aluminium in the Rovaniemi study areas is promoted by the acid water that results from weathering of the sulphide minerals contained in some rocks. One factor contributing to the high aluminium concentrations in the observation wells in the bedrock fracture zones is water percolating into the aquifers from acid, paludified deposits and carrying organic matter with it. These deposits cause aluminium to dissolve and be transported in the groundwater. It was significant in the present survey that aluminium concentrations in the observation wells declined markedly after the first sampling. Surveys of surface water quality in the Kuusamo and Pudasjärvi areas have pointed to a distinct correlation between aluminium concentrations and organic matter (Näpänkangas 1995).

Aluminium occurs in insoluble form in neutral or slightly acid surficial deposits (Bache 1974, 1985), but can dissolve and be transported with water percolating into the soil at lower pH (Olson 1988, Bain et al. 1990). In the bedrock it is mostly found in the form of virtually insoluble silicates. It is claimed by Perttunen et al. (1996) that mica gneisses that are rich in aluminium are to be found in the Pöyliöjärvi Formation in the Rovaniemi district and that these may influence the quality of the groundwater. The bedrock samples from sites of observation wells 6 and 7 also represent mica schist and mica gneiss, and the maximum aluminium content of the groundwater sample from site 7 is 250 µg/L. The mica gneisses of the Rovaniemi area also have a higher than average iron content (Perttunen et al. 1996), and are probably partly responsible for the high iron concentrations in the groundwater.

Of the granite area sites, observation well 4, in the Poikajärvi-Latvajärvi crush zone, had higher than average concentrations of both uranium and radon, and well 3 a significant radon value. Uranium is commonly found in granites and migmatites (Lahermo & Juntunen 1991) and is the principal source of radon and other radioactive substances occurring in water. It is claimed by Salonen (1994) that radioactivity is ten times higher on average in the water of wells drilled into bedrock than in surficial groundwater, but even so, Gustavsson et al. (2001) quote a figure of no more than 0.74 µg/L for the mean uranium content of drilled wells in Finland. Uranium can leach out of weathered granite and be transported into the groundwater in the form of dissolved uranyl ions (UO_2^{2+}). These can in turn bind to the surfaces of mineral grains and clay minerals contained in glacial sediments and weathering products in reducing conditions (Langmuir 1978, Bradshaw & Lett 1980, Rose & Wright 1980, Peuraniemi & Aario 1991). It is maintained by Peuraniemi and Aario (1991), however, that most of the uranium in till and sand is only weakly bound but that in the weathered crust is more tightly bound. Certainly the presence of substances leached out of the fractured porphyric granite in the area of Rovaniemi Airport is reflected in elevated radon values for spring water (Perttunen et al. 1996), the maximum recorded being 920 Bq/L, where values for springs are normally well below 100 Bq/L.

High uranium and radon concentrations in groundwater usually coincide, but there are also many cases in which vastly different concentrations have been measured in drilled wells located close together (Juntunen 1991). This is true in the Poikajärvi-Latvajärvi fracture zone, for instance, where observation wells 3 and 4, located only 40 m apart, had radon concentrations of 1600 and 1780 Bq/L whereas wells 2 and 5, only 300 m away, had less than 30 Bq/L. Uranium concentrations at these sites were in the range 0.01-2.7 µg/L. The high radon concentrations are due to the uranium contained in the minerals of the granite bedrock. Examination of the thin section for coring site 4 suggests that the uranium at that point is contained in apatite, which may thus be the original source of the radon. Apatite grains were also identified in the bedrock samples from coring sites 7-10, even though radon concentrations there were fairly low. Apatite also contains fluorine, which can dissolve in groundwater.

Concentrations of dissolved substances and heavy metals were in the groundwater observation wells in bedrock fracture zones lower than the averages for drilled bedrock wells in Northern Finland as a whole, and this is also reflected in the electrical conductivity readings. The figures are similar to those recorded for wells in surficial deposits but higher than those for natural springs. Both the mean and the median for the groundwater samples in the present observation wells were 6.7. The mean pH of the water in wells drilled into the bedrock varied in the range 6.1-7.7, the mean for the whole of Finland being 7.1. (Tarvainen et al. 2001, Lahermo et al. 2002). The water in the observation wells represents ground-water in a natural state, as there is no human activity in the areas concerned other than the presence of forest roads. The main factors affecting water quality in the observation wells are the geological and geochemical properties of the bedrock and Quaternary deposits, redox conditions and the residence time of the groundwater.

An attempt was made in the Poikajärvi-Latvajärvi area (observation wells 1-5) to determine whether the aluminium, iron, manganese and copper concentrations were correlated with concentrations in the soil, and their relative solubility, i.e. their solubility in an ammonium acetate solution, pH 4.5, relative to that in aqua regia, was studied on the basis of samples taken from the unconsolidated sediments close to the bedrock surface. No correlation was observed between the concentrations of these elements in the groundwater and in the corresponding samples of Quaternary deposits, however, presumably because of the acidic bedrock and its resistance to weathering.

The concentrations of most elements and anions in the water of three wells drilled into the bedrock in the Rovaniemi area were of approximately the same magnitude as those in the bedrock groundwater of Northern Finland as a whole, but many times greater than those in the surficial deposits as a result of slow turnover of the bedrock groundwater. The water of the deepest drilled well examined here (150 m), which is located in the same bedrock fracture zone as the observation wells 1-5, contained 2.4 mg/L fluoride, 42.8 µg/L uranium and 774 Bq/L radon, and a high value for radon was also obtained in a drilled well at Olkkajärvi, 1690 Bq/L.

An older set of groundwater investigations in the Rovaniemi area, dating from the 1970s, when 155 water samples were analysed in connection with Quaternary mapping, suggest that the area characteristically has more acid groundwater than is normal for Finland as a whole and that considerable iron and manganese concentrations are to be found in it. The influence of settlement was reflected in higher than average nitrate and potassium concentrations, and high uranium concentrations were recorded then, too, in a drilled well at Olkkavaara (map sheet 3612 11), 1150 µg/L, and in two drilled wells near Apukka, 14 µg/L and 19 µg/L. Further analyses performed later the same year gave figures of 2500, 41 and 9 µg/L for the three wells, respectively. On the other hand, a set of 10 springs and dug wells in the same area all had uranium concentrations below 1 µg/L (Kujansuu et al. 1982).

Many of the eskers in the Rovaniemi region are used both for pumping groundwater and for extracting sand and gravel which may affect the groundwater quality. The Kroopinpalo esker has been used extensively for the extraction of sand and gravel, over 30 % of the area being used for this purpose in the early 1990's, but extraction was discontinued and the gravel pits landscaped when the groundwater pumping station was set up there in 1994.

It was estimated in the late 1980s that the Jokkavaara esker contained some 53 million cubic metres of extractable sand and gravel (Johansson et al. 1989). The gravel pit in Jokkavaara accounted for less than 10 % of the area of the formation in 1994 and had extended by a few percent by 2001. It is probable that even now the protection zones left around the groundwater pumping stations successfully prevent the extraction of material from affecting water quality. The groundwater pumping station in this esker provides water for both the city of Rovaniemi and its rural district.

The highest lead and arsenic concentrations of all the groundwater samples in the Rovaniemi district were in the dug well in Jokkavaara, in the sandy area near the esker formation, even though the arsenic concentration was less than 1 µg/L. The groundwater at a site at Kumpuselkä in the Kiiminki schist belt close to the city of Oulu, which has been reported to contain high concentrations of copper, zinc, lead, nickel and cobalt, is known to coincide with a mineralization characterized, among others, by chalcopyrite, sphalerite, galena and nickel-cobalt arsenides (Roman & Peuraniemi 1999, Roman et al. 2000, 2001). It is not known any more precisely whether the bedrock of Jokkavaara may contain galena or arsenides, which would naturally explain the high lead and anomalously high arsenic concentrations in the well water.

Rovaniemi City Council has had a groundwater pumping station on Kolpeneenharju, part of the northern esker chain in the map sheet area, since 1959. High iron and manganese concentrations were recorded in its water in the 1960s, around the time when the water level in the River Kemijoki was raised by damming of its lower course, and the high values were attributed to either excessive extraction volumes or changes in the directions of groundwater flow brought about by the damming and the rise of water level of the river. Flood plain deposits from rivers frequently contain iron and manganese compounds, and these are to be found at the rivers Kemijoki and Ounasjoki in the Rovaniemi area. Also the groundwater on the edges of the esker is poorly oxygenated or virtually anoxic, on account of the peat and gyttja-clay deposits contained in the surrounding mires, and this is apt to promote the dissolving of iron and manganese from the soil and bedrock. Similarly, according to borings made by the foundation geology office of Oulujoki Oy in the 1960s, the esker was laid down in a deep depression or fracture zone in the bedrock, and it is therefore likely that water flows into it from the surrounding areas and via bedrock fractures and crush zones (Hyyppä 1966). Relatively high iron and manganese concentrations were also found in the water of Kolpeneenharju in the 1980s and 1990s as a consequence of too excessive extraction of water relative to the size of the aquifer.

One barrier to exploitation of the groundwater reserves in the Tavivaara esker is the existence of a cemetery in the area, although this cannot be demonstrated to have had any effect on water quality, as the maximum phosphorus concentration recorded is no more than 0.02 mg/L, for example. The majority of the esker of Hietavaara is located south of the Rovaniemi map sheet area. This formation has been used extensively for sand and gravel extraction. The Mellavaara and Mäntyvaara eskers have been used for sand and gravel extraction and they also have exploitable groundwater reserves. The Mäntyvaara esker was also found to contain high concentrations of iron, but concentrations of the other dissolved substances and heavy metals there and in the other eskers and also in till areas were in the main low.

Comparison of groundwater quality between the till and sand areas showed the differences to be small as far as most of the dissolved substances were concerned, but the mean pH of well water in sandy deposits was higher than in the wells in till areas. It was noticeable that the concentrations of many dissolved substances were very similar in the wells and springs of the till areas, a feature partly attributable to the fact that eight of the ten wells examined in such areas had been created by deepening natural springs and lining them with concrete rings in six cases or wooden frames in two. On the other hand, alkalinity, bicarbonate, calcium, sodium, potassium, boron, copper, rubidium and strontium were slightly lower in the springs of the till areas than in the dug wells, on account of the shorter groundwater residence time in the former. The groundwater of Quaternary deposits in the Rovaniemi district differs somewhat from the mean quality for Northern Finland in general in that electrical conductivity, sulphate, chloride, magnesium and nickel were lower on average, and in till areas also bicarbonate, calcium, copper, manganese, lead and zinc concentrations were lower, while sodium was higher (Table 6). This also concerns the concentrations of these anions and elements in the whole country. The differences of the element concentrations between the Rovaniemi region and Northern Finland, as well between Rovaniemi and all Finland, are not big (Lahermo et al. 1990). The concentrations of sulphate, chloride and nitrate have the biggest differences between the Rovaniemi region and all Finland. The mean and median aluminium concentration was in sandy areas higher in Rovaniemi than in Northern Finland (Table 7).

Most of the sampling sites in till areas were springs with short residence time with low concentrations of dissolved substances. The residence time in fracture zones in the bedrock is also short, and this is reflected in the low concentrations of dissolved substances in the samples from the observation wells, except high aluminium, iron and manganese concentrations.

The relatively thin Quaternary deposits to be found in Finland on average can easily entail a risk of groundwater pollution, but the danger is less in the case of bedrock groundwater. On the other hand, the shorter residence time of esker aquifers means that pollution can be eliminated relatively quickly, whereas the turnover of bedrock groundwater is slower and the time required for recovery from pollution is longer. The best situation exists in large eskers, where the surficial deposits themselves are so thick that pollutants cannot easily infiltrate into the aquifer.

Outstanding features of the situation in Nicaragua

The principal factors affecting groundwater quality in Nicaragua are the composition of the bedrock and of the unconsolidated sediments with volcanic material and alluvial deposits in the lowlands, the high degree of weathering of the material, interaction between water and weathered material, and the neutral conditions and high nutrient content of the surficial deposits. The effect of weathering products on the concentrations of elements in the groundwater is not great, however, all the time neutral conditions prevail and the present surface horizon has in some places become depleted in nutrients as a consequence of long-term cultivation or erosion. The unweathered bedrock surface lies at a considerable depth in most parts of Nicaragua. The observations of this surface in connection with the present survey were made at Santo Tomás. These soluble nutrients, chiefly calcium, magnesium, sodium and potassium, are derived from the weathered material and airborne volcanic depositions together with erosional material transported by winds and water and redeposited material.

The amounts of nutrients present, the humus content of the soil and proportions of well-weathered clay minerals in their surficial deposits, causing the cation exchange capacity, in the agricultural areas of Tisma and Diriamba are higher than in the León district, where the fertile tilled horizon has been removed by erosion in many places. This means that the soils of the Tisma and Diriamba areas are better able to bind toxic substances compared to the León district, where large amounts of soil material, and with them soluble cations and also toxic substances, are transported to the lower-lying areas ending up at the estuaries of the rivers and the sea, and also into the groundwater especially during the rainy season each year. Thus pollution from organic chlorine compounds has been reported previously in the estuaries of the León and Chinandega areas and toxic residues have been found in the tissues of marine organisms (Lacayo et al. 1997). Some substances are known to be mobilized under markedly alkaline condition. Trace element concentrations in the mountainous area of Santo Tomás were mostly lower than in the other areas studied in Nicaragua. The binding capacity of clay minerals is high, so that nutrients can be bound in the soil, and also toxins, which in turn serves to retard pollution of the groundwater.

The neutral trophic status of the surficial deposits in Nicaragua prevents the dissolving of detrimental aluminium and its transport into the groundwater, but such an effect would be conceivable if acidity conditions were to alter considerably. Silicon is more soluble than aluminium or iron, for instance, under tropical conditions, so that this element tends to be depleted in surficial deposits. The silica concentrations in the groundwater of Diriamba-La Trinidad were considerably higher than in the other study areas (Table 9, 11, 14 and 15). Silica enters the environment through weathering natural sources being more important than anthropogenic effects (Reimann et al. 1998). The neutral or slightly alkaline groundwater in Nicaragua may occasionally be effected by the main short-term factors likely to cause acidification of the soil or groundwater being acid rain caused by volcanic eruptions. The areas of León-Posoltega and Diriamba-La Trinidad are located near the sea, but e.g. concentrations of chloride or sodium did not differ much from those in the Tisma and Santo Tomás-La Libertad areas, whereas the sulphate concentrations were higher in the areas of León-Posoltega and Diriamba-La Trinidad.

The highest incidence of shallow, polluted wells was found in the Tisma, León and Posoltega areas, where the lack of sewerage facilities and the pasturing of cattle in the yards around the houses are common. Most of the wells were also poorly protected against contamination, and nitrate, chloride and sodium compounds, and bacteria and toxic substances were able to enter them from the surface water. Faecal coliform bacteria, which are large in size, 3-10 mm in diameter (Brush 1997), can pass into the groundwater most easily through coarse-grained alluvial deposits. The León area is a low-lying coastal plain, where pollution problems are compounded by the flooding and erosion caused by the annual rainy season, and the lower parts of the Tisma area are exposed to similar risks.

In the Tisma area the impact of human activity is reflected in the relatively high nitrate and manganese concentrations in the water of the shallower wells, the nitrate being derived from polluted surface water and the manganese e.g. from fertilizers and from weathering of the bedrock. High sodium, potassium, arsenic and boron concentrations are probably of anthropogenic origin. The concentrations of heavy metals were low and frequently below the detection limit. Vanadium reached levels of several hundred microgrammes per litre which are high figures by comparison with those recorded in Finland. Some wells also gave relatively high results for arsenic and lead, the highest lead concentration being 14 µg/L.

In the areas of León and Posoltega evidence of pollution through human activity was also obtained in the form of high nitrate concentrations in places, especially in shallow wells which were open to contamination by surface water through runoff or infiltration. High counts were obtained for total and faecal coliform bacteria in most wells, water quality being best in the drilled wells serving as sources for municipal water supplies. The physico-chemical properties in the three surface water samples from the León-Posoltega area were broadly similar to those in the well samples.

The climatic conditions in Nicaragua create a favourable environment for bacteria. Measurements carried out in Nicaragua showed the groundwater temperatures in wells to be in the range +25 ... +37°C, with the majority of readings concentrated in the interval +25 ... +30°C, which is also the principal statistical range for air temperatures in that country (JICA & INAA 1993). It is also known that geothermal heat causes groundwater temperatures to rise about 0.6°C for every 30 metres of depth (Driscoll 1986).

The groundwater and surface water samples in Diriamba had low heavy metal concentrations, but turbidity caused by suspended solids detracts from the quality of the surface water. Again toxic residues were to be found in the water samples and surficial deposits and high coliform bacteria counts in the wells and rivers. The montane location of Diriamba means that the effect of surface water in rainy seasons is not so marked as near the flooding low coastal area. General hygiene, lack of sewerage facilities and the shortage of composting sites are problems here, too, however, together with the traditional customs of depositing waste water and other refuse in the rivers. Considerable quantities of waste water and rubbish are transported into the Río Grande from the direction of Diriamba by its tributaries, and the Río La Trinidad receives loading from the village of the same name and from other centres of population on its upper course. No properly organized refuse tips exist in the area.

Observations of fish and shrimp deaths in the rivers had been reported in Diriamba, for instance, and although few cases of human poisoning had come to light, statistics pointed to a high incidence of kidney disease. No investigations had been conducted into any possible link between diseases and the use of pesticides or other toxic chemicals, however. Many of the wells in the Diriamba area as in many other areas dry up during the dry season of the year, from December to May, and the agricultural areas suffer from a shortage of irrigation water in many places. People have to use then river water, which was said in the interviews to cause skin problems. The problem in agriculture could be reduced, for example, by increasing the numbers of tanks for collecting rainwater.

