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Environmental Geology in Austria

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19 Figures and 6 Tables

Abstract

An overview of the Environmental Geology in Austria and several practical examples (case studies) are given. The most important topics discussed are the geological aspects of sediment and soil pollution, water resources and pollution, sanitary landfills, contaminated sites, particulates as air pollution and radon as a geo-hazard.

Sediment: The most recent sediment investigations were carried out on the basis of the Austrian Water Quality Monitoring System (239 monitoring sites). A factor analysis of the sediment data indicates five factors of mostly minor and seldom major contamination. In only 13% of the almost 1,000 sediment samples did the metal concentrations exceed guidance values. The organic micro-pollutants (VOX, PAH's, PCB) are present in traces at some sites of the Austrian Danube.

Soil: The soil information system "BORIS" and the standardized "Data Key for Soil Science" provides information in a standardized form for the whole of Austria. In addition to land sealing, erosion and the input of heavy metals, the major threats to soil are organic pollutants and acidification.

An increased nitrogen input causes eutrophication of *forest soils,* which exceeds the critical loads for eutrophication in nearly all of Austria. The distribution patterns of Cd and Pb indicate the long-range transport of these pollutants, and the significant increase of pollution levels with altitude.

Groundwater: The Austrian Water Quality Monitoring System (AWQMS) provides information on groundwater in porous aquifers (1782 groundwater wells) in the lowlands and mountain basins, as well as on 235 springs in Alpine carbonate (karst) and fractured crystalline rocks. The assessment of the groundwater data in *porous aquifers* shows that atrazine and its main decomposition product desethylatrazine are still the most frequently found pesticides in the groundwater of Austria. Tetrachloroethene is the most frequent chlorinated hydro carbon reported in groundwater. The springwater quality in more than 90% of the samples from *carbonate (karst) and fractured crystalline rock* aquifers is excellent. The main problem concerning drinking water supply by karst water is regarded to be the temporary microbiological contamination.

Waste: 60 sanitary landfills are located above sedimentary rocks and only 4 are situated above crystalline rocks. Only 23% fulfill the present regulation of a geological barrier with more than 5m ($k_f > 10^{-7}$ m/s) or more than 3 m ($k_f > 10^{-8}$ m/s) thickness. Currently 2,470 sites have been listed in the Austrian Register of Contaminated Sites. This number comprises about 2,300 landfills and about 170 industrial sites and includes mainly metal or mineral oil processing enterprises, dry cleaners, chemical industries and gas works, where substances harmful to water are handled (chloro-hydrocarbons or mineral oil, etc).

Air: The dust samples in Vienna consist of calcite, dolomite, quartz, organic matter (+soot), and gypsum as major phases. Changes in winter samples (more enriched in calcite, dolomite and gypsum) are important for the interpretation of the heavy metal and PAH content in city dust.

In a remote Alpine station slag glasses and the growth of gypsum on filters indicate a long range transport of dust particles and pollutants from an urban or industrial source. At least 10-40% of heavy metals were transported, associated with particulate matter and did not readily dissolve in rain water.

The little village Umhausen in the Ötz-Valley in the western Austrian Province of Tyrol is the only place in the world where a radon hazard was recognized by the high mortality due to lung cancer. Recent studies revealed that a major aquifer (>40m) in the alluvial debris fan with its coarse components of a major rock fall transports Ra-226 and Rn-222 (up to 1,127 Bq/l) continuously below the village of Umhausen. In the houses of the village Umhausen, built on this debris fan, Rn-226 values are in the range of 0.1-40 kBq/m^3.

Introduction

It is assumed that the Baltic biologist Jakob von UEXKÜLL introduced the word "Umwelt" [Environment] into the scientific literature (UEXKÜLL, 1909). Similarly, "Umweltgeologie" [Environmental Geology] is the science dealing with the total environment of the earth crust and its interaction with humans and/or other organisms. Environmental Geology overlaps to a certain extent with the topics of Hydrogeology and Engineering Geology and can be regarded as an own sub-discipline, since the start of environmental awareness in the Sixties and Seventies of this century. The interaction of the geological cycle with human activities in a physical and (bio-geo)chemical sense is the prime subject of the Environmental Geological research.

In the following chapters the author gives an overview of the Austrian environmental situation and activities in the field of the Environmental Geology. Due to the limited

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space, this will be given as short background information and additional practical examples.

A short history of the environmental geology in Austria

Initial activities in environmental geology in Austria were accomplished in connection with the improvement of water quality. The activities were induced by the famous geologist Eduard Suess investigating the geology and the quality of the ground water, which finally led to the construction of an aqueduct bringing contamination-free alpine karst water to the capital city of Vienna over a distance of 112 km (SUESS, 1862).

After the second World War, the applied geologist Heinrich HÄUSLER (1959) introduced the term "Anthropogeologie" [Anthropo-Geology] describing human activities interfering with the geological cycle. TOLLMANN (1986) summarized the environmental geological research in Austria up to the beginning Eighties, stressing the important contribution of the earth sciences to regional planning and the potential in raw materials, clean groundwater and geohazards of selected regions (GRÄF, 1984; PIRKL et al., 1991).

In recent years four scientific meetings ("Erdwissenschaftliche Aspekte des Umweltschutzes"), the first occurring in 1986, have been devoted to environmental and geological topics in Austria. The most important topics discussed in these meetings are the geological aspects of sediment and soil pollution, water resources and pollution, impact of daming rivers, sanitary landfills, contaminated sites, radon as a geohazard, climate change, quarrying and environmental problems etc. (MITT. ÖGG, 1986, 1990, 1997; ARSENAL, 1998) (Fig. 1).

Sediments

Adsorbable organic haolgenes (AOX), organic matter and heavy metals in Austrian riverine sediments

The sampling and chemical analysis of aquatic sediments constitutes an efficient tool for environmental protection by providing a way of indicating the regional distribution of natural and pollutant-derived concentrations of certain elements. The sediment analysis represents an important tool to evaluate surface water quality, because most contaminants are quickly adsorbed onto suspended matter and are continuously deposited as sediments in sites of low flow velocities.

The fine sediment fraction (<0.2 mm) is particularly useful for estimating the relative degree of pollution and for distinguishing between natural (geological) and anthropogenic sources. Coarser fractions (0.06-0.2 mm) have mainly been used for mineral prospection and include a larger proportion of rock fragments, mine tailings of operating and abandoned mines, as well as industrial particles removed by abrasion. Finer fractions (<0.06 mm) generally show higher concentrations of contaminants than coarser fractions and contain a greater proportion of substances (e.g. clay minerals, aluminum- and iron-/manganese-oxyhydroxides, amorphous silica and organic/humus matter) which actively "adsorb" and which thereby concentrate solutes (KRALIK, 1999a).

The chemical analysis of fine-grained river sediments has a long tradition in Austria. The largest analytical program of the crystalline areas in Austria (THALMANN et al., 1989) was undertaken for search of mineral resources. The resultant atlas of Austrian river sediments, which has made use of 30,000 samples, covers about two thirds of the Austrian territory. Further investigations covering large areas of particular provinces were undertaken in Carinthia (MÜLLER and SCHWAIGHOFER, 1990), Lower Austria (KRALIK et al., 1994; AUGUSTIN-GYURITIS and HOLNSTEINER, 1997), Upper Austria (MÜLLER and WIMMER, 1987) and Tyrol (PEHOFER et. al., 1990). These were based on about 2500 additional samples.

No limit values concerning quality standards of fine river sediments exist in Austria. Either natural geological background values (Geoindex; MÜLLER, 1979; KRALIK, 1999a) or guide values obtained from data in ecotoxicological literature are usually used as evaluation criteria. The Austrian guidance values for soils for agricultural use (ÖNORM L 1075) are reasonable to evaluate the contaminants in fine grained sediments as they are close to the concentrations which are regarded to have negative effects for aquatic flora and fauna (DUTCH MINISTRY OF ENVIRONMENT, 1994; SMITH et al., 1996; WACHS, 1995).

In only 13% of ca. 1,000 sediment analyses (see Tab. 1), covering 239 monitoring sites (Fig. 2), did the concentrations exceed the soil guidance values. However, in 53% of the monitoring sites the guidance values were exceeded at least once. Moreover there is no close correlation with the biological criteria to evaluate river quality (KRALIK, 1999b).

Generally, fine sediments from lowland rivers are slightly more contaminated with heavy metals than those from mountainous areas, due to higher population densities and *finer grain size distributions in low-land waters*. River basins where the concentrations of contaminants were frequently elevated are the Drau, Gailitz and Gail valleys in Carinthia, the Leitha, Fischa, Piesting, Triesting, Schwechat and Schwarza valleys in the southern Viennese Basin, the river Wien in Vienna itself, and the Mur, the Mürz and some of their tributaries in Styria.

A factor analysis of the sediment data indicates five contamination factors (see Fig. 2):

(1) General contamination by industrial and urban activities (cadmium, lead, zinc, copper);

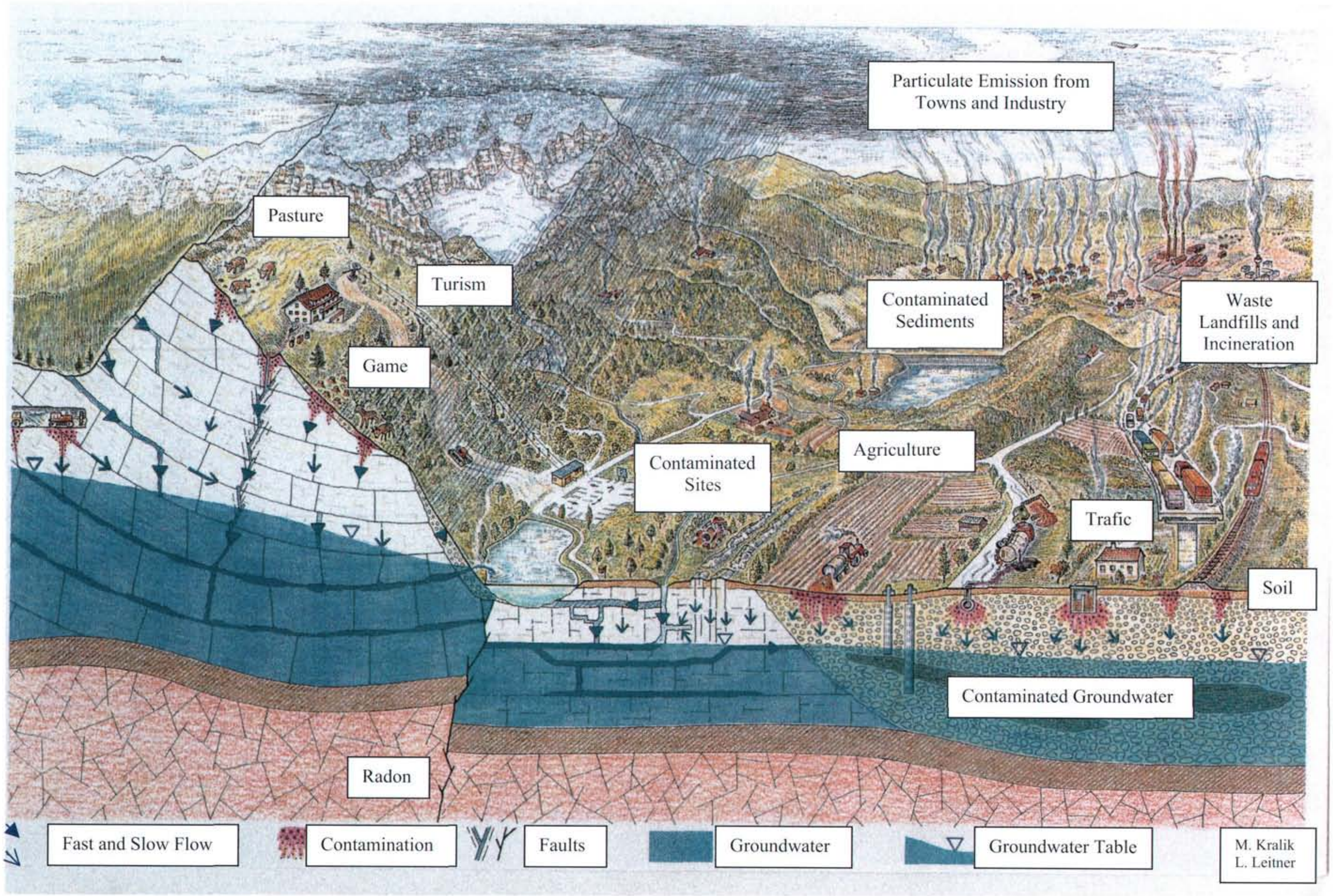
(2) Geologically or industrially induced elevation of chromium-nickel (copper) concentrations;

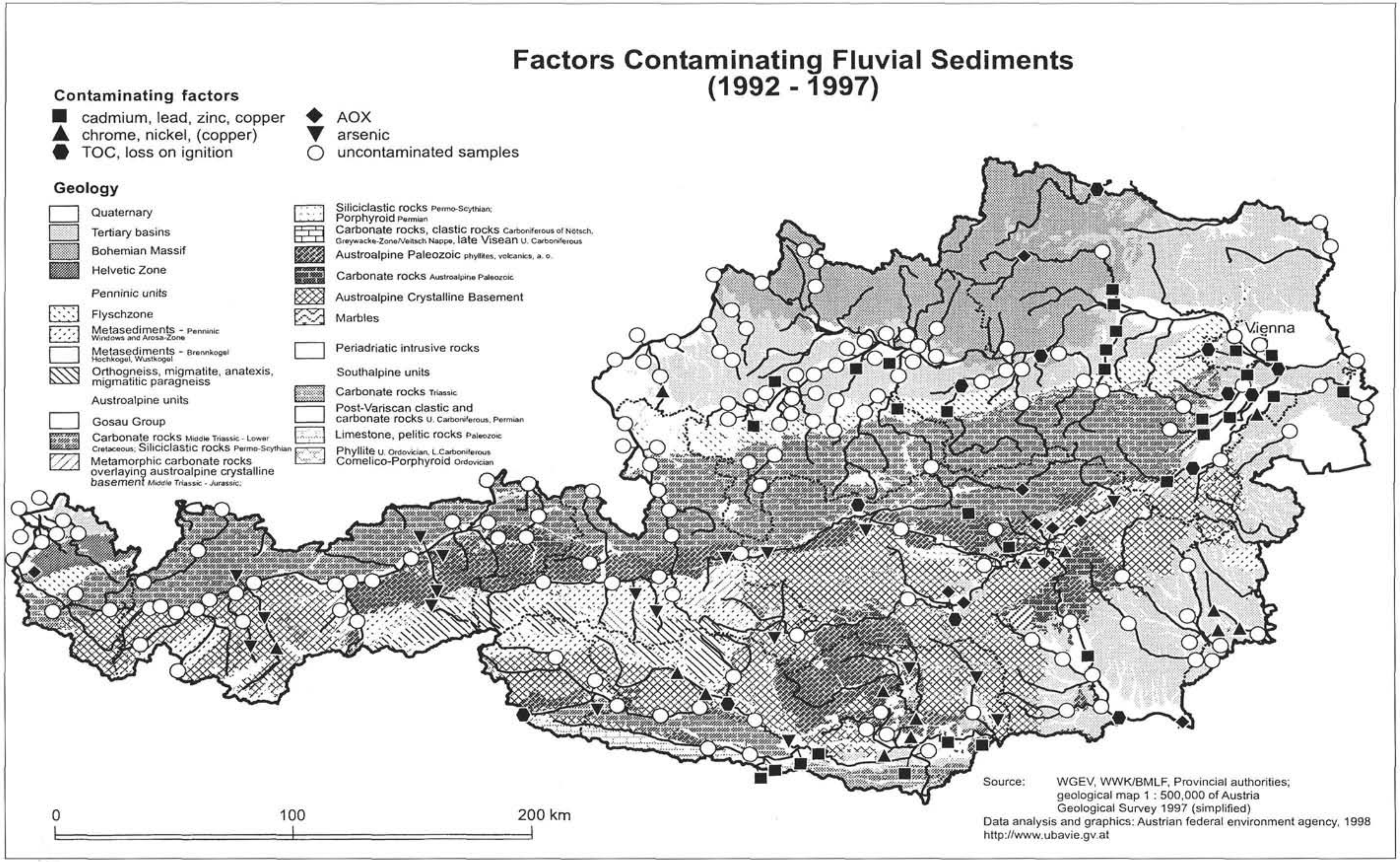
(3) High organic concentrations (>6% TOC – total organic carbon) in fine-grained river sediments due to agricultural or urban activities

(4) Elevated concentrations of organically bound chlorine (>75 mg/kg AOX) caused by industrial or urban activities

(5) High arsenic concentrations due to predominately geological peculiarities in the mountainous rivers of the Alps (KRALIK, 1999d).