Very little in the way of earlier data could be obtained from Diriamba, but some information on environmental problems was available from the office of the Salud Reproductiva y Empoderamiento de la Mujer (SILAIS, Reproductive Health and Women's Empowerment) organization, the local office of the Ministry of Health (Centro de Salud de Diriamba) and the Diriamba office of the national Ministry for the Environment (MARENA).

The dangers of pollution are great in the case of shallow wells and surface waters in all the study areas densely populated. The long-term use of toxic chemicals has also meant that their residues have been transported into the groundwater. The water obtained from deep wells is good, because the thick layer of unconsolidated sediments prevents pollutants from entering it. The seriously polluted Lago de Managua in the Tisma area has been shown to influence groundwater quality in the surrounding area in all probability (Plata et al. 1994). Interviews in the Tisma area also revealed that there had been a high incidence of poisoning in the area following the spraying of chemicals from the air. Serious efforts need to be made to protect the wells and prevent animals from approaching them, to arrange proper waste disposal and to improve general standards of hygiene. There are also serious risks in Managua, where several industrial plants near Managua conduct effluent into the crater lake Asososca, which is used as a source of water for the city (Bethune et al. 1996).

The community of Santo Tomás is suffering for lack of water with good quality. Water shortages are experienced especially in the dry season. Santo Tomás obtains its domestic water supplies from the Quipor reservoir, created by damming the rivers flowing down from the surrounding mountains, with additional water coming from four wells. The water is of good physico-chemical quality, but suspended solids cause problems at times, especially in rainy seasons. The water in the wells does not suffer from this problem, but the combined yields are no more than 130-330 m³/day and vary greatly between the rainy season and dry season, whereas the overall water requirement is about 2600 m³/day (INIFOM-AMUNIC 1997). Attempts have been made to drill new wells, but these have not provided sufficient water. Other solutions that have been proposed include extending the Quipor reservoir or conducting water from the Río Mico to a new purification plant that is planned for the area. The Río Mico has plenty of water in it all the year round, whereas the smaller rivers in the immediate vicinity dry up for part of the year, but use of its water presupposes a ban on the disposal of liquid and solid waste in it, and also prevention of the passage of waste water containing cyanide and mercury from the gold refinement processes into it.

In the volcanic areas of western Nicaragua interlayers with an extremely high hydraulic conductivity are to be found in places. These are alluvial deposits or channels formed by lava flows which may be of a porous, blister lava texture (Driscoll 1986). There are places in tropical areas with a sedimentary bedrock where deep drilled wells can yield thousands of cubic metres of water in 24 hours (Mälkki 1999). The research data available for Nicaragua are limited, and there may well be areas suffering from a serious shortage of water that in fact have good groundwater supplies. The mountain area of Santo Tomás has very little agriculture, in fact, and the quality of the groundwater is consequently better than in the other areas of Nicaragua studied here. One well locating near the gold mine area had an exceptionally high arsenic concentration, 35.9 µg/L. Arsenic is to be found in abundance in hydrothermal ores, in conjunction with these and precious metals, and its concentrations may also be thought of in general as being high in areas with rocks of volcanic origin that contain volatile substances.

The gold mines near Santo Tomás and La Libertad may cause problems in surface waters and surficial deposits. High concentrations of mercury and lead in the surficial deposits have been measured previously at Santo Domingo, close to La Libertad and to the sites where the gold ore is processed. The concentrations were as high as 4.8 mg/kg for mercury and 300 mg/kg for lead. Similarly, river water analyses have given results of 1.46 µg/L for mercury and 225 µg/L for lead. Lead has been found to persist in the sediments on the lower reaches of the river at a point 11 km from the source of pollution, and relatively high mercury concentrations have been measured in such sediments at a distance of 80 km (Rosén 1997). Mendoza (1997) also points to elevated mercury and lead concentrations in the surficial deposits, river bed and water. The surficial deposits of Santo Tomás are mainly composed of the weathering products of old lavas, while the river sediments are partly made up of sand and finer material removed from these weathered deposits by erosion and redeposited by the river.

Polluted groundwater represents a major risk to the health of humans and animals, as toxic substances are able to enter their bodies directly from drinking water or indirectly through plants that are harvested and used as human food or animal fodder. Persistent organic pollutants (POP) are the most harmful toxins in the environment and they can cause problems e.g. in breeding animals (http://www.vyh.fi/ympsuo/kemik/pops/paasivu.htm). DDT, aldrin, dieldrin and toxaphene are pesticides of this group and they were found in wells and samples of surficial deposits in Tisma, León-Posoltega and Diriamba together with other, less toxic pesticides. DDT, dieldrin and toxaphene have continued to be used in Nicaragua up to recent times and their residues have been identified also in human tissues. It is common in Nicaragua to mix toxaphene with other chemicals such as methyl parathion, ethyl parathion, malathion or DDT. Research has shown that it can also be transported in the air and can thus spread to lakes and rivers over a wide area and enter the food chain via fish populations (Saleh 1991). It was official banned as long ago as 1982. Interest in biological pest control methods has increased in recent years, and these are in use on some farms, but their spread is restricted by a lack of both information and capital.

The quality requirements and recommendations for domestic water supplies in most Central American countries are the same as those in force in Finland and the European Union with respect to water quality. Differences do exist, e.g. regarding the maximum permitted concentrations of cadmium and antimony, which are 50 µg/L in Central America (CAPRE 1994), but 5 µg/L in Finland. Similarly the limit for nickel is 50 µg/L in the CAPRE recommendations but 20 µg/L in Finland. The maximum permitted concentration of toxic chemicals in the EU is 0.1 µg/L for any one substance and 0.5 µg/L in total (Kolpin et al. 2000). Maximum permitted concentrations of certain individual toxic chemicals are laid down for domestic water supplies in Nicaragua, but these are lax relative to the EU regulations, and no maximum permitted total concentration is stated at all. The concentrations of one chemical, fenthion, in the most seriously polluted well in the León area exceed the limit for all toxic chemicals combined as laid down in the EU regulations.

A further serious problem for Nicaragua is erosion. The surface horizons of the cultivated land are frequently eroded and carried away by both wind and water, which both deprives the areas of fertile soil and deposits detrimental substances in the groundwater and surface water. The chemicals that are bound to the soil particles are frequently able to dissolve in the water as acidity conditions alter and are transported into the surface water and groundwater, reaching the groundwater more easily in areas with coarse grained deposits than in fine-grained deposits. The humus layer is important for the binding of detrimental substances, as demonstrated by the higher concentrations of toxic residues in the surface horizon than at greater depths in the Tisma area, for instance. The surface layer of the predominantly volcanic deposits of Tisma, León and Diriamba consists partly of ash, humus and volcanic weathering products. This kind of material is light and highly susceptible to erosion.

A further problem in the Tisma area is the existence of a hard talpetate layer close to the surface, which means that water permeability is very poor. Breaking up the talpetate horizon would do much to improve the penetration of water into the soil and surficial deposits, and would also release the abundant reserves of nutrients required for agriculture, notably calcium, magnesium, potassium and phosphorus (Kukkonen et al. 1995). On the other hand, the talpetate horizon in this area with a high annual rainfall contains less concretized carbonate than corresponding horizons in drier climates, as carbonates are readily leached out by the rain (Nimlos 1992).

The geological and geochemical features of the surficial deposits of Nicaragua represent both advantages and disadvantages as far as the state of the environment is concerned. The neutral deposits with their abundance of fine material and well weathered expanding lattice clays are able to retain toxins well and retard their passage into the groundwater, but this also means that the same substances are more likely to be taken up by plants and enter the food chain, and can also spread into the groundwater and surface water through the effects of erosion. Many such substances have the property of replacing nutrients through cation exchange reactions, causing the nutrients in the surface horizons to dissolve in the gravitational water and be transported into the groundwater, along with some of the toxins. The resulting polluted water and the presence of slowly decomposing organic environmental toxins represent major threats to health, as also do many of the heavy metals, which are capable of accumulating in the bodies of humans and animals.

As a consequence of protracted pollution of the environment, the binding capacity of the surficial deposits is no longer adequate to prevent toxic chemicals from passing into the environment, and the risk of groundwater pollution is enhanced further in the areas of recent lava flows by the sparseness of the vegetation and the lack of a humus layer. The danger of pollution is low, however, in areas where the groundwater table is deep, the gravitational water zone is compact and hydraulic conductivity is low.

SUMMARY

Geographical, climatic and geological distinctions, physical and chemical properties of the surficial deposits, differences in land use and in the environmental impacts of human activity can all be expected to give rise to variations in both groundwater and surface water quality between the Rovaniemi district of Finland and Nicaragua. The remarkable differences were the concentrations of anions (bicarbonate, nitrate, sulphate and chloride) and the soluble cations calcium, magnesium, sodium and potassium. The main reason for the higher nitrate, sulphate and chloride concentrations in Nicaragua lies in the infiltration of polluted surface water into the shallow wells. The cations occurred in greater abundance partly on account of geological factors and partly because of human activity. Soluble cations in the eluvial horizon of the podzol soil in Finnish conditions are transported with rainwater deeper into the ground in the gravitational water and enter the groundwater, especially in areas with thin Quaternary deposits, while the illuvial horizon prevents certain elements such as iron and manganese from being transported from the ground surface to such depths.

The pH values of rainwater which are lower in Finland than in Nicaragua also affect the geochemical reactions in the soil. The mineral composition of the bedrock affects the water chemistry, the effects being greater the finer-grained the till is and the longer the time over which the minerals have been able to react with the water. Nutrients are in Nicaragua mostly present in abundance, whereas the soil and surficial deposits of the Rovaniemi district are depleted in nutrients. The northern part of the study area in the Rovaniemi district belongs to the acid granitoid region, where till is poor in most of the main nutrient elements, and the southern part consists mostly of schists and mica schists, which are resistant to weathering.

The groundwaters in the Rovaniemi district were mostly calcium-bicarbonate type, slightly acid and electrical conductivities were smaller than those in Nicaragua, showing the smaller amount of dissolved electrolytes. The slightly acid groundwater represents the average situation in Finland as a whole. The main reasons for groundwater acidity are the acid rocks and their resistance against to weathering. A reason for the low concentrations reported here also lies in the fact that the majority of the samples represent springs, where the groundwater residence time is short, and little impact of human activity. In the Rovaniemi region some shallow wells and springs of natural state had anomalously high concentrations of sodium and potassium which is partly due to geological origin and partly to human impact.

The groundwater composition in Nicaragua

was generally calcium-bicarbonate type, but in the Tisma area sodium and potassium were dominant cations. Their concentrations were often high in shallow wells showing human impact and contamination. The groundwater samples of Santo Tomás represent both calcium-bicarbonate type and sodium-potassium-bicarbonate type. The groundwater in Nicaragua was neutral or alkaline on average and electrical conductivities were high compared to those in the Rovaniemi region.

Chemical and biological weathering are the main mechanisms of release from the bedrock under tropical conditions, whereas slow physical weathering is more powerful in cold and humid climatic situations in Finland. Weathering takes place more rapidly in Nicaragua than in Finland, and there are many old, thick horizons of weathering products which have a far higher buffer capacity than those in Finland. Ancient deposits of weathering products frequently contain expanding lattice clay minerals that are efficient binders of cations and toxic chemicals. The clays found in Finland have cation exchange capacities smaller than in Nicaragua on account of the fact that the weathering of their minerals has not yet advanced to the expanding lattice stage.

Elements can become dissolved in the groundwater more easily from the surficial deposits of Nicaragua, which contain larger amounts of heavily weathered material, than in those of Finland, although their solubility may be reduced somewhat by the neutral pH.

Concentrations of aluminium, iron and manganese, elements that are characteristic of volcanic areas and of the clayey weathering products and laterite soils to be found in tropical areas, were lower in the groundwater of Nicaragua than in the Rovaniemi district, but aluminium concentrations of surficial deposits in Nicaragua were notably high relative to those recorded in the Rovaniemi district. This indicates that these elements tend to occur in poorly soluble compounds under the neutral conditions prevailing in Nicaragua, but solubility increases in acid conditions. The high concentrations in the Rovaniemi district may be attributed in the case of iron and manganese, at least, to the prevailing redox conditions. The highest iron, manganese and aluminium concentrations in the Rovaniemi district were to be found in the bedrock fracture zones in anoxic conditions. The mica gneisses of the Rovaniemi area have a higher than average iron content, and are probably partly responsible for the high iron concentrations in the groundwater.

High iron and manganese concentrations are a common problem in groundwater in Finland. In the groundwater pumping station on Kolpe-neenharju high iron and manganese concentrations were recorded in its water in the 1960s, around the time when the water level in the River Kemijoki was raised by damming of its lower course, and the high values were attributed to either excessive extraction volumes or changes in the directions of groundwater flow brought about by the damming and the rise of water level of the river. Flood plain deposits from rivers frequently contain iron and manganese compounds, and these are to be found in the Rovaniemi area. Relatively high iron and manganese concentrations were also found in the 1980s and 1990s as a consequence of too excessive extraction of water relative to the size of the aquifer.

The solubility of aluminium in the Rovaniemi study areas is promoted by the acid water that results from weathering of the sulphide minerals contained in some rocks. One factor contributing to the high aluminium concentrations in the bedrock fracture zones is water percolating into the aquifers from acid, paludified deposits and carrying organic matter with it.

Arsenic concentrations in Nicaragua were higher than in Finland on average. The maximum concentration was near the gold mine area in La Libertad and is due to the bedrock. Arsenic can also enter the environment from fertilizers and agricultural chemicals. The highest lead concentration of all the groundwater samples in the Rovaniemi district was in the dug well in Jokkavaara, in the sandy area near the esker formation probably due to the composition of bedrock and Quaternary deposits. The vanadium concentrations were high in Nicaragua compared to those in Finland. Vanadium finds its way into the environment partly through weathering of the bedrock and partly in connection with volcanic eruptions. Vanadium bearing mafic rocks weather easily and its mobility is very high under neutral to alkaline conditions prevailing in Nicaragua. Barium and boron concentrations were more prevalent in the groundwater of Nicaragua on average than in Rovaniemi.

Concentrations of heavy metals like copper, zinc, nickel, lead, cadmium, cobalt, chromium, antimony and molybdenum and concentrations of beryllium, bismuth, litium, rubidium, selenium, silver, thorium, thallium and uranium were low, mostly below the detection limit both in the Rovaniemi region and Nicaragua. A few high zinc concentrations were found in wells of sandy deposits in the Rovaniemi district one of them being caused by human activity. Two drilled wells had high uranium concentrations in the Rovaniemi district. Uranium can leach out of weathered granite and be transported into the groundwater. High uranium and radon concentrations in groundwater usually coincide, but there are also many cases in which vastly different concentrations have been measured in drilled wells located close together. This was the case in the Poikajärvi-Latvajärvi fracture zone, for instance. The high radon concentrations are due to the uranium contained in the minerals of the granite bedrock. The uranium at that point is contained in apatite, which may thus be the original source of the radon.

The differences were small in groundwater quality between the samples from the sand and till areas in the Rovaniemi district. The reasons for this is the low proportion of fines in the till, insoluble compounds of elements and the fact that most of the sampling sites in till areas were springs with short residence time. It is also a reason for lower concentrations of dissolved substances in the springs than in the wells dug into the same kind of Quaternary deposits, while correspondingly, the higher concentrations in bedrock groundwater are the result of its slow turnover. The residence time in fracture zones in the bedrock is short, however, and this is reflected in the low concentrations in the samples from the observation wells, except high aluminium, iron and manganese concentrations.

The main factors affecting water quality in the Rovaniemi region are the geological and geochemical properties of the bedrock and Quaternary deposits, redox conditions and the residence time of the groundwater the effects of human activity being minor. The relatively thin Quaternary deposits to be found in Finland on average can easily entail a risk of groundwater pollution, but the danger is less in the case of bedrock groundwater. On the other hand, the shorter residence time of esker aquifers means that pollution can be eliminated relatively quickly, whereas the turnover of bedrock groundwater is slower and the time required for recovery from pollution is longer. The best situation exists in large eskers like Jokkavaara, Palovaara and Kroopinpalo, where the surficial deposits themselves are so thick and the groundwater table deep that pollutants cannot easily infiltrate into the aquifer.

Shallow, polluted wells were found in the Tisma, León and Posoltega areas, where the lack of sewerage facilities and the pasturing of cattle in the yards around the houses are common. Most of the wells were poorly protected against contamination, and nitrate, chloride, sulphate, sodium, manganese and toxic substances were able to enter them from the surface water. High counts were obtained for total and faecal coliform bacteria in many wells, water quality being best in the drilled wells serving as sources for municipal water supplies. Residues of pesticides, among other things DDT, aldrin, dieldrin and toxaphene, which are toxic, persistent organic pollutants (POP), were found in many wells and samples of surficial deposits. DDT, dieldrin and toxaphene have continued to be used in Nicaragua up to recent times and their residues have been identified also in human tissues.

The binding capacity of clay minerals in Nicaragua is high, so that nutrients can be bound in the soil, and also toxins, which in turn serves to retard pollution of the groundwater. The amounts of the humus content of the soil and proportions of well-weathered clay minerals in their surficial deposits, causing the cation exchange capacity, are high in Nicaragua and in the agricultural areas of Tisma and Diriamba higher than in the León district, where the fertile tilled horizon has been removed by erosion in many places. This means that the soils of the Tisma and Diriamba areas are better able to bind toxic substances compared to the León district, where large amounts of soil material, and with them soluble cations and also toxic substances, are transported to the lower-lying areas and also into the groundwater especially during the rainy season.