Fig. 1 →
Generalized contamination cycle in Alpine and lowland environments by tourist, agricultural and industrial impacts on the geological cycle.


Particulate Emission from Towns and Industry
Pasture
Turism
Game
Contaminated Sediments
Waste Landfills and Incineration
Contaminated Sites
Agriculture
Trafic
Soil
Contaminated Groundwater
Radon
Fast and Slow Flow
Contamination
Faults
Groundwater
Groundwater Table
M. Kralik
L. Leitner



Source: WGEV, WWK/BMLF, Provincial authorities; geological map 1 : 500,000 of Austria Geological Survey 1997 (simplified)
Data analysis and graphics: Austrian federal environment agency, 1998
http://www.ubavie.gv.at

Fig. 2
Factors influencing sediment quality based on 239 monitoring sites of medium and large Austrian rivers (KRALIK, 1999d).

Tab. 1
Statistical data of river sediments (<0.04 mm) of the Austrian Monitoring Program (1992-1997).

Parameter	Units	Def.1) EU	Mean	RSD2) %	Median	Min3)	Max	>10% 4)	<25%	<75%	<90%	n7)	>MDL %5)
LI6)	%	Mont.	5.8	50	5.2	0.9	18	2.5	3.4	7.8	9.1	151	100
LI	%	Low.	7.8	52	7.2	1.8	32	3.1	4.5	10.3	12.3	88	100
TOC	%	Mont.	3.5	43	3.2	0.4	9.7	1.5	2.3	4.2	6.0	147	100
TOC	%	Low.	3.6	45	3.1	0.9	8.5	2.0	2.6	4.5	5.7	73	100
AOX	mg/kg	Mont.	38	37	32	7	147	17	23	50	72	139	100
AOX	mg/kg	Low.	31	47	28	8	112	17	21	39	49	82	100
As	mg/kg	Mont.	15	62	13.8	<1	111	2.3	5.6	22	27	148	99
As	mg/kg	Low.	11	62	8.5	1.1	52	3.4	4.3	16	21	71	100
Cd	mg/kg	Mont.	1.0	105	0.3	<0.1	31	0.0	0.1	1.2	1.6	151	85
Cd	mg/kg	Low.	0.9	107	0.6	<0.1	8	0.0	0.3	1.2	1.7	86	87
Cr	mg/kg	Mont.	63	47	34	4	3500	13	23	51	68	151	100
Cr	mg/kg	Low.	53	61	46	11	208	22	36	61	80	87	100
Cu	mg/kg	Mont.	48	45	41	2.0	450	9.3	23	53	80	151	100
Cu	mg/kg	Low.	41	52	36	3.5	240	15	20	46	60	87	100
Hg	mg/kg	Mont.	0.29	87	0.19	<0.1	2.4	0.05	0.10	0.40	0.63	150	95
Hg	mg/kg	Low.	0.42	96	0.30	<0.1	3.4	0.08	0.20	0.58	0.76	73	99
Ni	mg/kg	Mont.	39	36	37	3	290	10	21	49	64	151	100
Ni	mg/kg	Low.	33	48	32	8	85	13	20	43	53	87	100
Pb	mg/kg	Mont.	62	46	34	4	1550	16	21	54	74	151	100
Pb	mg/kg	Low.	56	53	40	12	413	22	29	53	91	87	100
Zn	mg/kg	Mont.	208	38	118	19	3677	45	76	165	260	151	100
Zn	mg/kg	Low.	282	51	130	36	3277	62	94	227	496	87	100

1) Def EU EG 78/659/EG (1987): Mont.: Mountainous water = salmonid waters; Low.: Lowland waters = cyprinide waters.

2) RSD: Mean of the Relative Standard Deviations of the data from 2-6 samples from an individual sampling site during the investigation period.

3) Min: minimum value

4) Percentiles e.g. 10% of the measurements are below the 10th percentile, 90% are higher etc.

5) >MDL: Percentage of measured samples is above the given "Minimum Detection Limit" (FEDERAL LEGAL GAZETTE: BGBL 1991a)

6) Loss by Ignition 550° (2h)

7) n: Number of sampling sites

Case Study 1: Inorganic and organic micro-pollutants in the Danube (VOX, PAH, PCB etc.)

The uppermost few centimeter of sediment were sampled 1992, in selected Danube reservoirs, in the free flowing part below Vienna and in two small boot harbours along the Austrian part of the Danube (Fig. 3). The fine grained sediments are predominantly of silt grain size with small portions of clay and sand fraction (<20%). In a petrographic sense they may be classified as carbonatic shales (30% quartz, 30% clays and micas, 30% carbonate minerals) with few percent of organic matter (1.5-5%). This composition makes them suitable as raw material for cement production and sealing material for sanitary landfills and dams.

The small anthropogenic influence on the Danube sediments is in all fractions (<0.18 mm; Tab. 2) below the Austrian guidance value for soils (ÖNORM-L1075). Just in the fine sediments of the two small boot harbours Cd and Pb concentrations exceed these guidance values considerable (Fig. 4).

The organic micro-pollutants are at some sites present in traces, but in general they are below the US (LONG and MORGAN, 1991) and Dutch (DUTCH MINISTERY OF ENVIRONMENT, 1994) guidance values. From 5 volatile chlorinated hydrocarbons (VOX), just tetrachloroethene (Per) and trichloroethene (Tri) are present in traces in the fine Danube sediments (Fig. 5). PAH's (polyaromatic hydrocarbons) and PCB's (polychlorinated biphenyls) are enriched in the sediments of the two small boot harbours (Fig. 6), but the "Effect-Range-Medium-value" is exceeded in the sum of 6 PCB's in one harbour sediment only (Fig. 7; KRALIK, 1996). Concentrations above the "Effect-Range-Medium-value" may have a negative effect on aquatic organisms (LONG and MORGAN, 1991).

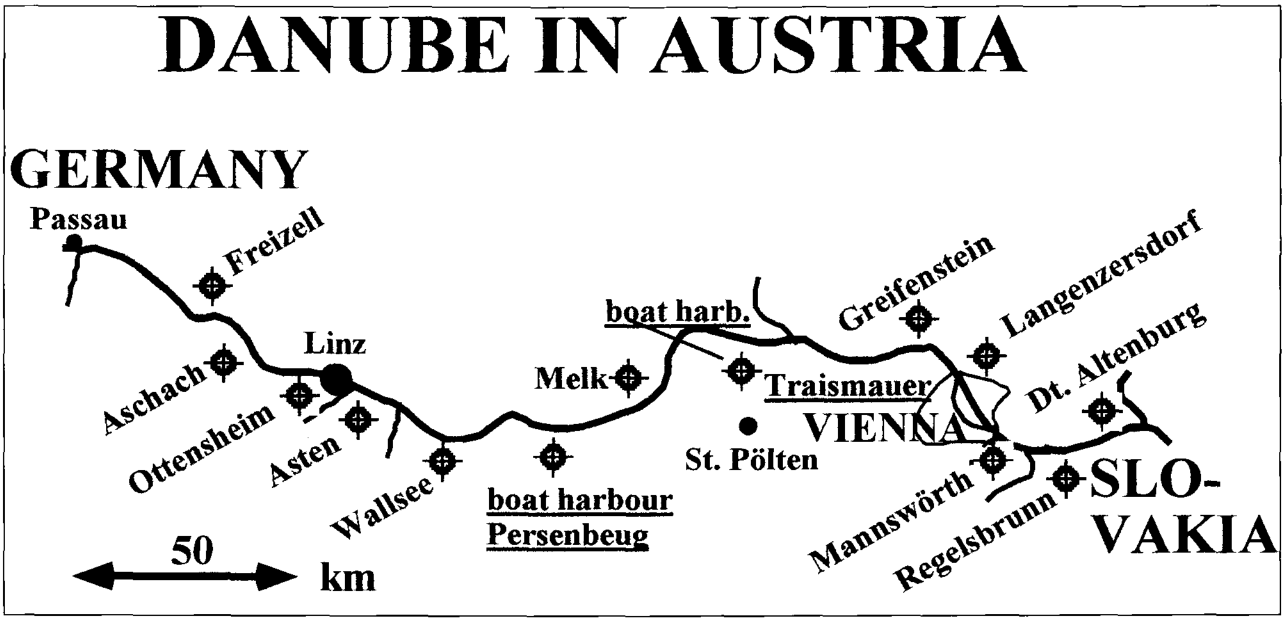


Fig. 3
Sediment sampling sites along the Austrian part of the Danube (stream km 1880-2220).

Soil and agriculture

The Alps cover about 60% of Austria and permanent settlement exists in only about 42 percent of the country. The Austrian utilized agricultural area covers about 45 per cent of the total area. Of its 3.4 million hectares about 2 million hectares are grassland. Forestry and extensive grassland production with cattle stocking prevail in the Alpine regions, while arable farming is concentrated on the lowlands and basins and especially the east of the country with its more moderate climate.

In addition to sealing and erosion, as well as input of heavy metals, the major threats to soil are organic pollutants and acidification. Besides wind erosion in the east of Austria, two types of water erosion can be distinguished. One takes place in intensively used agricultural land in hilly areas, the other in alpine regions. The latter can be enhanced by road construction, housing development, recreation facilities (mainly ski runs), alpine pastures (grazing and hoof damage and forest pasture), decline of forest protection because of game damage and unsuitable treatment of sensitive soils. Apart from the loss of fertile soil, erosion impairs water quality through the input of pesticides, nitrogen and phosphorous (GÖTZ et al., 1999).

Environmental state of soils in Austria

In the last years, Environmental Soil Surveys (ESS) have markedly improved the knowledge about the condition of and pressures on Austrian soils. "The Environmental Soil Survey" of the ASSS (Austrian Soil Science Society) estab-

Tab. 2
Mean value and Min.-Max. values of 11 sedimentsampler (<0.18 mm) of the Austrian part of the Danube.

SiO_2	Al_2O_3	TiO_2	Fe_2O_3[1]	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	S	1000 °C	Org.Mat.
(%)	(%)	(%)	(%)[1]	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
48	**12.7**	**0.59**	**3.8**	**0.103**	**10.3**	**5.7**	**2.2**	**1.08**	**0.28**	**0.087**	**14.8**	**2.81**
40-51	9.2-14.8	0.5-0.64	2.8-5.1	0.88-1.32	8.5-11.2	4.6-6.6	1.7-2.6	0.9-1.4	0.24-0.32	0.05-0.16	0.05-16.1	1.4-4.8

Ag	As	Ba	Be	Ce	Cd	Co	Cr	Cu	Ga	Hg	La	Mo	Nb
mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
0.22	**8.9**	**464**	**1.73**	**50**	**0.72**	**20**	**83**	**38**	**16**	**0.26**	**29**	**1.05**	**13**
0.07-0.6	5-16	388-532	1.1-2.4	42-64	0.4-9.0	15-27	56-102	22-58	10-22	0.11-0.63	24-36	0.7-2.4	11-15

Ni	Pb	Rb	Sb	Sc	Se	Sn	Sr	Th	V	Y	Zn	Zr	
53	**57**	**91**	**0.41**	**9.6**	**0.24**	**2.71**	**199**	**13**	**75**	**32**	**148**	**170**	
34-72	37-69	60-121	0.22-0.78	6.5-12.6	0.06--0.45	2.2-3.7	176-239	10-14	48-113	27-37	84-262	128-210	

[1] Total iron calculated as Fe_2O_3 (KRALIK, 1996)

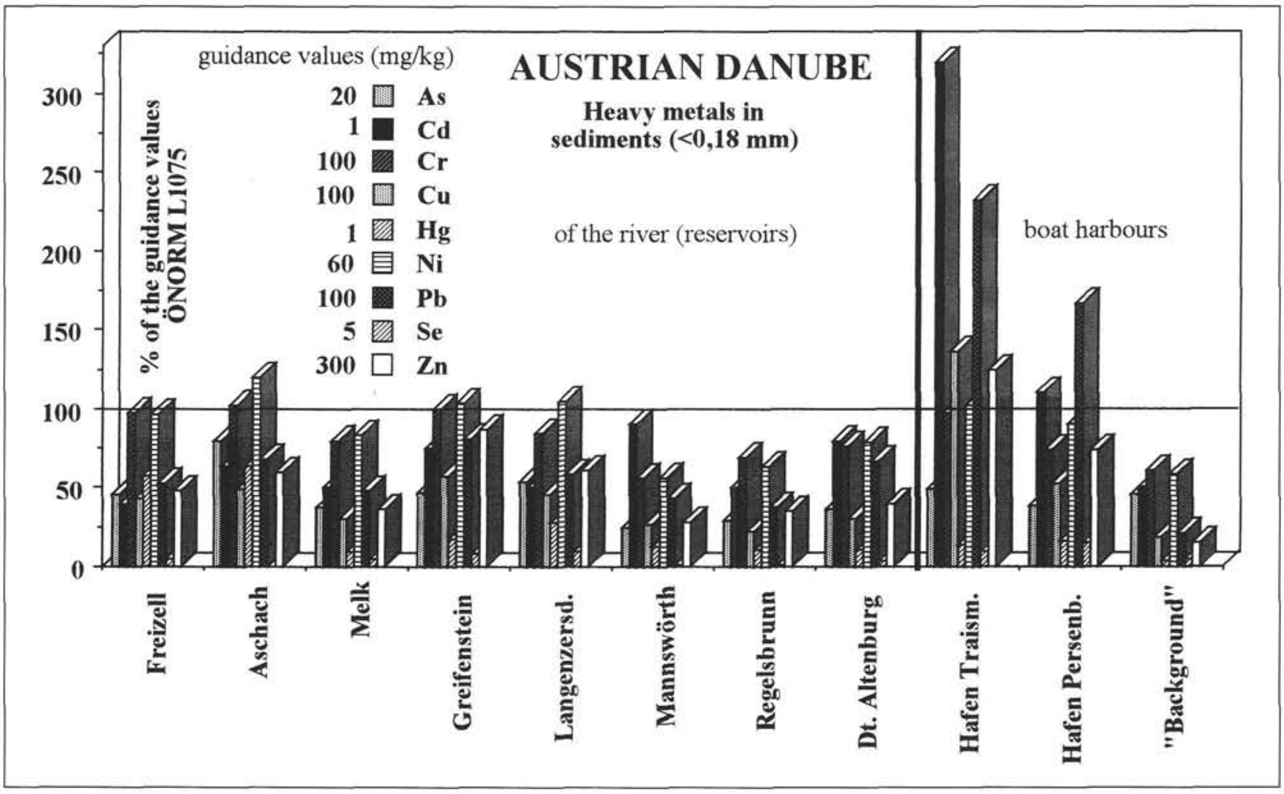


Fig. 4
Percentage of metal concentrations in Danube sediments (<0.18 mm) and two harbour sediments (KRALIK, 1996) compared to the Austrian guidance value for arable soils (ÖNORM L1075, 1993).