The community of Santo Tomás is suffering for lack of water with good quality. Water shortages are experienced especially in the dry season. Santo Tomás obtains its domestic water supplies from the Quipor reservoir, created by damming the rivers flowing down from the surrounding mountains, with additional water coming from four wells. The water is of good physico-chemical quality, but suspended solids cause problems at times, especially in rainy seasons. The gold mines near Santo Tomás and La Libertad have caused problems in surface waters. High concentrations of mercury and lead in water and the surficial deposits have been measured previously close to the sites where the gold ore is processed.

The principal factors affecting groundwater quality in Nicaragua are the composition of the bedrock and of the volcanic unconsolidated sediments, the high degree of weathering of the material, interaction between water and weathered material, the neutral conditions and high nutrient content of the surficial deposits. Human activities have caused pollution in many places. The effect of weathering products on the concentrations of elements in the groundwater is not great, however, all the time neutral conditions prevail. A problem in the Tisma area is the existence of a hard talpetate layer close to the surface, which means that water permeability is very poor.

The geological and geochemical features of the surficial deposits of Nicaragua represent both advantages and disadvantages as far as the state of the environment is concerned. The neutral deposits with their abundance of fine material and well weathered expanding lattice clays are able to retain toxins well and retard their passage into the groundwater, but this also means that the same substances are more likely to be taken up by plants and enter the food chain, and can also spread into the environment through the effects of erosion. Many detrimental substances have the property of replacing nutrients through cation exchange reactions, causing the nutrients in the surface horizons to dissolve in the gravitational water and be transported into the groundwater, along with some of the toxins.

The danger of contamination is low, however, in areas where the groundwater table is deep, the gravitational water zone is compact and hydraulic conductivity is low. The dangers of groundwater contamination in the Rovaniemi region are small relative to the situation in Nicaragua, even though the Quaternary cover is thin on average and the groundwater table mostly close to the ground surface.

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Appendix 1. Analyses and measurements made of the samples in the Rovaniemi study area. Samples of Quaternary deposits in drilling sites 1-10 in bedrock fracture zones (granulometric analyses, analyses of elements, determinations of minerals with X-ray diffraction, determinations of rock and minerals with polished thin sections).

Drilling site	Depth cm	Granulo-metric analysis	Analyses of elements, extraction with amm. acetate	Analyses of elements, extraction with aqua regia	Determ. of minerals, X-ray diffr.	Determ. of rock and minerals, polished thin section	Drilling site	Depth cm	Granulo-metric analysis	Analyses of elements, extraction with amm. acetate	Analyses of elements, extraction with aqua regia	Determ. of minerals, X-ray diffr.	Determ. of rock and minerals, polished thin section
1	200-230	x					6 E	15-20		x	x		
	270-300	x					6 B	40-45		x	x		
	340-350	x					6 C	75-80		x	x		
	330-350		x	x	x		6	90-100	x	x	x	x	
	740-750		x	x	x			190-200	x	x	x	x	
								390-400	x	x	x	x	
								490-500	x	x	x	x	
								890-900	x	x	x	x	
								1190-1200				x	x
2	120-130	x					7 E	15-20		x	x		
	230-250	x					7 B	38-42		x	x		
	260-300		x	x	x		7 C	50-55		x	x		
	360-400		x	x			7	90-100	x	x	x		
	490-500	x						190-200	x	x	x		
	590-600		x	x				290-300	x	x	x		
	690-700	x						490-500	x	x	x		
	790-800		x	x				690-700	x	x	x		
	1740-1750		x	x	x	x		790-800	x	x	x		
								1080-1090				x	x
3	70-90		x	x			8	290-300	x	x	x	x	
	200-230	x						390-400	x	x	x	x	
	250-280	x			x			590-600	x	x	x		
								690-700	x	x	x	x	
								790-800	x	x	x	x	

Appendix 1. cont.

								1080-1090				x	x
4	50-80		x	x			9 E	23-28		x	x		
	250-280	x			x		9 B	41-46		x	x		
	350-380		x	x			9 C	75-80		x	x		
	530-560	x					9	290-300	x	x	x		
	690-700	x						390-400	x	x	x		
	790-800		x	x				490-500	x	x	x		
	990-	x						920-930				x	x
	1000		x	x									
	1090-	x											
	1100		x	x	x								
	1390-				x	x							
	1400					x							
	1490-												
	1550												
	1740-												
	1750												
	1790-												
	1800												
5	110-120		x	x			10	190-200	x	x	x		
	150-160		x	x	x			290-300	x	x	x		
	150-180	x						390-400	x	x	x		
	690-700	x			x			490-500	x	x	x		
	790-800	x						690-700	x	x	x		
	890-900		x	x				740-750	x	x	x		
								930-940				x	x

Appendix 2. Sampling sites in Nicaragua.

Sampling site	Location	Position	Research year
1. River	Tisma, Río Tipitapa	12^{0}09’03’’N, 86^{0}02’07’’W	1994
2. Well	Tisma, Hato Grande	12^{0}09’07’’N, 86^{0}02’57’’W	1994
3. Well	Tisma, San Jerónimo	12^{0}07’57’’N, 86^{0}02’32’’W	1997
4. Corn field	Tisma, Santa Cruz	12^{0}07’07’’N, 86^{0}03’20’’W	1997
5. Well and chili field	Tisma, Las Conchas	12^{0}07’10’’N, 86^{0}02’10’’W	1997
6. Spring	Tisma, Las Conchas	12^{0}07’07’’N, 86^{0}01’48’’W	1997
7. Lake	Laguna de Tisma	12^{0}05’40’’N, 85^{0}59’22’’W	1994, 1997
8. Well	Tisma village	12^{0}05’00’’N, 86^{0}01’00’’W	1994
9. Well	Tisma village	12^{0}04’55’’N, 86^{0}01’00’’W	1994
10. Well	Tisma village	12^{0}04’57’’N, 86^{0}00’53’’W	1997
11. Well and corn field	Tisma, Noel Morales	12^{0}04’27’’N, 86^{0}00’15’’W	1994
12. Well and fallow field	Tisma, El Rodal	12^{0}04’02’’N, 86^{0}01’53’’W	1994, 1997
13. Well and corn field	Tisma, Cuatro Esquinas	12^{0}04’02’’N, 86^{0}01’52’’W	1997
14. Well	Tisma, El Espejo	12^{0}03’18’’N, 86^{0}01’43’’W	1997
15. Well and corn field	Tisma, 16 de Julio	12^{0}02’57’’N, 86^{0}02’25’’W	1994
16. Well and chili field	Tisma, La Montañita	12^{0}02’08’’N, 86^{0}03’32’’W	1997
17. Well and fallow field	León,La Hoyada	12^{0}35’22’’N, 86^{0}55’16’’W	1999
18. Well and corn field	León, Los Velásquez	12^{0}34’33’’N, 86^{0}56’23’’W	1999
19. Well	León, San Luis	12^{0}34’36’’N, 86^{0}56’40’’W	1999
20. Drilled well, field-forest plantation and corn field	León, La Trinidad, Pp 124	12^{0}34’36’’N, 86^{0}56’40’’W	1999
21. Well and peanut field	León, La Primavera	12^{0}34’10’’N, 86^{0}57’03’’W	1999
22. Well and cross sections of a road	León, Maria, de la Concección,	12^{0}34’10’’N, 86^{0}57’03’’W	1999
23. Well	León, Juan Ramón	12^{0}32’53’’N, 86^{0}56’00’’W	1999
24. Well and soybean field	León, Hayde Larios, El Tanque, Posoltega	12^{0}32’53’’N, 86^{0}58’50’’W	1999
25. Drilled well and pasture	León, Entre Ríos, Pp 122, Posoltega	12^{0}32’22’’N, 86^{0}58’46’’W	1999
26. Well, sugarcane and banana plantation	León, German Pomares	12^{0}31’13’’N, 86^{0}59’35’’W	1999
River	German Pomares, Río Posoltega	12^{0}31’13’’N, 86^{0}59’35’’W	1999
River	German Pomares, Río San Pablo	12^{0}31’13’’N, 86^{0}59’35’’W	1999
Well	German Pomares, La Casa	12^{0}31’13’’N, 86^{0}59’35’’W	1999
27. River and section of a river bed	León, Río Télica	12^{0}30’58’’N, 86^{0}51’55’’W	1999

Appendix 2. cont.

Sampling site	Location	Position		Research year
28. River and fluvial deposit	Diriamba, Río La Trinidad	$11^0$44’16’’N,	$86^0$20’10’’W	1999
29. Well, corn field and fallow field	Diriamba, San Helén, La Trinidad	$11^0$43’26’’N,	$86^0$19’22’’W	1999
30. Well	Diriamba, Amayito	$11^0$43’18’’N,	$86^0$19’12’’W	1999
31. River and fluvial deposit	Diriamba, Río Amayito	$11^0$43’10’’N,	$86^0$19’10’’W	1999
32. Cross section of a road	Santo Tomás, Puertas de Paris	$12^0$09’16’’N,	$85^0$10’37’’W	1997
33. Well	Santo Tomás, Jesus Maria	$12^0$08’05’’N,	$85^0$09’58’’W	1997
34. Well (new)	Santo Tomás, brick works	$12^0$03’56’’N,	$85^0$06’10’’W	1997
35. Well (old)	Santo Tomás, brick works	$12^0$03’56’’N,	$85^0$06’10’’W	1997
36. Gravel pit	Santo Tomás, raw material for brick works	$12^0$03’32’’N,	$85^0$06’57’’W	1997
37. Well	Santo Tomás, dumping area	$12^0$02’40’’N,	$85^0$07’57’’W	1997
38. Well	Santo Tomás, Santa Fé	$12^0$02’45’’N,	$85^0$07’27’’W	1997
39. Cross section of a road	Santo Tomás, Llano el Jobo	$12^0$02’45’’N,	$85^0$07’40’’W	1997
40. Well and cross section of a road	Santo Tomás, San Luis, Lóvago	$12^0$00’10’’N,	$85^0$10’05’’W	1997
41. River and fluvial deposit	Santo Tomás, Río Lóvago	$12^0$00’18’’N,	$85^0$09’58’’W	1997
42. River, fluvial deposit and cross sections of a road	Santo Tomás, San Juan, La Libertad	$12^0$03’27’’N,	$85^0$10’33’’W	1997, 1999
43. River, fluvial deposit and cross section of a road	Santo Tomás, Río Mico, La Libertad	$12^0$03’03’’N,	$85^0$09’57’’W	1997, 1999
44. River, fluvial deposit and bottom sand of a river	Santo Tomás, Río Mico, San Pedro de Lóvago	$12^0$07’30’’N,	$85^0$07’17’’W	1997, 1999
45. River and fluvial deposit	Santo Tomás, Río Mico	$12^0$05’14’’N,	$85^0$01’05’’W	1997, 1999
46. Well	Santo Tomás, San Ramón	$12^0$05’04’’N,	$85^0$03’06’’W	1997
47. Reservoir	Santo Tomás, Quipor	$12^0$03’19’’N,	$85^0$04’55’’W	1997

Appendix 3. Concentrations of elements (mg/kg) in samples of Quaternary deposits (till) in the Rovaniemi area: in the Poikajärvi-Latvajärvi fracture zone (drilling sites 1-5), in the Häkinvaara-Kalliovaara fracture zone (drilling sites 6 and 7) and in the Viiksjärvi fracture zone (drilling sites 8-10). The samples have been extracted with ammonium acetate and aqua regia (methods 201P and 512P). Bedrock samples have been analysed from the drilling sites 6-10.

	Drilling site 1				Drilling site 2									
	Depth 340 cm		Depth 750 cm		Depth 280 cm		Depth 380 cm		Depth 600 cm		Depth 800 cm		Depth 1750 cm	
	201P	512P	201P	512P	201P	512P	201P	512P	201P	512P	201P	512P	201P	512P
Ag		<1		<1		<1		<1		<1			<1	<1
Al	63.5	5390	56.2	5150	32.3	3990	16	1650	33	2650	68	4870	46.8	3040
As	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5
B	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5
Ba	14.6	38.0	12.9	35.9	12.0	31.5	3.1	10.7	5.6	18.5	12.9	46.0	3.1	16.3
Be		0.3		0.2		0.2		0.1		0.2		0.2		0.3
Ca	229	2230	200	2000	100	2390	80	1550	85	2030	131	2880	104	1390
Cd	<0.02	<0.5	<0.02	<0.5	<0.02	<0.5	<0.02	<0.5	<0.02	<0.5	<0.02	<0.5	<0.02	<0.5
Co	7.88	14.9	0.26	4.5	0.42	4.1	0.99	3.4	0.13	2.9	0.27	4.5	0.34	3.1
Cr	0.30	25.5	0.32	22.5	0.28	19.8	0.04	17.1	0.18	19.0	0.23	22.3	0.39	11.1
Cu	1.41	7.8	2.17	9.3	1.02	5.9	0.44	3.2	0.77	8.0	1.17	5.9	0.75	6.1
Fe	338	16200	282	15600	317	16900	26.2	10500	67	12900	267	16600	182	9400
K	92	1500	88	1400	27	900	<20	500	28	700	77	1200	33	700
Li	0.05	7.0	<0.05	7.2	<0.05	5.1	<0.05	2.8	<0.05	3.7	<0.05	4.8	<0.05	5.8
Mg	80.3	2990	73.4	2890	23.8	2140	19.5	1070	28.7	1590	47.7	2600	31.2	2200
Mn	14.30	137.0	17.30	139.0	6.17	99.9	0.26	52.3	1.31	75.6	9.97	118.0	3.44	93.3
Mo	<0.05	<1	<0.05	1.9	<0.05	<1	<0.05	<1	<0.05	<1	<0.05	<1	<0.05	<1
Na	13.0	220	16.0	200	7.0	120	7.5	90	19.1	190	21.9	330	21.6	120
Ni	0.43	8.7	0.46	8.0	0.33	6.5	<0.05	4.3	0.16	5.6	0.33	7.2	0.27	4.7
P	8.1	456	17.3	100	2.9	692	4.6	423	3.8	459	4.2	596	1.3	253
Pb	1.3	9	<0.5	6	1.1	6	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	5
S	7.5	76	10.5	100	11.3	85	0.6	10	12.0	65	21.8	247	164.0	608
Sb	<1.5	<15	<1.5	<15	<1.5	<15	<1.5	<15	<1.5	<15	<1.5	<15	<1.5	<15
Sc		2.3		2.3		1.8		0.9		1.4		2.2		1.4
Si	56	170	53	160	16	160	13	150	21	160	49	180	12	170
Sr	2.05	7.9	1.83	7.1	0.66	6.1	0.48	3.7	0.58	5.7	0.91	9.1	0.71	4.7
Th		17		12		12		8		13		18		18
Ti	0.44	891	0.39	852	0.80	857	0.39	497	0.33	703	0.29	970	0.55	588
V	1.32	33.6	0.72	31.9	1.52	37.2	0.08	23.6	0.22	28.9	0.27	35.4	0.33	17.7
Zn	0.56	15.1	0.49	15.1	0.41	12.2	0.13	5.7	0.15	8.5	0.47	13.1	0.21	12.2

Appendix 3. cont.

	Drilling site 3				
	Depth 80 cm			Depth 80 cm	
	201P	512P		201P	512P
Ag		<1	Mn	2.87	134.0
Al	218.0	8160	Mo	<0.05	<1
As	<0.5	<5	Na	8.1	150
B	<0.1	<5	Ni	0.12	9.1
Ba	12.2	35.0	P	2.6	672
Be		0.3	Pb	0.5	10
Ca	238	2480	S	5.1	47
Cd	<0.02	<0.5	Sb	<1.5	<15
Co	14.50	26.4	Sc		2.1
Cr	0.33	24.4	Si	18	170
Cu	0.24	7.8	Sr	2.03	8.8
Fe	328	23200	Th		12
K	34	1000	Ti	0.67	1080
Li	<0.05	7.6	V	0.10	45.1
Mg	58.9	2790	Zn	0.54	15.6

Appendix 3. cont.

	Drilling site 4										Drilling site 5					
	Depth 65 cm		Depth 365 cm		Depth 800 cm		Depth 1100 cm		Depth 1550 cm		Depth 110 cm		Depth 155 cm		Depth 900 cm	
	201P	512P	201P	512P	201P	512P	201P	512P	201P	512P	201P	512P	201P	512P	201P	512P
Ag		<1		<1		<1		<1		<1		<1		<1		<1
Al	264.0	7730	14.9	1670	58.3	5330	53.4	5230	87.7	8450	96.6	5790	18.4	1740	73.0	5820
As	<0.5	<5	<0,5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	0.5	<5
B	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5
Ba	14.8	39.2	316	11.4	12.1	37.2	9.8	36.3	2.7	51.9	14.2	48.1	13.8	33.4	4.5	12.3
Be		0.3		0.1		0.3		0.3		0.4		0.3		0.3		0.1
Ca	48	1610	45	1630	174	2590	147	2300	303	2540	131	2330	87	1600	150	2640
Cd	<0.02	<0.5	<0.02	<0.5	<0.02	<0.5	<0.02	<0.5	<0.02	<0.5	<0.02	<0.5	<0.02	<0.5	<0.02	<0.5
Co	0.94	5.2	3.46	9.0	0.23	4.5	0.21	5.6	0.78	7.7	0.32	5.0	0.91	6.8	0.87	3.5
Cr	0.71	22.3	0.08	15.2	0.26	24.3	0.27	25.5	0.48	35.6	0.45	27.2	0.19	22.9	0.04	16.0
Cu	0.40	6.6	0.50	5.3	1.86	8.7	2.40	20.2	1.68	14.7	1.62	9.3	0.35	8.1	0.28	3.3
Fe	305	16700	47	11700	263	16900	231	19100	580	21500	115	18200	22	11000	201	17400
K	<20	800	<20	400	73	1500	71	1600	42	1800	<20	900	<20	400	72	1700
Li	<0.05	6.4	<0.05	2.8	<0.05	7	0.05	9.2	0.07	11.8	0.06	7.5	<0.05	5.4	<0.05	2.4
Mg	9.4	2630	9.3	1020	52.6	2970	44.5	3180	74.3	4360	31.6	2470	16.8	1000	66.8	3340
Mn	0.59	87.0	0.60	60.6	15.80	141.0	12.80	163.0	22.40	179.0	1.06	125.0	0.39	52.3	6.19	130.0
Mo	<0.05	<1	<0.05	<1	<0.05	<1	<0.05	1.4	<0.05	1.6	<0.05	1.1	<0.05	<1	<0.05	<1
Na	4.8	130	7.9	100	18.9	270	27.3	240	17.5	160	7.1	140	7.1	110	25.7	310
Ni	0.07	8.1	<0.05	3.9	0.41	8.6	0.42	8.8	1.04	14.5	0.45	9.3	<0.05	6.7	<0.05	3.7
P	16.6	561	2.2	411	5.8	476	5.2	398	4.6	496	5.8	689	2.8	404	2.8	529
Pb	<0.5	8	0.7	6	<0.5	5	0.8	8	0.6	8	<0.5	6	<0.5	6	<0.5	<5
S	5.0	37	9.0	119	10.1	112	15.9	223	456.0	1480	2.5	15	0.6	<10	24.6	167
Sb	<1.5	<15	<1.5	<15	<1.5	<15	<1.5	<15	<1.5	<15	<1.5	<15	<1.5	<15	<1.5	<15
Sc		2.0		1.0		2.4		2.5		3.6		2.7		2.3		0.9
Si	21	190	10	150	50	170	44	180	18	190	28	200	13	150	53	190
Sr	0.57	6.3	0.30	4.6	1.49	8.2	1.25	7.4	1.56	8.8	1.15	9.8	1.42	7.9	0.66	4.5
Th		8		11		15		18		17		17		11		10
Ti	1.12	1030	0.60	566	0.39	966	0.46	1030	0.72	1270	0.60	1060	0.73	529	0.28	1060
V	0.30	39.3	0.33	26.0	0.62	34.4	0.48	33.8	1.17	44.9	0.22	36.8	0.05	38.8	0.06	24.1
Zn	0.24	15.8	0.13	6.2	0.67	15.3	0.52	20.1	1.58	25.3	0.07	12.0	0.08	5.6	0.45	18.2

Appendix 3. cont.

Drilling site 6

	E-horizon		B-horizon		C-horizon			E-horizon		B-horizon		C-horizon	
	Depth 15-20 cm		Depth 40-45 cm		Depth 75-80 cm			Depth 15-20 cm		Depth 40-45 cm		Depth 75-80 cm	
	201P	512P	201P	512P	201P	512P		201P	512P	201P	512P	201P	512P
Ag		<1		<1		<1	Si	3		22		139	
Al	64.2	720	474.0	5570	1020.0	7410	Sr	0.08	1.0	0.18	2.0	0.17	2.0
As	<0.5	<10	<0.5	<10	<0.5	<10	Ti	0.41	238	0.99	449	1.08	341
B	<0.1	<5	<0.1	<5	<0.1	<5	V	0.03	6.0	0.28	26.0	0.28	15.0
Ba	0.8	2.0	1.6	7.0	1.8	9.0	Zn	0.26	1.0	0.29	7.0	0.98	10.0
Ca	5	170	11	590	15	690							
Cd	<0.02	<1	0.03	<1	<0.02	<1							
Co	<0.02	<1	0.03	2.0	0.31	3.0							
Cr	0.03	3.0	0.43	14.0	0.94	17.0							
Cu	<0.02	<1	0.06	2.0	0.27	3.0							
Fe	9	2000	200	12000	178	8380							
K	<20	<200	<20	300	<20	500							
Li	<0.05		<0.05		<0.05								
Mg	2.0	170	3.1	1310	3.3	1560							
Mn	0.17	11.0	1.42	52.0	15.40	109.0							
Mo	<0.05	<2	<0.05	<2	<0.05	<2							
Na	3.4	<100	1.3	<100	3.5	<100							
Ni	<0.05	<3	<0.05	4.0	0.13	5.0							
P	1.2	<50	25.1	737	6.3	309							
Pb	<0.5	<5	<0.5	<5	<0.5	<5							
S	1.3	<20	11.1	49	20.9	47							
Sb	<1.5	<20	<1.5	<20	<1.5	<20							

Appendix 3. cont.

	Drilling site 6											
											Bedrock sample	
	Depth 100 cm		Depth 200 cm		Depth 400 cm		Depth 500 cm		Depth 900 cm		Depth 1190 cm	
	201P	512P	201P	512P	201P	512P	201P	512P	201P	512P	201P	512P
Ag		<1		<1		<1		<1		<1		<1
Al	401.0	4110	173.0	4350	28.7	5770	23.1	2300	40.5	11400	414.0	18900
As	<0.5	<10	<0.5	<10	<0.5	<10	<0.5	<10	<0.5	<10	<0.5	<10
B	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5
Ba	2.1	15.0	3.9	18.0	13.8	40.0	6.1	16.0	8.8	58.0	8.6	68.0
Ca	15	560	20	1050	129	2010	577	1160	234	1900	72.5	660
Cd	<0.02	<1	<0.02	<1	<0.02	<1	<0.02	<1	<0.02	<1	0.02	<1
Co	0.06	3.0	0.06	4.0	0.07	5.0	0.03	2.0	1.66	12.0	5.03	18.0
Cr	0.41	13.0	0.28	16.0	0.16	25.0	0.09	12.0	0.66	45.0	1.02	53.0
Cu	0.09	2.0	0.18	8.0	2.17	15.0	0.82	6.0	0.83	18.0	64.7	279.0
Fe	121	6520	71	11200	176	16000	59	9260	141	19600	459	28500
K	<20	700	<20	600	23	1800	34	700	33	6100	667	12500
Li	<0.05		<0.05		<0.05		<0.05		0.06		0.47	
Mg	3.0	1760	6.2	2410	39.4	3900	13.4	1310	57.8	8570	226.0	12000
Mn	6.76	174.0	1.68	66.0	3.10	98.0	1.63	48.0	24.70	162.0	13.60	131.0
Mo	<0.05	<2	<0.05	<2	<0.05	<2	<0.05	<2	<0.05	<2	<0.05	<2
Na	5.6	<100	4.5	<100	9.0	170	22.4	120	18.6	180	34.9	<100
Ni	0.05	6.0	0.09	8.0	0.18	11.0	0.09	4.0	0.49	25.0	1.12	52.0
P	22.0	385	3.3	357	2.4	485	2.9	303	1.7	334	<0.5	286
Pb	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5
S	6.1	24	3.1	<20	2.2	20	3.1	25	3.7	245	1.2	308
Sb	<1.5	<20	<1.5	<20	<1.5	<20	<1.5	<20	<1.5	<20	<1.5	<20
Si	35		37		19		15		28		258	
Sr	0.16	2.0	0.20	2.0	0.92	5.0	0.46	3.0	0.92	5.0	0.32	2.0
Ti	0.64	301	1.30	465	0.16	838	0.22	391	0.29	1190	1.85	1740
V	0.12	14.0	0.10	23.0	0.26	33.0	0.11	18.0	0.21	39.0	0.77	37.0
Zn	0.23	9.0	0.05	8.0	0.15	14.0	0.05	5.0	0.22	12.0	0.19	3.0

Appendix 3. cont.

Drilling site 7	E-horizon Depth15-20 cm		B-horizon Depth 38-42 cm		C-horizon 50-55 cm	
	201P	512P	201P	512P	201P	512P
Ag		<1		<1		<1
Al	56.9	820	875.0	11800	344.0	9600
As	<0.5	<10	<0.5	<10	<0.5	<10
B	<0.1	<5	<0.1	<5	<0.1	<5
Ba	1.3	3.0	5.2	26.0	6.1	40.0
Ca	11	230	30	1130	16	1990
Cd	<0.02	<1	<0.02	<1	<0.02	<1
Co	<0.02	<1	0.25	8.0	0.04	6.0
Cr	0.04	3.0	0.75	40.0	0.25	31.0
Cu	0.02	<1	1.10	15.0	0.41	21.0
Fe	11	1990	120	34100	79	18900
K	<20	<200	<20	800	<20	1700
Li	<0.05		<0.05		<0.05	
Mg	3.8	230	4.2	2880	3.9	4570
Mn	1.34	14.0	12.20	181.0	1.05	125.0
Mo	<0.05	<2	<0.05	<2	<0.05	<2
Na	4.3	<100	2.9	<100	4.1	210
Ni	<0.05	<3	0.11	12.0	<0.05	13.0
P	1.6	<50	6.1	557	10.5	466
Pb	<0.5	<5	<0.5	<5	<0.5	<5
S	1.6	<20	23.8	80	11.6	37
Sb	<1.5	<20	<1.5	<20	<1.5	<20
Si	4		105		68	
Sr	0.14	2.0	0.35	4.0	0.22	7.0
Ti	0.37	305	1.1	848	1.6	1220
V	0.04	6.0	0.37	72.0	0.14	43.0
Zn	0.24	2.0	0.28	13.0	0.03	13.0

Appendix 3. cont.

	Drilling site 7													
	Bedrock sample													
	Depth 100 cm		Depth 200 cm		Depth 300 cm		Depth 500 cm		Depth 700 cm		Depth 900 cm		Depth1080 cm	
	201P	512P	201P	512P	201P	512P	201P	512P	201P	512P	201P	512P	201P	512P
Ag		<1		<1		<1		<1		<1		<1		<1
Al	383.0	6860	33.1	3120	44.5	4620	30.7	3740	36.3	6010	20.6	3330	501.0	22800
As	<0.5	<10	<0.5	<10	<0.5	<10	<0.5	<10	<0.5	<10	<0.5	<10	<0.5	<10
B	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5
Ba	9.6	28.0	20.0	29.0	25.0	46.0	21.0	10.5	12.2	11.6	9.8	6.8	11.8	69.0
Ca	46	990	140	1140	148	1660	194	1710	239	1790	143	1300	220	2050
Cd	<0.02	<1	<0.02	<1	<0.02	<1	<0.02	<1	<0.02	<1	<0.02	<1	<0.02	<1
Co	0.06	4.0	0.02	2.0	0.17	5.0	0.04	3.0	0.40	5.0	0.12	3.0	5.28	16.0
Cr	0.29	20.0	0.04	13.0	0.07	25.0	0.05	17.0	0.16	24.0	0.15	15.0	1.78	120.0
Cu	0.22	12.0	0.40	9.0	0.58	18.0	1.22	15.0	1.17	15.0	1.21	9.0	0.60	2.0
Fe	60.9	11300	38	8450	36	12500	46	10400	71	13400	36	9930	463	38800
K	<20	1100	<20	800	<20	1300	<20	1000	24	100	<20	1300	801	16300
Li	<0.05		<0.05		<0.05		<0.05		<0.05		<0.05		1.22	
Mg	12.6	2800	25.5	1920	27.6	3200	44.6	2450	59.8	4030	34.7	2670	684.0	28700
Mn	1.44	65.0	0.55	48.0	1.45	74.0	1.19	83.0	5.24	124.0	3.00	72.0	23.60	414.0
Mo	<0.05	<2	<0.05	<2	<0.05	<2	<0.05	<2	<0.05	<2	<0.05	<2	<0.05	<2
Na	4.5	<100	7.9	<100	8.4	110	9.5	140	20.1	180	9.1	<100	128.0	680
Ni	0.09	9.0	0.05	6.0	0.37	10.0	0.12	8.0	0.60	12.0	0.27	7.0	0.84	45.0
P	5.4	367	3.3	315	2.6	409	2.1	366	1.6	332	1.9	312	2.8	655
Pb	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5
S	12.4	57	3.1	<20	14.4	44	3.5	<20	65.9	188	5.5	58	0.6	<20
Sb	<1.5	<20	<1.5	<20	<1.5	<20	<1.5	<20	<1.5	<20	<1.5	<20	<1.5	<20
Si	59		18		16		24		26		17		379	
Sr	0.62	3.0	1.26	3.0	1.01	4.0	0.92	5.0	0.94	5.0	0.59	3.0	1.52	7.0
Ti	0.86	635	0.31	405	0.36	671	0.18	571	0.19	788	0.18	490	1.49	2510
V	0.14	27	0.06	19	0.04	32	0.06	23	0.04	29	0.06	20	2.64	104
Zn	0.19	11.0	0.06	6.0	0.08	9.0	0.14	9.0	0.38	14.0	0.45	12.0	0.47	21.0

Appendix 3. cont.

	Drilling site 8											
	Depth 300 cm		Depth 400 cm		Depth 600 cm		Depth 700 cm		Depth 800 cm		Bedrock sample Depth1080 cm	
	201P	512P	201P	512P	201P	512P	201P	512P	201P	512P	201P	512P
Ag		<1		<1		<1		<1		<1		<1
Al	21.4	2520	42.6	4060	26.7	4150	14.2	1380	28.0	4180	245.0	4360
As	<0.5	<10	<0.5	<10	<0.5	<10	<0.5	<10	<0.5	<10	<0.5	<10
B	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5
Ba	8.7	20.0	8.6	22.0	5.0	28.0	3.0	12.0	9.7	34.0	17.5	46.0
Ca	17	2180	37	1590	87	3030	27	1150	81	2110	156	890
Cd	<0.02	<1	<0.02	<1	<0.02	<1	<0.02	<1	<0.02	<1	<0.02	<1
Co	0.09	2.0	0.70	4.0	0.96	5.0	0.13	2.0	0.24	3.0	14.80	15.0
Cr	0.14	14.0	0.80	15.0	0.50	19.0	0.10	10.0	0.24	18.0	0.70	5.0
Cu	0.46	3.0	1.18	5.0	1.30	8.0	0.74	4.0	1.20	5.0	0.25	1.0
Fe	163	11300	338	6200	443	11800	89	9750	234	13900	436	9590
K	<20	500	<20	500	26	700	<20	500	<20	900	366	1300
Li	<0.05		<0.05		<0.05		<0.05		<0.05		0.29	
Mg	4.3	1250	9.0	1530	16.0	2280	6.9	860	21.3	2210	125.0	3100
Mn	0.80	52.0	1.79	57.0	9.66	111.0	11.35	37.0	12.00	103.0	26.80	132.0
Mo	<0.05	<2	<0.05	<2	<0.05	<2	<0.05	<2	<0.05	<2	<0.05	<2
Na	7.5	110	7.7	110	12.3	200	7.6	100	8.8	130	176.0	540
Ni	0.10	4.0	1.09	7.0	0.87	7.0	0.22	3.0	0.42	6.0	0.26	<3
P	4.1	658	4.8	454	1.0	667	1.3	360	2.2	601	2.7	263
Pb	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	1.1	<5
S	0.8	<20	18.8	142	57.1	263	15.0	147	22.4	125	0.7	<20
Sb	<1.5	<20	<1.5	<20	<1.5	<20	<1.5	<20	<1.5	<20	<1.5	<20
Si	10		16		15		6		15		149	
Sr	0.28	6.0	0.52	5.0	0.47	9.0	0.23	3.0	0.62	6.0	3.27	11.0
Ti	0.67	643	0.58	703	0.60	976	0.38	352	0.38	728	0.33	216
V	0.51	26.0	3.32	28.0	1.56	29.0	0.20	19.0	0.79	32.0	0.52	13.0
Zn	0.06	7.0	0.38	11.0	0.28	12.0	0.13	4.0	0.24	11.0	1.07	27.0

Appendix 3. cont.