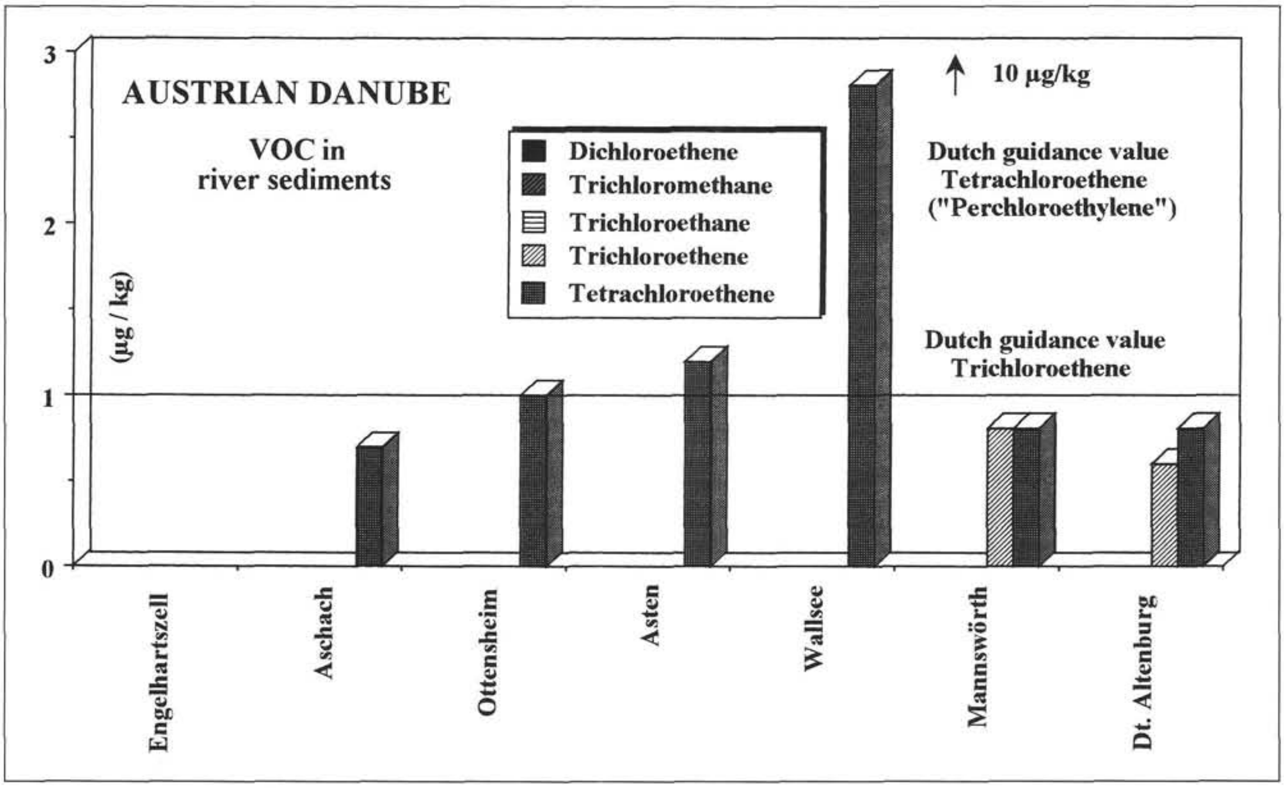


Fig. 5
Of the 5 volatile chlorinated hydrocarbons (detection limit of 0.5 µg/kg) analyzed in the Danube sediments just traces of tetrachloroethene ("Per") and trichloroethene ("Tri") have been found. These concentrations however are considerable lower than "Dutch guidance values for aquatic sediments" (Dutch Ministeryof Environment, 1994).

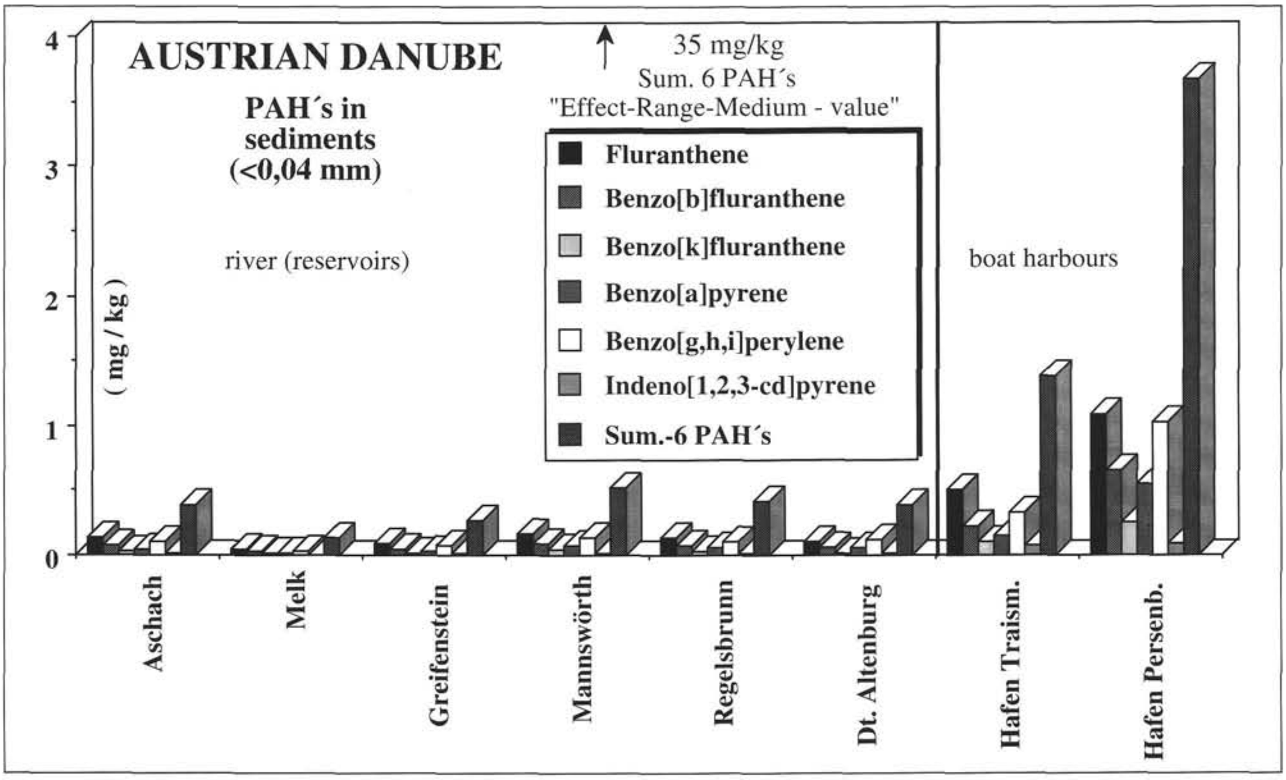


Fig. 6
The sum of the six analyzed PAH's is even in the sediments of the small boot harbours considerable lower than the "Effect-Range-Medium" (35 mg/kg) recommended by the NOAA (KRALIK, 1996).

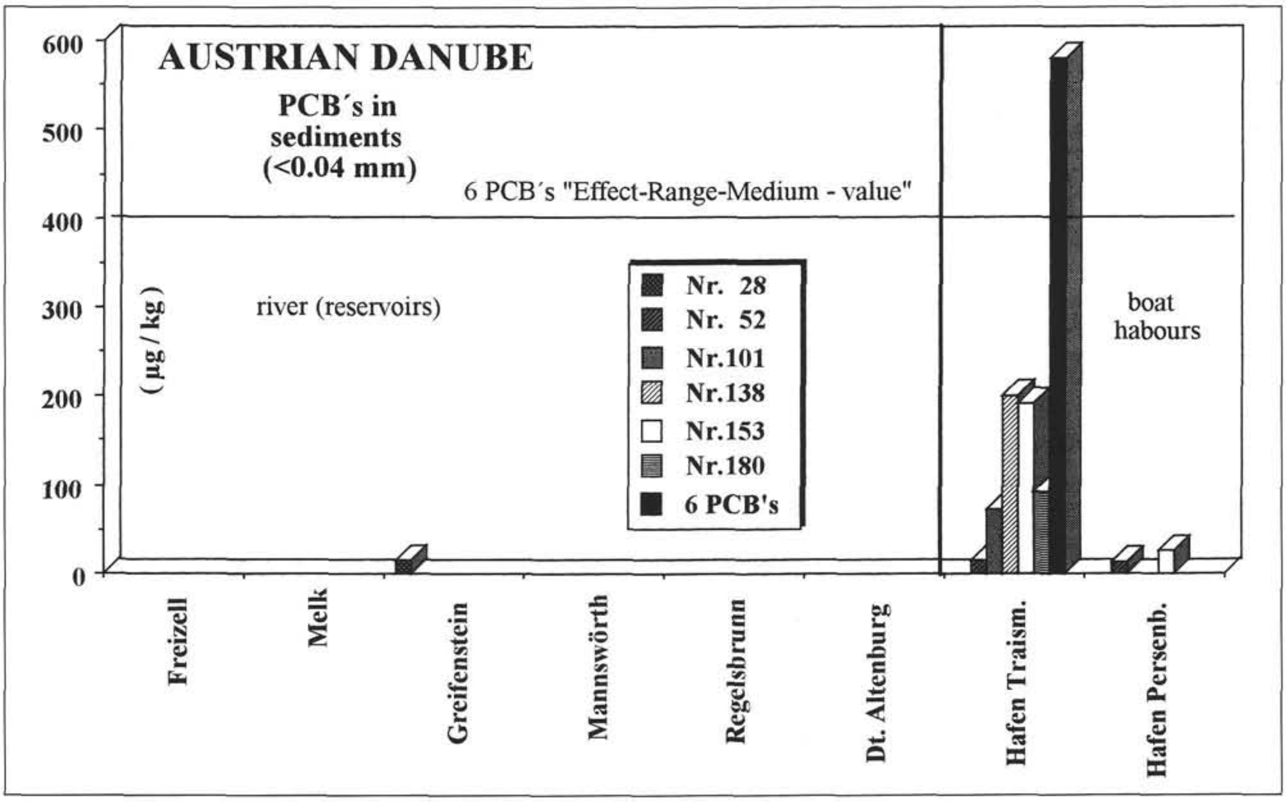


Fig. 7
Selected PCB's have been found just in sediments of a small boot harbour (detection limit 20 µg/kg). Just in the sediments of the harbour of Traismauer the "Effect-Range-Medium" (above 400 µg/kg negative effects on biota are likely) of the sum of 6 PCB's is exceeded (KRALIK, 1996).

lished guidelines on how to handle environmental soil surveys (BLUM et al., 1996). The sites are situated in a basic grid of about 4×4 km.