	Drilling site 9													
	E-horizon		B-horizon		C-horizon								Bedrock sample	
	Depth 23-28 cm		Depth 41-46 cm		Depth 75-80 cm		Depth 300 cm		Depth 400 cm		Depth 500 cm		Depth 920 cm	
	201P	512P	201P	512P	201P	512P	201P	512P	201P	512P	201P	512P	201P	512P
Ag		<1		<1		<1		<1		<1		<1		<1
Al	162.0	2330	1340.0	7450	1470.0	7000	22.5	2440	24.7	2140	35.6	4480	138.0	2650
As	<0.5	<10	<0.5	<10	<0.5	<10	<0.5	<10	<0.5	<10	<0.5	<10	<0.5	<10
B	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5
Ba	2.4	8.0	5.7	19.0	3.4	17.0	6.0	20.0	6.4	17.0	12.1	30.0	12.3	36.0
Ca	13	250	74	1660	33	2320	55	2390	58	2080	114	2090	91	300
Cd	<0.02	<1	0.04	<1	0.03	<1	<0.02	<1	<0.02	<1	<0.02	<1	0.02	<1
Co	<0.02	<1	0.06	2.0	0.03	2.0	0.16	3.0	0.17	2.0	0.41	4.0	17.5	23.0
Cr	0.12	6.0	1.06	15.0	1.61	20.0	0.14	15.0	0.14	13.0	0.38	18.0	0.42	1.0
Cu	<0.02	<1	0.10	3.0	0.18	3.0	0.61	4.0	0.64	3.0	0.97	6.0	0.30	3.0
Fe	82	3530	1360	15900	989	18400	143	12700	165	10800	222	10900	235	11000
K	<20	<200	<20	400	<20	500	<20	600	25	500	32	700	365	1200
Li	<0.05		<0.05		<0.05		<0.05		<0.05		<0.05		0.13	
Mg	3.1	440	5.3	1410	2.5	1570	15.0	1550	16.0	1290	31.4	1840	43.4	900
Mn	0.22	32.0	0.12	49.0	0.15	63.0	5.22	66.0	5.90	59.0	4.72	75.0	16.00	63.0
Mo	<0.05	<2	<0.05	<2	<0.05	<2	<0.05	<2	<0.05	<2	<0.05	<2	<0.05	<2
Na	5.3	<100	5.0	<100	3.3	130	6.8	<100	7.9	<100	9.6	<100	103.0	470
Ni	<0.05	<3	0.08	4.0	<0.05	4.0	0.29	5.0	0.23	4.0	0.54	6.0	0.25	<3
P	5.7	62	7.5	552	9.1	694	2.2	664	2.1	583	1.4	525	2.0	59
Pb	<0.5	6	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5
S	3.5	41	19.1	116	22.8	80	4.4	122	4.2	105	19.3	210	0.9	<20
Sb	<1.5	<20	<1.5	<20	<1.5	<20	<1.5	<20	<1.5	<20	<1.5	<20	<1.5	<20
Si	5		19		64		9		10		16		84	
Sr	0.18	3.0	1.58	7.0	0.63	7.0	0.47	6.0	0.52	5.0	0.99	7.0	1.74	6.0
Ti	0.51	785	3.49	650	2.50	776	0.29	644	0.28	544	0.54	763	0.16	93
V	0.13	19.0	0.25	33.0	0.29	40.0	0.42	27.0	0.49	24.0	2.29	32.0	0.11	11.0
Zn	0.10	3.0	0.17	8.0	0.28	8.0	0.27	8.0	0.27	7.0	0.31	12.0	0.62	11.0

Appendix 3. cont.

	Drilling site 10													
	Depth 200 cm		Depth 300 cm		Depth 400 cm		Depth 500 cm		Bedrock sample Depth 700 cm		Depth 750 cm		Depth 930 cm	
	201P	512P	201P	512P	201P	512P	201P	512P	201P	512P	201P	512P	201P	512P
Ag		<1		<1		<1		<1		<1		<1		<1
Al	135.0	2830	499.0	5060	40.9	2950	50.6	1990	32.6	2490	25.4	3150	116.0	2610
As	<0.5	<10	<0.5	<10	<0.5	<10	<0.5	<10	<0.5	<10	<0.5	<10	<0.5	<10
B	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5	<0.1	<5
Ba	6.6	17.0	8.1	19.0	8.1	22.0	3.4	13.0	4.4	13.0	7.1	16.0	13.4	28.0
Ca	19	1830	57	1610	19	1430	17	1320	24	1570	59	1590	623	1090
Cd	<0.02	<1	<0.02	<1	<0.02	<1	<0.02	<1	<0.02	<1	<0.02	<1	<0.02	<1
Co	0.03	2.0	0.05	2.0	0.24	3.0	0.18	2.0	0.37	3.0	0.11	3.0	13.70	16.0
Cr	0.56	14.0	1.26	14.0	0.31	14.0	0.33	12.0	0.21	10.0	0.12	5.0	0.45	3.0
Cu	0.61	3.0	0.18	2.0	0.85	4.0	0.50	2.0	1.54	4.0	1.19	4.0	0.17	1.0
Fe	209	9590	495	6220	213	10200	158	8390	127	11200	80.3	14700	216	9840
K	<20	400	<20	300	<20	700	<20	300	<20	400	28	500	188	700
Li	<0.05		<0.05		<0.05		<0.05		<0.05		<0.05		0.17	
Mg	3.8	1170	9.5	1250	5.1	1390	3.8	890	7.9	580	20.3	2620	75.5	1970
Mn	1.32	50.0	1.93	45.0	0.97	52.0	0.92	39.0	1.45	78.0	2.53	138.0	29.80	178.0
Mo	<0.05	<2	<0.05	<2	<0.05	<2	<0.05	<2	<0.05	<2	<0.05	<2	<0.05	<2
Na	9.3	110	5.8	<100	13.5	<100	8.8	<100	10.3	<100	25.6	<100	89.6	390
Ni	0.25	4.0	0.18	4.0	0.47	6.0	0.29	4.0	0.53	4.0	0.13	<3	0.21	<3
P	3.5	526	13.0	519	4.7	442	3.5	399	1.3	439	1.0	431	1.1	119
Pb	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	3.3	11
S	2.4	<20	5.7	80	2.8	<20	16.4	56	12.9	97	2.2	66	1.1	<20
Sb	<1.5	<20	<1.5	<20	<1.5	<20	<1.5	<20	<1.5	<20	<1.5	<20	<1.5	<20
Si	29		32		13		10		9		13		82	
Sr	0.27	5.0	0.81	5.0	0.30	4.0	0.22	4.0	0.30	4.0	0.64	3.0	2.46	6.0
Ti	1.36	576	1.72	598	0.83	640	0.58	452	0.50	657	0.62	904	0.29	99
V	1.03	21.0	3.60	23.0	1.15	27.0	1.08	22.0	0.54	21.0	0.36	18.0	<0.02	3.0
Zn	0.05	6.0	0.09	6.0	0.12	8.0	0.11	5.0	0.25	14.0	0.18	25.0	0.47	14.0

Appendix 4. Concentrations of elements (mg/kg) in samples of surficial deposits of Nicaragua. The samples were extracted with ammonium acetate (pH 7.0 and pH 4.5; methods 221P and 201P), aqua regia (method 512P, samples of the year 1997) and nitric acid (method 500P for samples of the year 1994, and method 503P for samples of the year 1999). Method 521U was used for analysing gold (GAAS technique) and method 500H (nitric acid extraction) for analysing mercury.

					TISMA									
	Site 4		Site 5		Site 11				Site 12					
	Santa Cruz,		Las Conchas,		Noel Morales,				El Rodal,					
	corn field		chili field		corn field				fallow field					
	Depth 18-24 cm		Depth 15-20 cm		Depth 10-15 cm		Depth 25-30 cm		Depth 5-10 cm		Depth 20-24 cm		Depth 40 cm (talpetate)	
	221P	512P	221P	512 P	221P	500P	221P	500 P	221P	500P	221P	500P	221P	500P
Ag	<0.05	<1	<0.05	<1	<0.05		<0.05		<0.05		<0.05		<0.05	
Al	1.4	61700	1.5	50200	1.5	46800	<0.5	47800	1.6	90000	1.5	101000	1.9	107000
As	<0.5	<10	<0.5	<10	<0.5		<0.5		<0.5		<0.5		<0.5	
Ba	225.0	637.0	103.0	573.0	90.3	500.0	82.7	414.0	402.0	945.0	437.0	1060	687.0	1140
Ca	5440	6400	5640	15600	6640	13400	5900	13200	3600	4660	3880	4940	4930	5230
Cd	<0.05	0.6	<0.05	<0.5	<0.05		<0.05		<0.05		<0.05		<0.05	
Co	0.31	31.0	0.20	27.0	0.19	26.3	0.19	24.7	0.47	46.0	0.53	47.1	0.79	47.9
Cr	<0.3	20.0	<0.3	16.0	<0.3	<10	<0.3	<10	<0.3	<10	<0.3	<10	<0.3	<10
Cu	0.26	209.0	<0.2	195.0	0.25	197.0	0.23	184.0	0.50	357.0	0.56	397.0	1.36	436.0
Fe	<2	77400	<2	61500	<2	52800	<2	53300	<2	92300	<2	102000	<2	101000
K	820	3600	1200	4270	1720	5310	934	4610	414	<3000	304	<3000	118	<3000
Mg	843	5100	875	6700	880	7970	830	7740	722	4300	784	4530	1130	5560
Mn	0.25	1780	0.48	1040	0.74	1400	1.13	1160	<0.1	1860	0.78	2050	0.44	2020
Mo	<0.2	<5	<0.2	<5	<0.2	<3	<0.2	<3	<0.2	3.27	<0.2	<3	<0.2	4.7
Na	17.9	290	23.1	1000	84.0	1130	69.1	1100	7.4	256	12.7	263	38.6	263
Ni	<0.2	9.0	<0.2	7.0	<0.2	<15	<0.2	<15	<0.2	<15	<0.2	<15	<0.2	18.2
P	3.0	382	5.0	3810	4.0	781	2.0	541	<1	654	2.0	634	4.0	390
Pb	<0.5	7	<0.5	<5	<0.5		<0.5		<0.5		<0.5		<0.5	
S	<5	170	9.2	268	9.1		<0.5		6.2		10.3		15.6	
Sb	<5		<5		<5		<5		<5		<5		<5	
Sr	67.50	90.3	53.10	140.0	48.40	105.0	41.90	101.0	80.00	111.0	90.20	124.0	173.00	186.0
Ti	<0.25	4050	<0.25	3250	<0.25	3230	<0.25	3160	<0.25	5990	<0.25	6550	<0.25	6680
V	<0.25	270.0	<0.25	173.0	<0.25	352.0	<0.25	367.0	<0.25	289.0	<0.25	319.0	<0.25	290.0
Zn	0.11	57.0	0.11	76.0	<0.10	64.3	0.11	57.8	0.15	73.5	0.11	79.7	0.11	75.3

Appemdix 4. cont.

			TISMA				LEÓN			
	Site 13		Site 15		Site 16					
	Cuatro Esquinas, corn field		16 de Julio, corn field		La Montañita, chili field		Site 17, La Hoyada, fallow field			
	Depth 10-30 cm		Depth 10-15 cm		Depth 20-24 cm		Depth 10-15 cm		Depth 240-250 cm	
	221P	512P	221P	500P	221P	512P	221P	503P	221P	503P
Ag	<0.05	<1	<0.05		<0.05	<1				
Al	2.0	77000	1.1	90600	1.3	81200	<1	38200	<1	37900
As	<0.5	<10	<0.5		<0.5	<10	<0.5	<10	<0.5	<10
B							<0.5	<5	<0.5	<5
Ba	159.0	782.0	329.0	936.0	510.0	947.0	20.3	98.9	36.1	147.0
Be							<0.05	<0.5	<0.05	<0.5
Ca	4120	5600	3420	5300	6590	6100	509	22400	892	19500
Cd	<0.05	0.5	<0.05		<0.05	0.5	<0.05	1.5	<0.05	1.5
Co	0.22	36.0	0.39	101.0	0.57	34.0	<0.1	9.8	<0.1	10.7
Cr	<0.3	24.0	<0.3	<10	<0.3	21.0	<0.1	13.2	<0.1	13.8
Cu	0.37	245.0	0.51	327.0	0.43	274.0	0.35	0.1	0.50	66.7
Fe	<2	90000	<2	92100	<2	90000	<2	22300	<2	25900
K	2340	4380	410	<3000	288	1090	65	614	144	791
Mg	780.0	4500	576.0	4140	693.0	5400	35.0	7580	69.0	7570
Mn	0.7	2050	<0.1	1810	0.3	1800	0.1	319.0	0.2	411.0
Mo	<0.2	<5	<0.2	<3	<0.2	<5	<0.2	<3	<0.2	<3
Na	11.4	310	12.4	293	12.9	240	<3	3110	4.4	2610
Ni	<0.2	11.0	<0.2	15.7	<0.2	10.0	<0.1	16.8	<0.1	17.7
P	5.0	1290	1.0	594	3.0	415	<2	307	<2	533
Pb	<0.5	8	<0.5		<0.5	9	<0.5	<5	<0.5	5
S	12.2	301	8.8		<5	125	<2	171	2.1	296
Sb	<5		<5		<5		<2	16	<2	<15
Sr	58.50	85.2	78.50	131.0	263.00	261.0	3.75	163.0	6.81	143.0
Ti	<0.25	5250	<0.25	5980	<0.25	5030	<0.1	989	<0.1	1200
V	<0.25	312.0	<0.25	308.0	<0.25	311.0	<0.1	50.4	<0.1	64.5
Zn	<0.1	78.0	0.12	72.1	0.12	56.0	0.14	30.6	0.17	46.9
Zr								14.4		19

Appendix 4. cont.

	LEÓN							
	Site 18, Los Velásquez, corn field							
	Depth 0-5 cm		Depth 5-15 cm		Depth 15-30 cm		Depth 30-60 cm	
	221P	503P	221P	503P	221P	503P	221P	503P
Al	<1	45600	<1	44900	<1	47300	<1	48700
As	<0.5	<10	<0.5	<10	<0.5	<10	<0.5	<10
B	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5
Ba	48.8	209.0	36.2	189.0	38.6	212.0	40.6	236.0
Be	<0.05	0.6	<0.05	<0.5	<0.05	<0.5	<0.05	0.5
Ca	1170	17200	1040	18200	1120	17500	1420	18200
Cd	<0.05	<1	<0.05	<1	<0.05	<1	<0.05	<1
Co	<0.1	15.8	<0.1	15.3	<0.1	14.2	<0.1	14.5
Cr	<0.1	13.9	<0.1	13.2	<0.1	13.4	<0.1	14.1
Cu	<0.1	84.7	<0.1	84.4	0.1	82.5	<0.1	91.7
Fe	<2	31700	<2	30200	<2	31100	<2	31500
K	330	1330	222	1130	249	1200	374	1380
Mg	126.0	6540	100.0	6780	86.0	6970	119.0	6740
Mn	0.66	618.0	0.40	580.0	0.21	566.0	0.13	597.0
Mo	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	<3
Na	3.8	2490	4.0	2590	5.6	2400	4.8	2290
Ni	<0.1	21.4	<0.1	19.4	<0.1	6.7	<0.1	7.5
P	<2	1160	<2	1260	<2	1240	<2	1300
Pb	<0.5	6	<0.5	10	<0.5	10	<0.5	10
S	5.2	508	5.1	515	4.1	486	3.3	533
Sb	<2	<15	<2	<15	<2	<15	<2	16
Sr	9.36	137.0	6.83	141.0	7.12	139.0	8.89	143.0
Ti	<0.1	1610	<0.1	160	<0.1	1680	<0.1	1790
V	0.30	61.5	0.20	55.3	0.20	60.4	<0.1	54.1
Zn	0.13	62.1	0.11	59.6	0.08	61.6	0.07	61.2
Zr		29.2		26.6		26.8		27.4

Appendix 4. cont.

LEÓN

	Site 20 a, La Trinidad, field-forest plantation								Site 20 b, La Trinidad, corn field							
	Depth 0-5 cm		Depth 5-15 cm		Depth 15-30 cm		Depth 30-60 cm		Depth 0-5 cm		Depth 5-15 cm		Depth 15-30 cm		Depth 30-60 cm	
	221P	503P	221P	503P	221P	503P	221P	503P	221P	503P	221P	503P	221P	503P	221P	503P
Al	<1	48600	<1	52500	<1	54300	<1	46300	<1	45400	<1	44100	<1	45800	<1	49700
As	<0.5	<10	<0.5	13	<0.5	11	<0.5	<10	<0.5	<10	<0.5	<10	<0.5	<10	<0.5	<10
B	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5
Ba	57.1	243.0	67.0	281.0	75.6	256.0	70.6	211.0	35.6	160.0	29.9	142.0	46.5	177.0	75.0	221.0
Be	<0.05	<0.5	<0.05	0.6	<0.05	0.5	<0.05	<0.5	<0.05	<0.5	<0.05	<0.5	<0.05	<0.5	<0.05	<0.5
Ca	1370	18100	1820	18900	2070	23700	1450	22900	1110	22400	711	22400	1090	22100	1190	24300
Cd	<0.05	<1	<0.05	<1	<0.05	<1	<0.05	<1	<0.05	<1	<0.05	<1	<0.05	<1	<0.05	<1
Co	<0.1	17.3	<0.1	17.5	<0.1	16.8	<0.1	16.5	<0.1	18.1	<0.1	17.5	<0.1	14.6	<0.1	17.3
Cr	<0.1	15.3	<0.1	15.5	<0.1	18.1	<0.1	15	<0.1	17.2	<0.1	17.2	<0.1	14.2	<0.1	17.6
Cu	0.20	97.1	0.30	112.0	<0.1	107.0	0.20	85.4	0.20	62.8	0.10	65.4	0.10	82.5	0.20	90.1
Fe	<2	36300	<2	38800	<2	35800	<2	30600	<2	31800	<2	30900	<2	28200	<2	32100
K	466	1650	443	1740	392	1500	202	932	273	1220	194	945	207	892	252	1080
Mg	141.0	7100	189.0	6950	226.0	7300	146.0	7980	121.0	9250	93.0	8820	114.0	6360	112.0	8100
Mn	0.56	711.0	0.30	800.0	0.31	722.0	0.10	580.0	0.32	546.0	0.14	521.0	0.15	522.0	0.16	585.0
Mo	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	<3
Na	6.7	2310	7.6	2300	12.0	3140	12.3	3090	3.9	3190	4.3	3260	6.9	3050	9.4	3600
Ni	<0.1	12.9	<0.1	11.9	<0.1	14.7	<0.1	18.5	<0.1	22.7	<0.1	22.2	<0.1	18.9	<0.1	23.8
P	<2	931	<2	884	<2	649	<2	472	<2	674	<2	515	<2	525	<2	440
Pb	<0.5	9	<0.5	9	<0.5	10	<0.5	10	<0.5	10	<0.5	<5	<0.5	9	<0.5	6
S	5.2	448	3.8	473	2.8	426	2.3	223	5.5	410	4.0	347	3.3	317	2.2	244
Sb	<2	<15	<2	<15	<2	<15	<2	<15	<2	<15	<2	<15	<2	<15	<2	<15
Sr	9.08	138.0	12.90	145.0	18.30	183.0	13.80	174.0	6.06	165.0	4.62	167.0	7.36	166.0	12.30	188.0
Ti	<0.1	1890	<0.1	2060	<0.1	1870	<0.1	1680	<0.1	1560	<0.1	1560	<0.1	1610	<0.1	1550
V	<0.1	47.5	<0.1	54.0	0.20	48.3	0.20	39.5	<0.1	56.2	<0.1	55.9	0.10	39.7	0.20	56.4
Zn	0.13	67.8	0.13	71.8	0.13	58.0	0.15	43.0	0.17	59.3	0.13	55.4	0.10	43.7	0.16	43.8
Zr		31		36		34.9		21.1		22.9		21.8		22.9		26

Appendix 4. cont.

LEÓN

	Site 21, La Primavera, peanut field								Site 22 a, cross section of a road				Site 22 b, cross section of a road	
	Depth 0-5 cm		Depth 5-15 cm		Depth 15-30 cm		Depth 30-60 cm		Depth 100 cm		Depth 250 cm		Depth 100 cm	
	221P	503P	221P	503P	221P	503P	221P	503P	221P	503P	221P	503P	221P	503P
Al	<1	58500	<1	56000	<1	52800	<1	58100	<1	68400	<1	109000	<1	42500
As	<0.5	<10	<0.5	<10	<0.5	<10	<0.5	<10	<1	28	<1	23	<1	19
B	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	6	<0.5	<5	<0.5	<5
Ba	43.9	239.0	44.6	228.0	53.8	226.0	100.0	303.0	192.0	435.0	359.0	771.0	67.1	149.0
Be	<0.05	0.6	<0.05	<0.5	<0.05	<0.5	<0.05	<0.5	<0.05	0.6	<0.05	1.1	<0.05	<0.5
Ca	1180	24100	1140	23400	1340	22100	1560	23600	2 060	17100	3550	4630	789	20400
Cd	<0.05	<1	<0.05	1.2	<0.05	1.2	<0.05	1.3	<0.05	<1	<0.05	<1	<0.05	<1
Co	<0.1	18.2	<0.1	18.1	<0.1	16.0	<0.1	18.5	<0.1	19.7	<0.1	26.4	<0.1	16.9
Cr	<0.1	18.0	<0.1	17.1	<0.1	15.4	<0.1	18.4	<0.1	17.4	<0.1	22.6	<0.1	14.8
Cu	<0.1	86.9	<0.1	82.0	0.1	78.7	0.20	101.0	0.70	151.0	0.60	260.0	0.20	52.3
Fe	<2	38500	<2	38400	<2	35500	<2	41600	<2	49600	<2	73200	<2	35800
K	264	1560	283	1430	239	1240	267	1450	696	2310	999	3030	240	930
Mg	89.0	9610	92.0	9720	109.0	8230	159.0	8970	236.0	6770	762.0	4700	119.0	12900
Mn	0.2	664.0	0.2	633.0	0.2	597.0	0.2	691.0	0.4	977.0	0.1	1860.0	0.5	557.0
Mo	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	3
Na	3.9	3430	5.2	3080	8.2	2910	15.6	3240	49.2	2530	56.5	451	6.0	2020
Ni	<0.1	6.7	<0.1	7.4	<0.1	4.0	<0.1	5.3	<0.1	10.4	<0.1	9.0	<0.1	17.9
P	<2	993	<2	929	<2	846	<2	678	<2	339	<2	274	<2	242
Pb	<0.5	10	<0.5	10	<0.5	12	<0.5	12	<0.5	24	<0.5	28	<0.5	14
S	6.4	481	4.6	472	4.4	402	6.1	286	7.4	238	7.8	210	2.7	95
Sb	<2	<15	<2	<15	<2	<15	<2	<15	<2	<15	<2	<15	<2	<15
Sr	8.17	191.0	8.25	180.0	10.80	172.0	22.90	201.0	46.20	183.0	65.60	108.0	10.70	157.0
Ti	<0.1	1960	<0.1	2100	<0.1	2000	<0.1	2150	<0.1	1630	<0.1	3000	<0.1	1350
V	<0.1	73.5	0.20	81.9	0.20	72.6	0.20	89.6	<0.1	128.0	<0.1	140.0	<0.1	73.2
Zn	0.08	70.1	0.09	67.4	0.10	58.7	0.17	59.7	0.23	63.6	<0.05	90.8	0.13	40.4
Zr		31.4		32.9		32.5		37.7		51.4		86.1		<1

Appendix 4. cont.

LEÓN

Site 24, Hayde Larios, soybean field

	Depth 0-5 cm		Depth 5-15 cm		Depth 15-30 cm		Depth 30-60 cm		Depth 120 cm	
	221P	503P	221P	503P	221P	503P	221P	503P	221P	503P
Al	<1	50100	<1	51000	<1	58600	<1	57000	<1	62800
As	<0.5	17	<0.5	15	<0.5	11	<0.5	26	<0.5	24
B	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5
Ba	72.1	224.0	69.8	219.0	103.0	303.0	86.7	308.0	175.0	359.0
Be	<0.05	0.9	<0.05	0.8	<0.05	1.0	<0.05	1.0	<0.05	0.9
Ca	838	18000	919	19000	1610	19500	2110	17400	1880	18700
Cd	<0.05	<1	<0.05	<1	<0.05	<1	<0.05	<1	<0.05	<1
Co	<0.1	18.4	<0.1	17.2	<0.1	18.3	<0.1	16.9	<0.1	19.2
Cr	<0.1	16.1	<0.1	13.8	<0.1	16.5	<0.1	15.5	<0.1	14.7
Cu	<0.1	93.9	0.10	95.9	<0.1	125.0	<0.1	136.0	0.30	138.0
Fe	<2	39400	<2	36500	<2	41900	<2	40200	<2	43000
K	379	1480	400	1490	545	1860	366	1640	785	2070
Mg	89.0	9730	87.0	9470	183.0	8200	191.0	7270	226.0	8500
Mn	10.50	633.0	3.45	620.0	0.31	740.0	0.36	777.0	0.26	786.0
Mo	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	3	<0.2	<3
Na	4.5	2930	6.3	2740	13.6	3010	22.9	2600	32.5	2470
Ni	<0.1	14.8	<0.1	14.4	<0.1	12.4	<0.1	10.0	<0.1	12.4
P	<2	578	<2	608	<2	666	<2	834	<2	449
Pb	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	7.8	<0.5	<5
S	2.9	308	2.4	260	3.4	333	2.6	436	<2	221
Sb	<2	<15	<2	<15	<2	17	<2	<15	<2	<15
Sr	11.30	146.0	10.40	147.0	21.80	162.0	16.90	136.0	47.50	175.0
Ti	<0.1	1960	<0.1	1840	<0.1	2160	<0.1	2220	<0.1	2180
V	0.20	133.0	0.20	110.0	0.30	119.0	<0.1	114.0	0.20	123.0
Zn	0.15	58.1	0.13	55.2	0.13	64.7	0.14	69.9	0.08	49.1
Zr		34.2		33.6		42.5		45.9		54.5

Appendix 4. cont.

LEÓN								
	Site 25, Entre Ríos, pasture							
	Depth 0-5 cm		Depth 5-15 cm		Depth 15-30 cm		Depth 30-60 cm	
	221P	503P	221P	503P	221P	503P	221P	503P
Al	<1	53300	<1	59900	<1	68500	<1	67000
As	<0.5	<10	<0.5	<10	0.5	10	<0.5	<10
B	<0.5	<5	<0.5	<5	<0.5	5	<0.5	<5
Ba	22.3	264.0	30.3	314.0	9.7	440.0	187.0	509.0
Be	<0.05	<0.5	<0.05	1.0	<0.05	1.2	<0.05	1.0
Ca	2710	19500	2310	17700	2240	11600	2810	10800
Cd	<0.05	<1	<0.05	<1	<0.05	<1	<0.05	<1
Co	<0.1	17.6	<0.1	19.3	<0.1	20.9	<0.1	22.0
Cr	<0.1	16.5	<0.1	16.9	<0.1	19.0	<0.1	18.5
Cu	<0.1	103	0.20	132.0	0.20	168.0	0.20	171.0
Fe	<2	39500	<2	45200	<2	66100	<2	65100
K	1850	4490	1950	3780	3040	4880	961	2980
Mg	538.0	9240	544.0	8020	544.0	6510	400.0	5670
Mn	1.91	714.0	0.99	848.0	0.47	1060	0.84	1110
Mo	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	4
Na	6.4	2220	6.7	2200	9.9	1510	9.5	1340
Ni	<0.1	13.4	<0.1	9.6	<0.1	8.5	<0.1	7.2
P	24.0	2430	13.0	2520	6.0	1600	<2	1450
Pb	<0.5	9	<0.5	<5	<0.5	7	<0.5	6
S	11.9	544	6.2	441	5.1	270	2.5	269
Sb	<2	<15	<2	<15	<2	<15	<2	<15
Sr	13.70	139.0	12.60	131.0	15.00	93.5	30.60	105.0
Ti	<0.1	1860	<0.1	2140	<0.1	2240	<0.1	2300
V	0.10	94.3	<0.1	116.0	0.10	115.0	0.20	133.0
Zn	0.08	90.5	0.12	90.9	<0.05	75.6	0.17	91.9
Zr		36.8		44.4		63.2		60.5

Appendix 4. cont.

	LEÓN															
	Site 26 a, German Pomares, sugarcane plantation								Site 26 b, German Pomares, banana plantation							
	Depth 0-5 cm		Depth 5-15 cm		Depth 15-30 cm		Depth 30-60 cm		Depth 0-5 cm		Depth 5-15 cm		Depth 15-30 cm		Depth 30-60 cm	
	221P	503P	221P	503P	221P	503P	221P	503P	221P	503P	221P	503P	221P	503P	221P	503P
Al	<1	64200	<1	52500	<1	60700	<1	70600	<1	54900	<1	55800	<1	58400	<1	62500
As	<0.5	21.0	<0.5	16.0	<0.5	16.0	<0.5	14.0	<0.5	<10	<0.5	<10	<0.5	10.0	<0.5	<10
B	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5
Ba	128.0	407.0	88.6	296.0	116.0	364.0	197.0	441.0	76.4	295.0	93.8	319.0	164.0	451.0	283.0	645.0
Be	<0.05	0.6	<0.05	<0.5	<0.05	<0.5	<0.05	<0.5	<0.05	<0.5	<0.05	<0.5	<0.05	<0.5	<0.05	0.6
Ca	2240	14000	1870	18200	2000	19900	2190	19200	2030	22800	1930	21400	2000	20400	1860	16500
Cd	<0.05	1.0	<0.05	<1	<0.05	<1	<0.05	<1	<0.05	1.2	<0.05	1.1	<0.05	1.1	<0.05	1.1
Co	<0.1	16.0	<0.1	15.8	<0.1	17.0	<0.1	18.3	<0.1	16.2	<0.1	16.2	<0.1	17.3	<0.1	20.1
Cr	<0.1	16.3	<0.1	16.0	<0.1	18.3	<0.1	17.4	<0.1	17.6	<0.1	17.2	<0.1	18.0	<0.1	9.7
Cu	0.20	111.0	<0.1	102.0	0.1	121.0	0.50	135.0	0.10	92.7	0.40	96.1	0.30	113.0	0.30	126.0
Fe	<2	46700	<2	38200	<2	42200	<2	46800	<2	40900	<2	40800	<2	44900	<2	48100
K	557	1990	352	1390	223	1220	69	710	515	2070	430	1960	476	1910	512	1970
Mg	487.0	4940	397.0	6070	370.0	5480	362.0	4120	392.0	8130	428.0	6810	473.0	6870	367.0	8570
Mn	1.61	798.0	1.33	574.0	0.86	660.0	0.42	694.0	1.66	531.0	0.85	526.0	0.55	636.0	0.18	1060
Mo	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	<3
Na	18.4	1790	18.0	2300	39.2	2700	103.0	2250	6.0	2630	8.6	2760	14.1	2360	23.9	2000
Ni	<0.1	2.3	<0.1	13.3	<0.1	13.0	<0.1	13.4	<0.1	15.5	<0.1	14.6	<0.1	14.3	<0.1	18.4
P	<2	651	<2	444	<2	467	<2	324	<2	438	<2	364	<2	381	<2	264
Pb	<0.5	17	<0.5	<5	<0.5	12	<0.5	13	<0.5	15	<0.5	13	<0.5	<5	<0.5	9
S	5.4	458	3.9	293	3.5	371	4.3	244	4.7	335	2.4	244	<2	264	2	147
Sb	<2	<15	<2	<15	<2	23	<2	19	<2	16	<2	<15	<2	<15	<2	<15
Sr	27.10	131.0	17.20	139.0	27.80	170.0	61.10	194.0	12.60	160.0	12.60	156.0	16.00	151.0	24.60	140.
Ti	<0.1	2540	<0.1	1910	<0.1	1760	<0.1	1900	<0.1	2040	<0.1	1740	<0.1	2190	<0.1	2380
V	0.10	110.0	0.10	113.0	0.10	119.0	<0.1	125.0	<0.1	118.0	<0.1	115.0	<0.1	129.0	<0.1	144.0
Zn	0.13	70.0	0.10	67.6	0.13	74.1	0.14	71.2	0.10	68.1	0.07	64.7	0.08	67.3	0.06	68.8
Zr		55.3		33.2		41.1		51.4		35.5		35.1		40.7		52

Appendix 4. cont.

LEÓN

Site 27, Río Télica, cross section of a river bed

	Depth 100 cm		Depth 200 cm		Depth 300 cm		Depth 400 cm		Depth 500 cm		Depth 600 cm		Depth 700 cm		Depth 800 cm		Depth 900 cm	
	221P	503P	221P	503P	221P	503P	221P	503P	221P	503P	221P	503P	221P	503P	221P	503P	221P	503P
Al	<1	102000	<1	67300	<1	33700	<1	44400	<1	62500	<1	24600	<1	53900	<1	74600	<1	81500
As	<0.5	<10	<0.5	23	<0.5	17	<0.5	21	<0.5	27	<0.5	17	<0.5	22	<0.5	<10	<0.5	20
B	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5
Ba	259.0	773.0	300.0	679.0	393.0	635.0	474.0	824.0	423.0	775.0	127.0	313.0	199.0	441.0	516.0	882.0	378.0	722.0
Be	<0.05	1.1	<0.05	1.0	<0.05	<0.5	<0.05	0.9	<0.05	0.7	<0.05	<0.5	<0.05	0.6	<0.05	1.1	<0.05	0.9
Ca	3400	3800	2790	4200	1890	3830	2230	4850	3070	7090	1230	6350	1890	11500	3200	9150	3450	4570
Cd	<0.05	<1	<0.05	<1	<0.05	<1	<0.05	<1	<0.05	<1	<0.05	<1	<0.05	<1	<0.05	<1	<0.05	<1
Co	<0.1	34.6	<0.1	20.5	<0.1	5.1	<0.1	7.8	<0.1	17.0	<0.1	10.3	<0.1	14.6	<0.1	16.6	<0.1	19.7
Cr	<0.1	30.7	<0.1	23.8	<0.1	9.0	<0.1	12.9	<0.1	19.0	<0.1	9.1	<0.1	16.0	<0.1	16.6	<0.1	20.3
Cu	0.2	145.0	0.10	118.0	0.40	29.2	0.50	50.6	2.10	157.0	0.30	87.0	0.30	82.4	0.30	53.0	0.50	115.0
Fe	<2	81300	<2	67000	<2	30200	<2	44100	<2	54000	<2	26000	<2	45300	<2	52100	<2	61600
K	366	1630	221	1480	569	1320	708	1830	682	2230	349	1480	323	1290	509	1620	552	1540
Mg	1110	3480	979	3240	494	1590	549	2160	502	4880	257	4230	255	4080	548	3590	625	4180
Mn	<0.05	2490	<0.05	1500	0.33	945	0.96	1290	1.30	1040	1.05	581	0.25	1030	0.21	1710	0.22	1580
Mo	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	<3
Na	358.0	842	374.0	1130	71.2	473	71.5	630	77.7	836	32.9	988	60.7	1900	98.9	1280	193.0	482
Ni	<0.1	11.7	<0.1	6.8	<0.1	2.3	<0.1	<2	<0.1	8.3	<0.1	4.7	<0.1	7.6	<0.1	6.8	<0.1	9
P	<2	<50	<2	495	<2	664	<2	823	<2	301	<2	227	<2	393	<2	229	<2	229
Pb	<0.5	28	<0.5	18	<0.5	16	<0.5	14	<0.5	22	<0.5	9	<0.5	19	<0.5	20	<0.5	21
S	24.4	<50	8.3	326	<2	82	2.7	199	5.8	170	2.7	193	3.3	151	3.5	77	5.5	139
Sb	<2	<15	<2	<15	<2	<15	<2	<15	<2	<15	<2	<15	<2	<15	<2	<15	<2	<15
Sr	36.80	66.2	37.00	85.2	43.70	74.3	48.60	88.6	40.80	95.4	12.80	69.3	29.20	117.0	42.90	102.0	55.20	88.0
Ti	<0.1	3030	<0.1	2110	<0.1	2160	<0.1	2190	<0.1	1790	<0.1	927	<0.1	1480	<0.1	2870	<0.1	3430
V	<0.1	201.0	<0.1	107.0	<0.1	18.1	<0.1	38.6	<0.1	91.7	<0.1	40.6	<0.1	65.3	<0.1	19.2	<0.1	98.3
Zn	<0.05	124.0	<0.05	126.0	0.52	62.9	0.74	94.5	0.08	70.5	0.09	37.6	0.14	63.3	0.64	81.3	<0.05	57.9
Zr		79.2		105		69.4		98.7		70.7		12.9		53.2		85.9		67.7

Appendix 4. cont.