Acidification, Humus and Heavy Metals

Strongly acidic sites with a pH-value below 4.5 in agricultural used soil are found in Styria (14%), Tyrol (35%) and Salzburg (38%).

The humus content in grassland is higher than in agricultural land and therefore is higher in the west of Austria than in the east. As an example: In Salzburg 40% of the soils show more than 8% humus, whereas in Lower Austria about 40% show less than 2%. In the agriculturally used areas in the east of Austria the humus content can be as low as 0.5%. It is not clear whether the reasons for this are an intensification of soil tillage and former straw burning or a thinning of humus caused by increasing plough depth.

The guidance values for most heavy metals of (ÖNORM L 1075) are exceeded in less than 3% of the sites (mainly arsenic, lead and cadmium). *Arsenic* contents are especially high in some regions of Salzburg, Styria and Lower Austria, due to geogenic and partly anthropogenic sources.

The guidance value of ÖNORM L 1075 for *lead* (100 mg/kg) is exceeded in the soils of Tyrol at 9.2% of the sites and in Salzburg at 3.6% of them. This could be due to local emissions, impacts of mining and long-range transport of pollutants. The latter is seen as contamination north of the main Alpine ridge. High transit traffic makes the valley of the Inn river the most polluted region in Tyrol.

High *cadmium* contents can be partly explained by long-range pollution and subsequent deposition on exposed slopes. On the other hand, the Northern Calcareous Alps seem to have a naturally elevated content of cadmium.

Soil Monitoring

Since 1992, the Federal Environment Agency has been developing the soil information system "BORIS" (SCHWARZ et al., 1998) and the standardized "Data Key for Soil Science" (SCHWARZ et al., 1999). Right now the data base holds a soil map of Austria (scale 1:750,000) and more than 500,000 records from more than 5,000 sites (GÖTZ et al., 1999).

Environmental Impacts of Agriculture

In Austria agriculture is characterized by small, non-industrial agricultural units (average 15.4 hectares agriculturally used land); 35% of all farms are mountain farms.

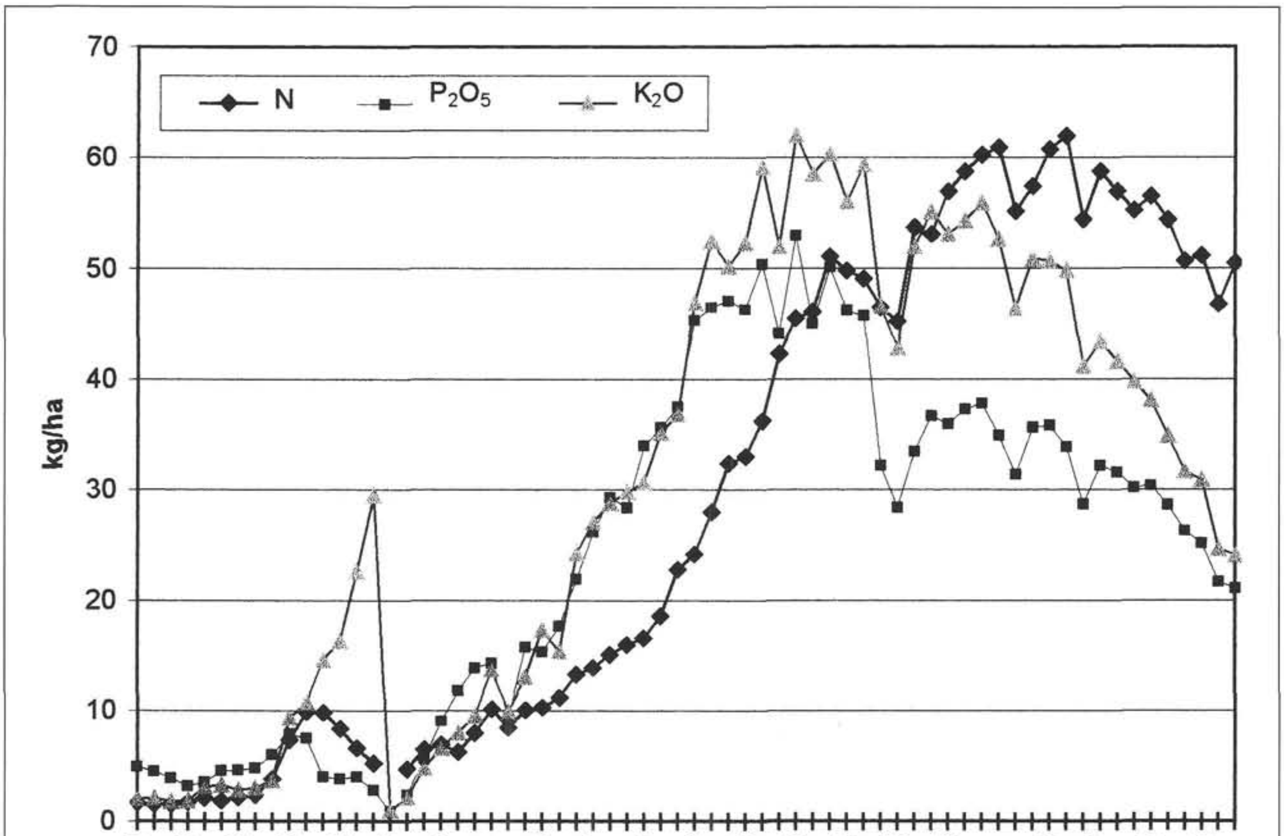


Fig. 8

Sales of artificial fertilizers in Austria in kg of pure nutrients per ha agricultural land chosen to be fertilized (comprising Austrian arable and grassland area without alpine pastures, rough pastures, litter meadows and arable land and grassland out of production) and year (Source: Federal Agency and Research Center for Agriculture (BFL), 1997 in GÖTZ et al., 1999).

The Austrian use of mineral nitrogen fertilizer of 47 kg N per hectar land chosen to be fertilized, as well as that of phosphorus (22 kg P_2O_5 per ha) and potassium (25 kg K_2O per ha) is below the European average (Fig. 8).

Since there is no evidence of falling nitrate levels in ground water yet (see chapter groundwater), the amount of fertilizer used should at least be kept at current levels (GÖTZ et al., 1999).

Acidifying and eutrophying pollutants

These mainly comprise oxidized sulfur and nitrogen compounds, as well as reduced N-compounds. These pollutants may cause soil acidification, which in the long run leads to nutrient leaching, the release of toxic substances to the soil solution as well as root damage.

Secondary soil acidification processes were ascertained for about 12% of Austrian forest soils, another 20% were found to be sensitive to acidification (FORSTLICHE BUNDESVERSUCHSANSTALT, 1992). The critical loads for acidification have been exceeded in many Austrian forest areas, in particular in areas with silicate bedrock.

An increased nitrogen input causes eutrophication of forest ecosystems, which, in turn, may lead to changes in species composition, as well as nutrient imbalances in tree nutrition. In nearly all of Austria, the critical loads for eutrophication have been exceeded (HACKL et al., 1999).

Heavy metals and organic pollutants

The nation-wide forest soil condition survey of the Federal Forest Research Center Vienna showed that the standard values for soil pollution with lead and cadmium were exceeded at 26% and 34% of the investigated sites, respectively (FORSTLICHE BUNDESVERSUCHSANSTALT, 1992). The distribution patterns indicate long-range transport of these pollutants, and the significant increase of pollution levels with altitude underlines the unfortunate geographic conditions, which make an alpine country like Austria a sink for air pollutants from very distant sources (Fig. 1).

Furthermore, proof was established (WEISS, 1998) that the Austrian forests are also polluted with Persistent Organic Pollutants (POPs). A number of background sites, i.e. sites located away from potential pollution sources (settlements, industry and traffic routes) showed high concentrations of substances (HACKL et al., 1999), the use of which has been reduced or banned in Austria for years (e.g. DDT).

Groundwater

Groundwater Quality in Austria: 2000 Monitoring Sites are reporting

Background

Groundwater is one of the most important drinking water resources in Europe, as well as in other parts of the world. The existing European regulations set high priorities to protection of the ground water for drinking water supply (EU COUNCIL RESOLUTION, 1992). In Austria more than 99% of the drinking water is abstracted from groundwater. About 50% is supplied from Quaternary and Tertiary sediments (porous media) and 50% from carbonate and crystalline rocks (karst- and fractured aquifers) of variable ages. The sedimentary basins are densely populated areas with agricultural and industrial use. The karst and fractured crystalline rocks are mainly in more remote Alpine areas with partly intense tourist use. Due to their particular structure, karst aquifers are more vulnerable to pollution than groundwater in porous aquifers. However, the resulting complexity of the properties and the dynamics of various aquifers makes it even more important to run a monitoring system to unravel pollution sources at an early stage, in order to allow time to set preventive measures.

The Austrian Water Quality Monitoring System (AWQMS)

New legislative and administrative procedures concerning water pollution have been the basis for the AWQMS for ground water and running water since 1990. Federal and provincial authorities, as well as a large number of private laboratories, are involved in the monitoring system. As part of this AWQMS (altogether 2000 sampling sites) for porewater (1782 groundwater wells) a sampling density of about 10 km^2 per sampling site for most important aquifers is achieved. Monitoring wells, domestic wells, industrial wells and water supplying facilities are used as sampling sites. The density of the sampled springs in karstic and fractured rocks (235 springs) is about 200 km^2 per sampling site. The selection of the sampling site was based on experts' hydrological, geological and geochemical knowledge (Fig. 9).

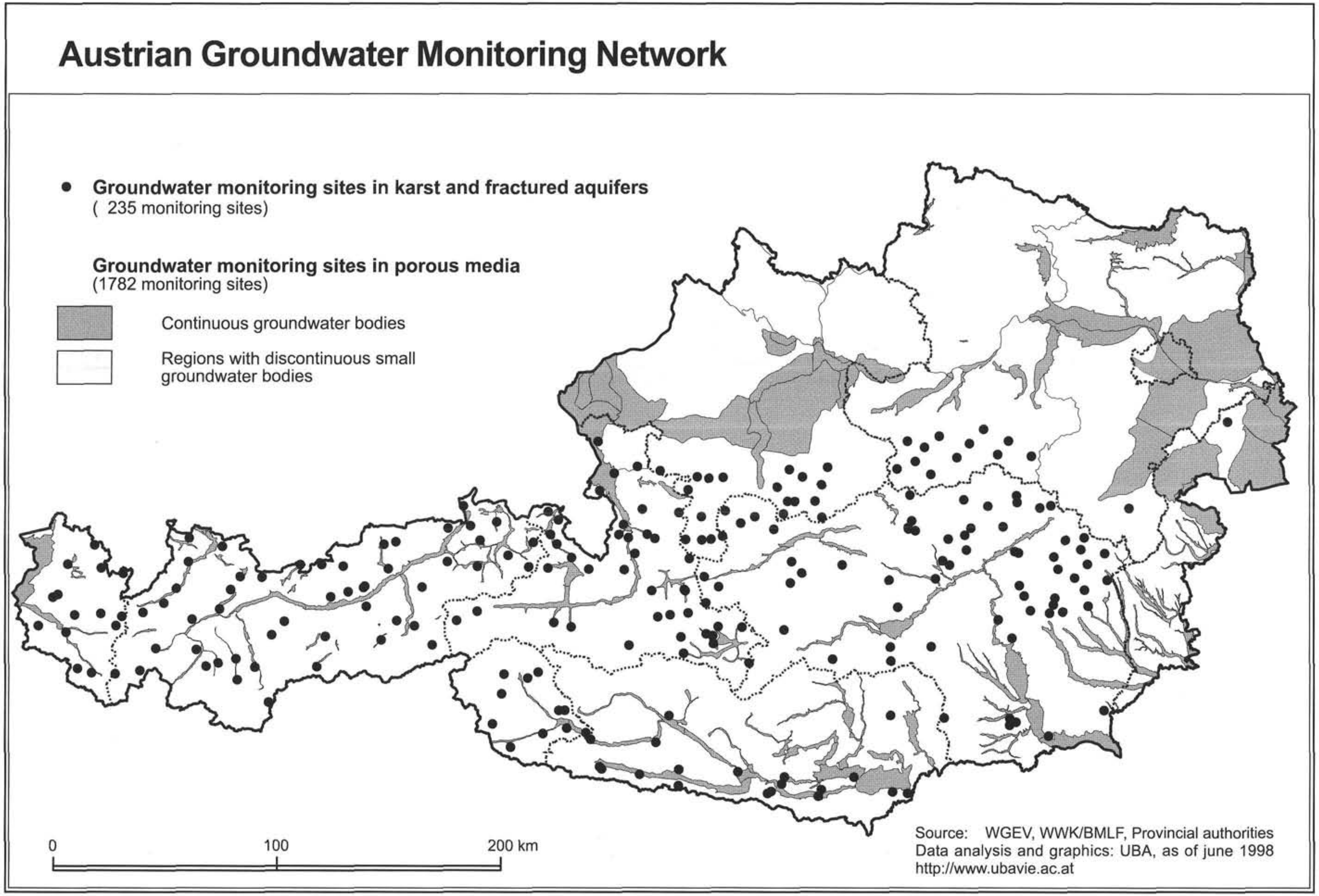
All wells and springs have generally been sampled four times a year since 1991. The design of the monitoring network integrates elements of background, impact, trends and compliance monitoring. The rapid access to data of every parameter and sampling site is provided on the internet *(http://www.ubavie.gv.at)* and biannual expert reports (KRALIK et al., 1999).

Groundwater in porous media

Quality of groundwater in porous media is endangered by both, diffuse and point pollution sources. The main pollutants in Austria are nitrate, pesticides and chlorinated hydrocarbons. Whereas nitrate and pesticides mainly result from diffuse sources, chlorinated hydrocarbons arise from point sources. Most important results of the groundwater quality monitoring program and assessment are given below. An ordinance on groundwater threshold values has been developed (BGBL, 1991b, 1997; BGBL – FEDERAL LEGAL GAZETTE) for the assessment of pollutants due to diffuse sources. The threshold values in this ordinance are due to the precautionary principle as a rule below or at maximum equal to drinking water standards. If these threshold are exceeded over a longer period at a minimum of at 25% of sampling sites within a groundwater body, remediation measures have to be introduced by the provincial authority.

Nitrate

Results for nitrate in groundwater are summarized in Tab. 3 for Austria and each of the nine Austrian provinces. Detailed analyses of time series from 1992 to 1995 gave evidence that there is no significant change (summarized all over Austria). Neither a significant increase nor a decrease of concentrations has been documented (details in WWK/UBA, 1999).



Source: WGEV, WWK/BMLF, Provincial authorities
Data analysis and graphics: UBA, as of june 1998
http://www.ubavie.ac.at

Fig. 9 Groundwater monitoring in Austria (JUNE 1998). Observed porous aquifers and springs.

Tab. 3
Nitrate in Austrian groundwaters in porous media (period 1995 to 1998; PAVLIK et al., 1999).

Classes\Provinces	Bgld	Car	LA	UA	Sbg	Sty	T	Vbg	Vie	GPM	A tot
% <10 mg/l	38.1	41.2	22.9	19.0	67.6	32.9	74.0	85.4	11.0	37.8	42.5
% >10-30 mg/l	17.9	40.0	32.5	40.5	26.7	34.9	25.4	14.6	12.4	31.5	29.2
% >30-45 mg/l	9.6	9.4	13.6	22.8	4.3	14.1	0.6	0.0	14.4	11.6	10.8
% >45-50 mg/l	2.2	2.1	3.8	5.1	0.8	4.4	0.0	0.0	5.0	3.1	2.8
% >50 mg/l	32.2	7.3	27.2	12.6	0.6	13.7	0.0	0.0	57.2	16.0	14.7
Total No of analyses	913	1533	3506	1708	968	2373	1357	479	355	13192	14409

Bgld: Burgenland; Car: Carinthia; LA: Lower Austria; UA: Upper Austria; Sbg: Salzburg; Sty: Styria; T: Tyrol; Vbg: Vorarlberg; Vie: Vienna; A: Austria; GPM: Groundwater in porous media; A tot: All Austrian monitoring sites including groundwater from springs.