	DIRIAMBA							
	Site 28, Río La Trinidad, fluvial deposit		Site 29 a, San Helén, corn field Depth 5-15 cm		Site 29 b, San Helén, fallow field Depth 5-15 cm		Site 31, Río Amayito, fluvial deposit	
	221P	503P	221P	503P	221P	503P	221P	503P
Al	<1	54300	<1	83700	<1	105000	<1	37000
As	<0.5	<10	<0.5	<10	<0.5	<10	<0.5	<10
B	<0.5	<5	<0.5	11	<0.5	<5	<0.5	<5
Ba	213.0	510.0	97.3	349.0	285.0	705.0	125.0	322.0
Be	<0.05	1.0	<0.05	0.7	<0.05	1.1	<0.05	0.6
Ca	5790	11100	4710	5290	4180	4780	6100	11300
Cd	<0.05	<1	<0.05	<1	<0.05	1.6	<0.05	<1
Co	<0.1	22.0	<0.1	18.3	<0.1	39.9	<0.1	10.2
Cr	<0.1	25.5	<0.1	26.4	<0.1	33.5	<0.1	22.4
Cu	0.30	146.0	0.30	112.0	0.20	217.0	0.30	84.0
Fe	<2	65800	<2	59900	<2	95900	<2	53100
K	201	2920	734	6960	563	4400	63	1680
Mg	970.0	7610	657.0	7760	863.0	4490	1070.0	7000
Mn	0.25	1380	1.60	591	0.73	2370	0.29	321
Mo	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	<3
Na	63.5	760	39.3	198	18.2	141	87.8	561
Ni	<0.1	12.6	<0.1	5.8	<0.1	6.2	<0.1	7.8
P	<2	132	<2	594	<2	<50	<2	204
Pb	<0.5	7	<0.5	17	<0.5	17.2	<0.5	<5
S	<2	<50	12.5	271	9.7	<50	<2	<50
Sb	<2	<15	<2	<15	<2	<15	<2	<15
Sr	35.80	117.0	50.60	72.0	46.30	65.5	46.70	168.0
Ti	<0.1	2860	<0.1	465	<0.1	3090	<0.1	1940
V	<0.1	154.0	0.10	57.6	<0.1	133.0	<0.1	188.0
Zn	<0.05	88.7	<0.05	98.4	<0.05	119.0	<0.05	89.8
Zr		52.1		20.3		70.6		31.4

Appendix 4. cont.

	Site 32, Puertas de Paris, cross section of a road Depth 100 cm		Site 36, gravel pit, raw material of brick works Depth 200 cm		SANTO TOMÁS Site 39, Llano el Jobo, cross section of a road Depth 100 cm		Site 40, San Luis, Lóvago, cross section of a road Depth 100 cm		Site 41, Río Lóvago, fluvial deposit		Site 42 a, San Juan, La Libertad, fluvial deposit	
	221P	512P	221P/201P	512P	221P/201P	512P	221P/201P	512P	221P/201P	512P	221P	503P
Ag			<0.05/<0.05	<1	<0.05/<0.05	<1	<0.05/<0.05	<1	<0.05/<0.05	<1		
Al	5.2	56000	1.2/62.3	37600	41.0/2520.0	68000	1.3/89.2	30300	1.8/72.4	42200	<1	13100
As	<0.5	10	<0.5/<0.5	<10	<0.5/<0.5	<10	<0.5/<0.5	<10	<0.5/<0.5	<10	<0.5	<10
B	<0.5	<5									<0.5	<5
Ba	33.3	49.9	6/7.6	63.0	102.0/129.0	136.0	75.3/82.1	146.0	51.1/56.9	402.0	74.1	165.0
Be	<0.05	0.7									<0.05	0.6
Ca	216	254	3130/3160	14600	3290/3800	3400	2860/2840	3400	5940/6800	12800	426	572
Cd	<0.05	<0.5	<0.05/<0.05	<0.5	<0.05/<0.05	<0.5	<0.05/<0.05	<0.5	<0.05/<0.05	<0.5	<0.05	1.1
Co	<0.1	<1	0.1/0.07	34.0	0.25/0.52	41.0	0.14/0.13	12.0	0.14/0.13	24.0	1.13	26.3
Cr	<0.1	26.9	<0.3/<0.3	73.0	<0.3/<0.3	112.0	<0.3/<0.3	6.0	<0.3/<0.3	41.0	<0.1	8.2
Cu	0.20	52.8	<0.2/0.3	109.0	<0.2/0.3	108.0	<0.2/0.3	36.0	<0.2/<0.3	66.0	1.30	112.0
Fe	<2	85600	<2/10	54800	<2/36	74300	<2/8	27300	<2/<2	49100	<2	46700
K	38	286	12/12	300	136/159	1910	245/249	1350	90/102	1550	30	792
Mg	199.0	1570	929.0/943.0	18400	2630.0/3070.0	12500	559.0/584.0	5300	1130.0/1310.0	12200	161.0	865
Mn	0.22	66.2	<0.1/1.52	893.0	0.98/2.03	692.0	0.31/1.94	624.0	<0.1/2.00	880.0	383.00	1340
Mo	<0.2	<3	<0.2/<0.25	<5	<0.2/<0.25	<5	<0.2/<0.25	<5	<0.2/<0.25	<5	<0.2	<3
Na	12.8	<50	20.4/21.2	3020	62.0/72.1	110	73.2/71.3	170	169.0/172.0	1350	10.4	<50
Ni	<0.1	2.3	<0.2/<0.5	54.0	<0.2/<0.5	129.0	<0.2/<0.5	2.0	<0.2/<0.5	23.0	0.20	8.2
P	<2	216	3.0/4.0	983	4.0/14.0	116	2.0/5.0	<100	2.0/2.0	336	<2	238
Pb	<0.5	11	<0.5/<0.5	<5	<0.5/<0.5	5	<0.5/<0.5	7	<0.5/<0.5	<5	0.5	46
S	8.2	<50	<5/<5	<50	20.5/20.5	89	<5/<5	<50	<5/<5	51	20.8	171
Sb	<2	<15	<5/<5		<5/<5		<5/<5		<5/<5		<2	<15
Sr	6.84	11.9	27.80/27.60	138.0	47.70/56.30	45.6	30.30/30.80	31.6	40.30/41.30	210.0	2.61	9.5
Ti	<0.1	654	<0.25/<0.25	2630	<0.25/<0.25	697	<0.25/<0.25	1710	<0.25/<0.25	1580	<0.1	114
V	<0.1	205.0	<0.25/<0.25	220.0	<0.25/0.41	152.0	<0.25/<0.25	112.0	<0.25/<0.25	166.0	0.30	106.0
Zn	<0.05	22.7	<0.1/<0.1	40.0	<0.1/<0.1	27.0	<0.1/<0.1	19.0	<0.1/<0.1	44.0	0.84	99.8
Zr		27.8										5.6
Hg												0.035
Au (µg/kg)		<10										1930

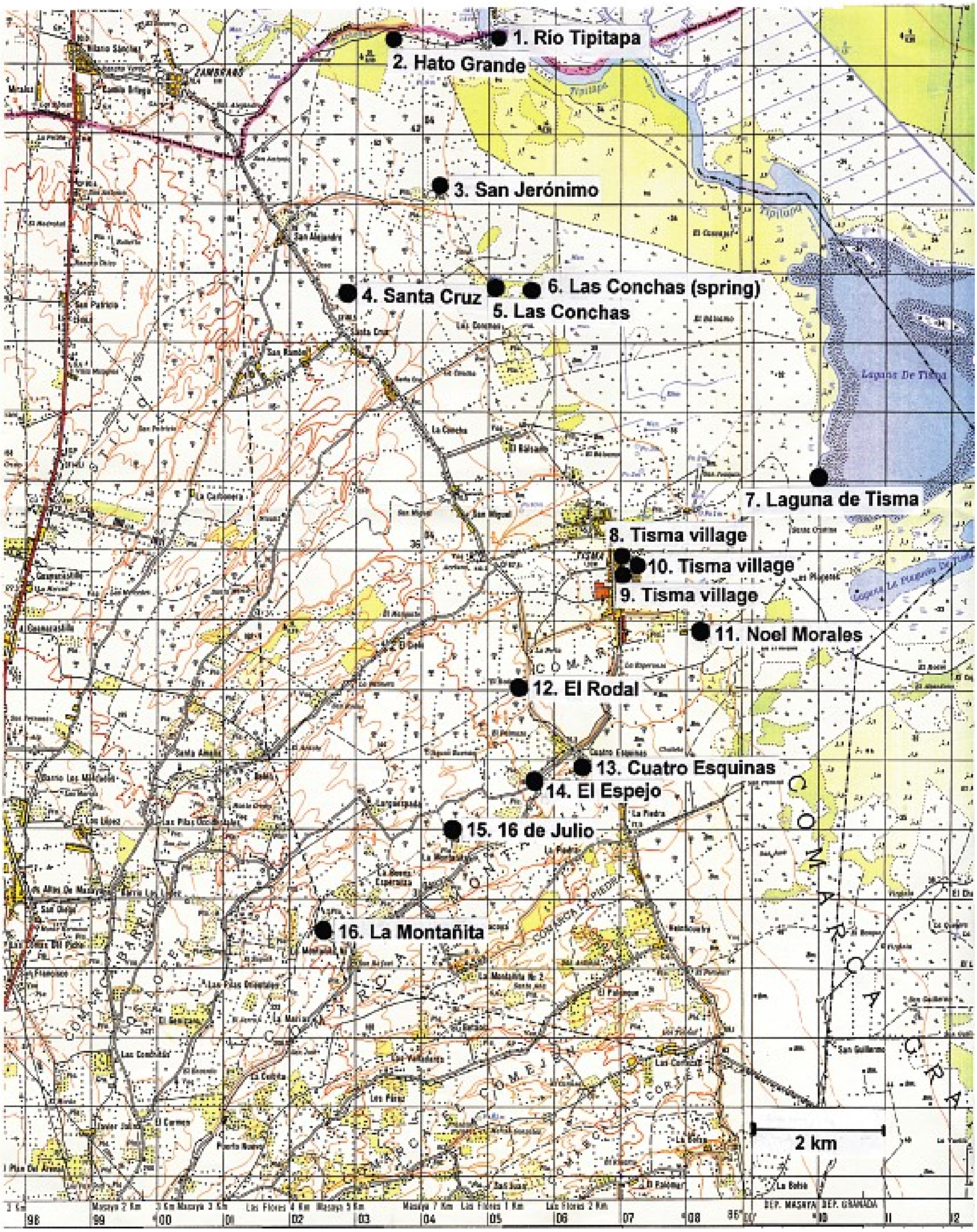
Appendix 4. cont.

SANTO TOMÁS

	Site 42 b, San Juan, cross section of a road		Site 42 c, San Juan, cross section of a road		Site 43 a, Río Mico, La Libertad, fluvial deposit		Site 43 b, La Libertad, cross section of a road		Site 44 a, San Pedro de Lóvago, fluvial deposit		Site 44 b, San Pedro de Lóvago, bottom sand of the river		Site 45, Santo Tomás, fluvial deposit	
	Depth 100 cm		Depth 100 cm				Depth 100 cm							
	221P	503 P	221P/201P	512P	221P	503P	221P	503P	221P	503P	221P	503P	221P	503P
Ag			<0.05/<0.5	<1										
Al	3.0	92400	1.2/41.1	25900	<1	12000	4.9	88800	<1	32200	<1	15400	<1	30900
As	<0.5	<10	<0.5/<0.5	<10	<0.5	<10	<0.5	<10	<0.5	11	<0.5	<10	<0.5	<10
B	<0.5	<5			<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5	<0.5	<5
Ba	78.5	476.0	0.1/0.6	22.0	21.5	167.0	1.4	5.9	92.9	219.0	48.7	185.0	60.5	342.0
Be	<0.05	1.5			<0.05	<0.5	<0.05	0.6	<0.05	0.7	<0.05	0.6	<0.05	0.5
Ca	33	61	4590/5520	9800	605	880	<5	<50	2980	4070	1480	5740	3440	5410
Cd	<0.05	<1	<0.05/<0.05	<0.5	<0.05	1.2	<0.05	<1	<0.05	1.0	<0.05	1.3	<0.05	1.2
Co	0.57	168.0	0.09/0.09	35.0	<0.1	42.8	<0.1	1.9	<0.1	17.5	<0.1	12.0	<0.1	18.3
Cr	<0.1	30.6	<0.3/<0.3	55.0	<0.1	20.9	<0.1	53.9	<0.1	16.6	<0.1	18.1	<0.1	28.5_
Cu	1.90	279.0	<0.2/<0.3	45.0	1.00	123.0	0.10	48.7	0.10	56.7	<0.1	34.5	0.40	49.9
Fe	<2	90300	<2/5	60800	<2	41200	<2	74300	<2	48000	<2	36600	<2	42900
K	53	1820	10/13	70	28	982	<10	376	50	879	113	1120	73.2	1250
Mg	283.0	3960	1350/1640	14300	237.0	907	83.0	1440	829.0	4230	343.0	3050	778.0	4220
Mn	5.81	5420	<0.1/1.73	1030	5.59	1940	<0.05	235.0	7.66	1000	0.26	541.0	23.10	1230
Mo	<0.2	<3	<0.2/<0.25	<5	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	<3	<0.2	<3
Na	28.9	172	56.9/66.9	160	10.9	<50	4.9	<50	95.9	220	63.3	251	834.0	1110
Ni	0.20	24.8	<0.2/<0.5	23.0	0.10	9.8	<0.1	5.7	<0.1	11.0	<0.1	5.1	<0.1	12.9
P	<2	115	4.0/4.0	752	<2	312	<2	<50	<2	170	<2	419	<2	212
Pb	<0.5	<5	<0.5/<0.5	<5	<0.5	40	<0.5	9	<0.5	<5	<0.5	7	<0.5	<5
S	43.2	<50	<5/<5	<50	43.4	246	321.0	415	5.9	93	2.8	<50	3.4	123
Sb	<2	<15	<5/<5		<2	<15	<2	17	<2	<15	<2	<15	<2	<15
Sr	0.42	7.5	27.50/33.40	39.5	4.00	13.6	<0.05	6.3	27.70	76.8	14.30	99.8	25.30	128
Ti	<0.1	361	<0.25/<0.25	2290	<0.1	84	<0.1	709	<0.1	396	<0.1	401	<0.1	482
V	<0.1	236.0	<0.25/<0.25	171.0	0.10	66.8	<0.1	148.0	<0.1	124.0	<0.1	67.0	<0.1	97.1
Zn	0.18	125.0	<0.1/<0.1	67.0	0.70	110.0	<0.05	27.0	0.11	76.0	0.06	57.5	0.06	69.4
Zr		26.5				3.1		21.3		18.2		13.5		21.9
Hg										0.285				0.037
Au (µg/kg)		<10				1628		<10		109		1853		149

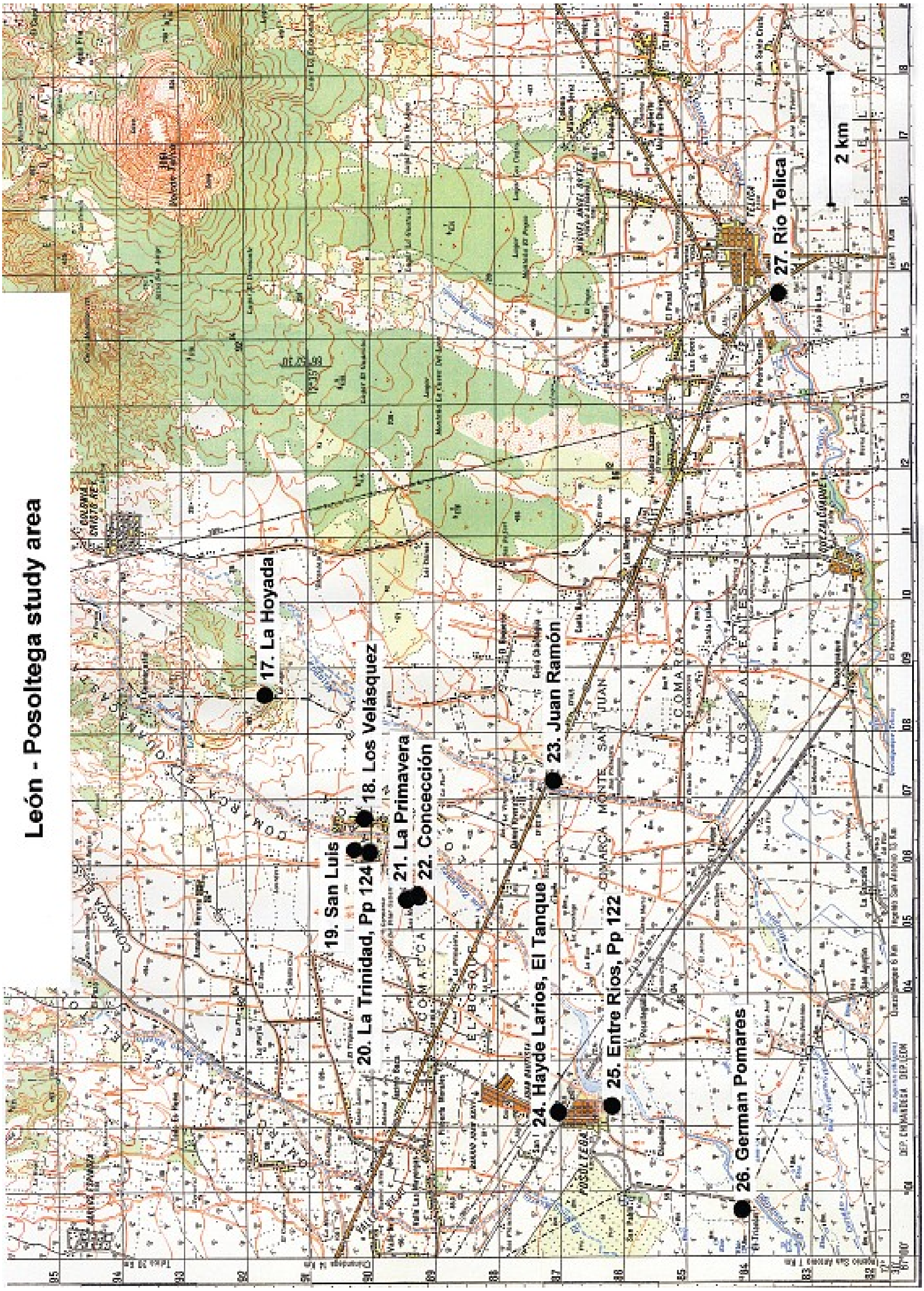
Appendix 5.: Maps of tresearch areas in Nicaragua

Tisma study area



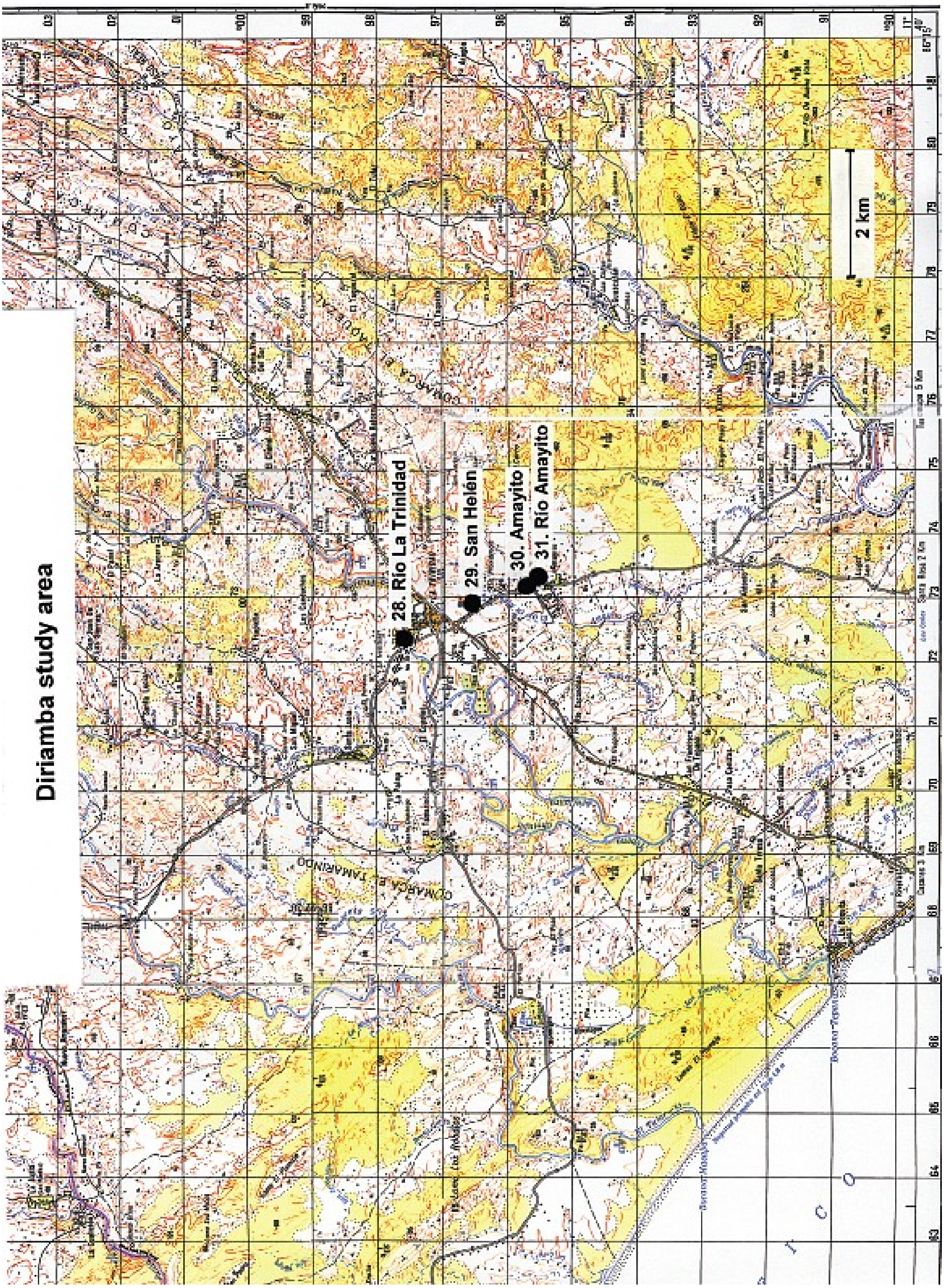
Reduction of the topographic map (1:50 000) of INETER (Instituto Nicaragüense de Estudios Territoriales), Managua, Nicaragua 1988

Appendix 5. (cont.)



Reduction of the topographic map (1:50 000) of INETER (Instituto Nicaragüense de Estudios Territoriales), Managua, Nicaragua 1988

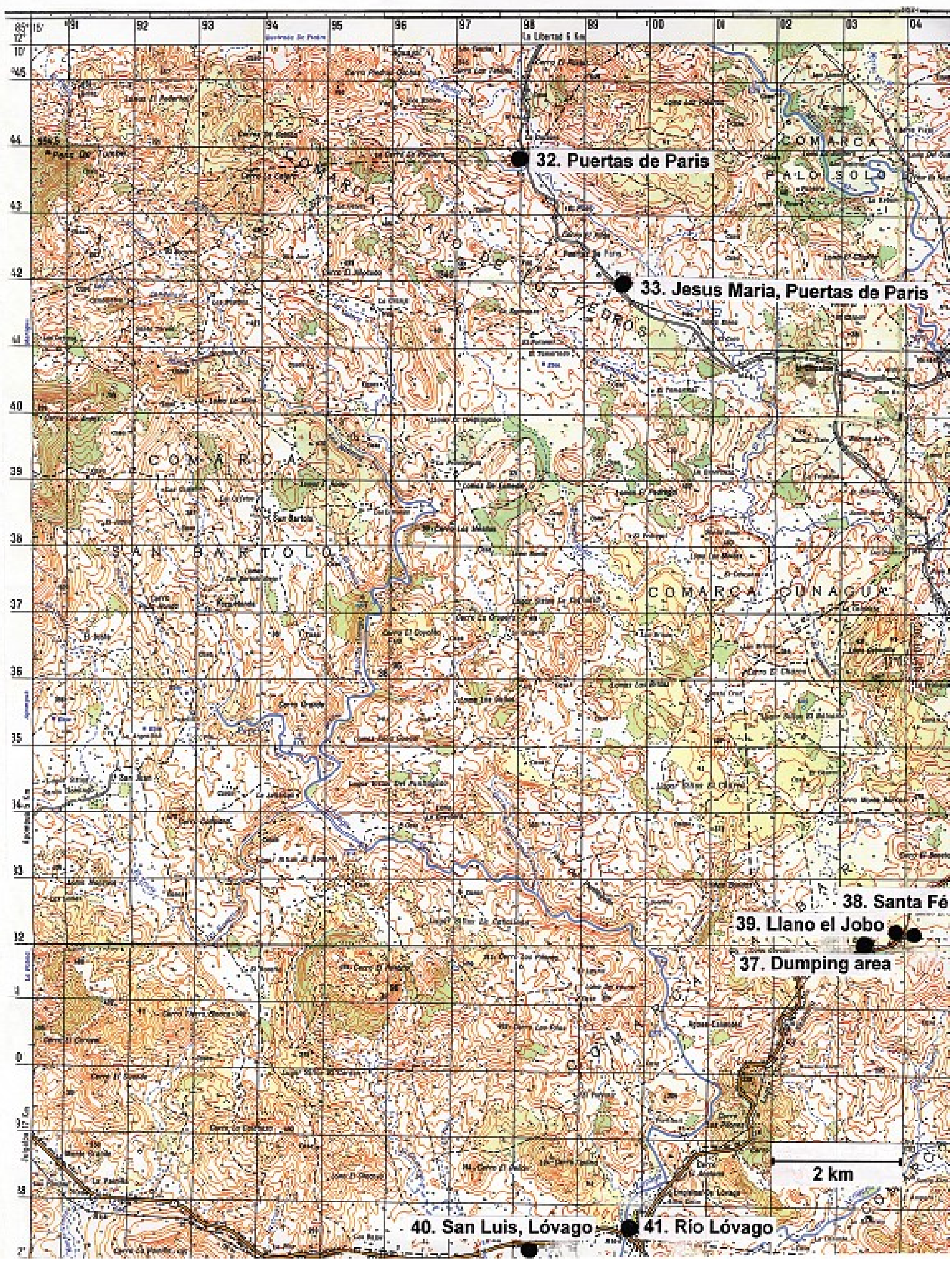
Appendix 5. (cont.)



Reduction of the topographic map (1:50 000) of INETER (Instituto Nicaragüense de Estudios Territoriales), Managua, Nicaragua 1988

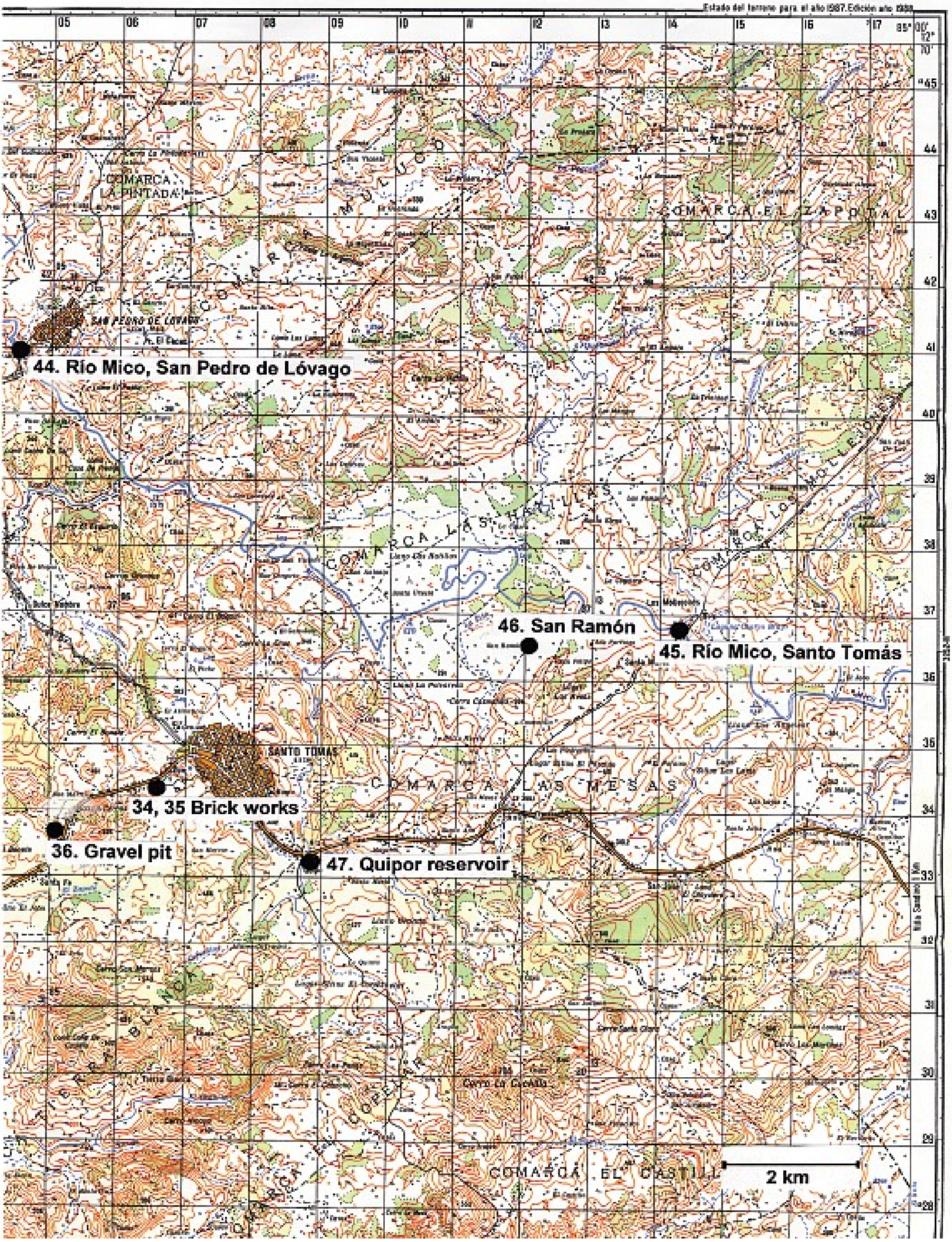
Appendix 5. (cont.)

Santo Tomás - La Libertad study area



Reduction of the topographic map (1:50 000) of INETER (Instituto Nicaragüense de Estudios Territoriales), Managua, Nicaragua 1988

Appendix 5. (cont.)

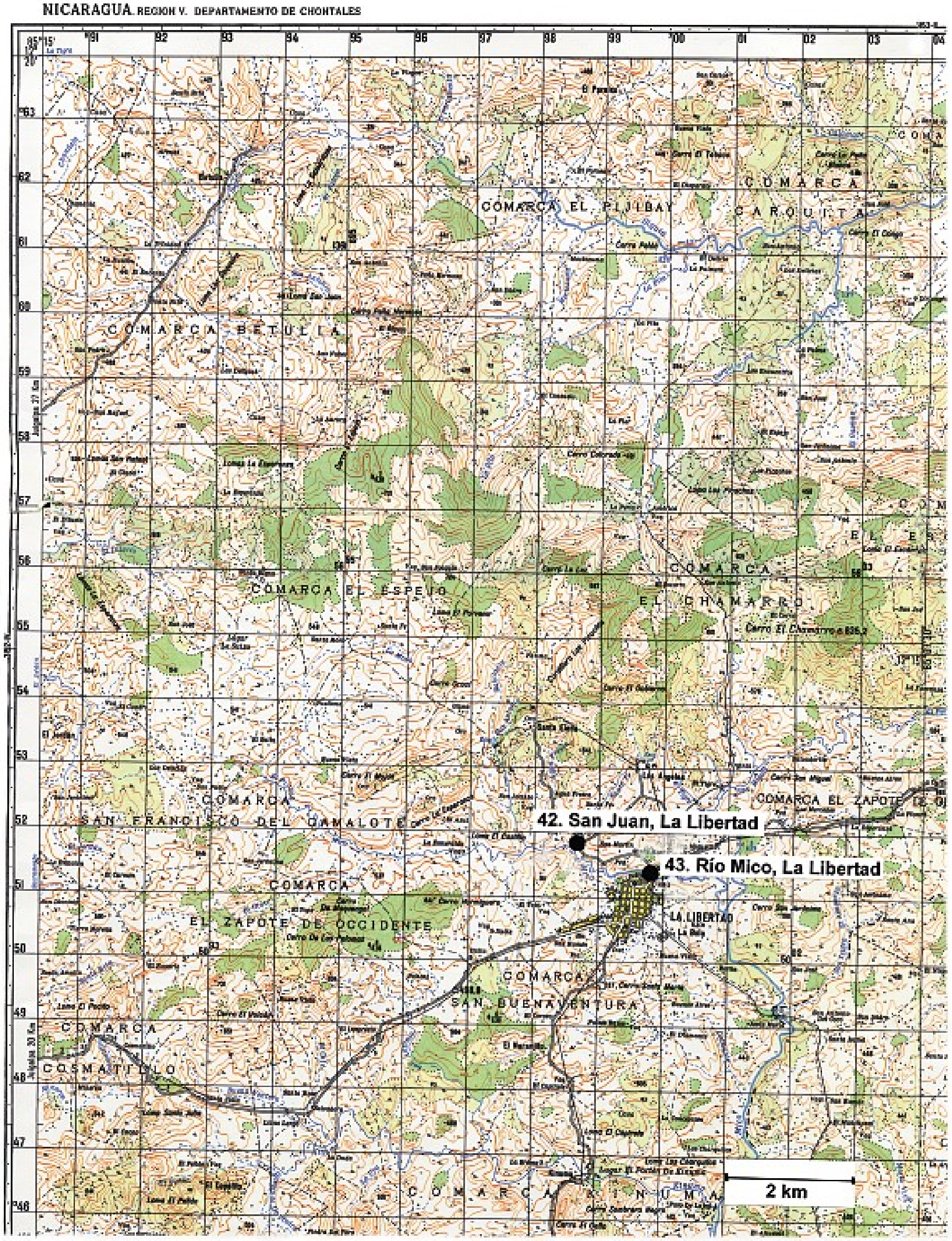


Santo Tomás - La Libertad study area

Reduction of the topographic map (1:50 000) of INETER (Instituto Nicaragüense de Estudios Territoriales), Managua, Nicaragua 1988

Appendix 5. (cont.)

Santo Tomás - La Libertad study area



Reduction of the topographic map (1:50 000) of INETER (Instituto Nicaragüense de Estudios Territoriales), Managua, Nicaragua 1988