Atrazine

In total, data of 47 pesticides are available from the investigations based on the legal ordinance on water quality assessment (BGBL, 1991a). The assessment of the data show that atrazine and the main decomposition product desethylatrazine are still the most frequently found pesticides in Austrian groundwater (WWK/UBA, 1999). In many cases the concentration exceeds the threshold values of the ordinance on groundwater (BGBL, 1991b, 1997) and drinking water standards, which are in this case both 0.1 μg/l.

The percentage of samples above 0.1 μg/l atrazine and desethylatrazine in groundwater are given in Tab. 4 for each of the nine Austrian provinces, as well as for all of Austria (1. 1. 1992 – 30. 6. 1995). Atrazine was legally banned in Austria in 1995.

Volatile chlorinated hydrocarbons (VOX) in porous groundwater

An overview of the occurrence and frequency of chlorinated hydrocarbons in porous groundwater was given in one of the biannual reports (WWK/UBA, 1999). In the following table the four most frequently found hydrocarbons are presented. Tetrachloroethene (called Perchlorethylene or "Per") is the most frequent substance reported in groundwater, followed by Trichloroethene, 1,1,1-Trichloroethane and Chloroform. Other substances such as Tribrommethane, Bromdichloromethane, Dibromchloromethane, Dichloromethane, 1,2-Dichloroethane, Tetrachloromethane and 1,1-Dichloroethene) are reported at only a few monitoring sites only (KRALIK et al., 1999).

Groundwater in Karst and Fractured Aquifers

Due to the excellent water quality in more than 90% of the samples from karst and fractured crystalline rock aquifers, "elevated concentrations" are in reality only slightly above natural median concentrations, which cannot be directly compared with the contamination occurring in groundwater from porous media.

Pollution sources of spring waters

The main problem concerning drinking water supply by karst water is the temporary microbiological contamination (KRALIK, 1999b). This contamination usually occurs along with heavy rains. This fact makes specific treatment of karst water obligatory for maintaining an excellent drinking water supply.

The limiting values for drinking water were only temporarily exceeded in 6% of the springs for Al, Hg, Pb and desethylatrazine concentrations. The detection limits (>MDL; Tab. 5) of many of the other analyzed contaminants are exceeded in a small percent of the analyzed samples.

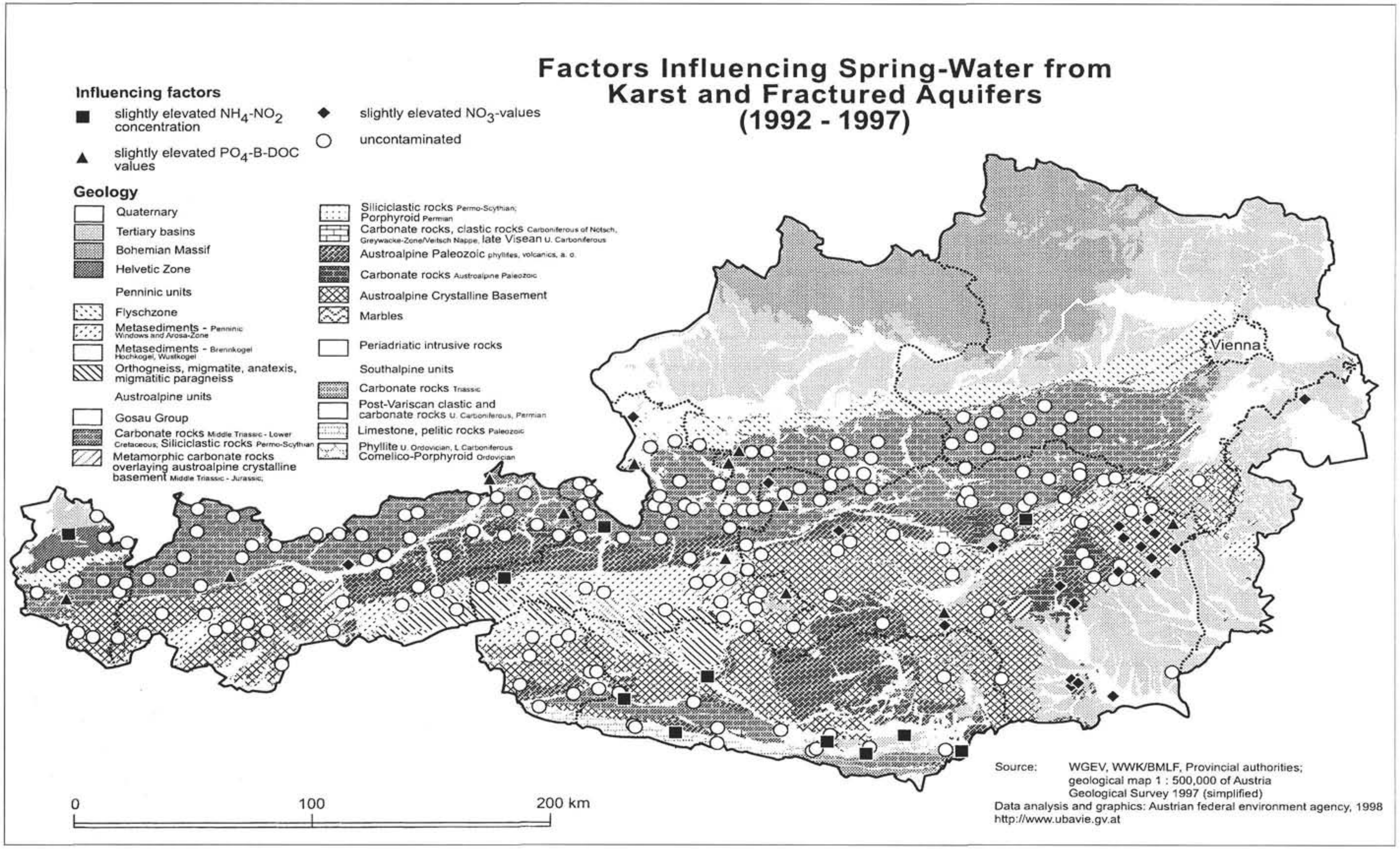
Despite the generally low concentrations of pollutants due to their sites in remote Alpine areas, factor analysis allows for the discernment of the pollution sources at a very low level. Agricultural sources are characterized by elevated levels NO_3-Atrazine-Desethylatrazine. Sewage waters, however, are indicated by elevated DOC-AOX-PO_4 (dissolved organic carbon – adsorbable organic halogenes – orthophospate) concentrations, whereas elevated NH_4-NO_2 (ammonium – nitrite) concentrations may be related to atmospheric pollution (Fig. 10). The second pollution-source factor is most frequently found around sedimentary basins in Carinthia, Salzburg and Vorarlberg, where in some cases traces of chlorinated hydrocarbons occur as well.

Heavy metals concentrations are just above the minimum detection limits (MDL) and exceed the Austrian limit values in just five single spring water samples. They are generally attributed to natural mineralisations in Carinthian Goldeck-Kreuzeck mountains (As, Hg), the Styrian Hügelland (Pb, Zn, As, Hg) and the Northern Calcareous Alps (Pb, Zn, Hg). Concentrations just above the minimum detection limits

Tab. 4
Atrazine and desethylatrazine in Austrian groundwaters in porous media (1.1.1992 – 30.6.1995).

	Bgld	Car	LA	UA	Sbg	Sty	T	Vbg	Vie	A
Total N° of samples	1351	2116	3941	2774	832	3033	1486	767	480	16780
% Atrazine >0.1 μg/l	27	11	22	39	6	35	5	3	32	23
% Desethylatrazine >0.1 μg/l	28	26	27	53	11	46	11	5	45	32

Bgld: Burgenland; Car: Carinthia; LA: Lower Austria; UA: Upper Austria; Sbg: Salzburg; Sty: Styria; T: Tyrol; Vbg: Vorarlberg; Vie: Vienna; A: Austria



Factors Influencing Spring-Water from Karst and Fractured Aquifers (1992 - 1997)

Source: WGEV, WWK/BMLF, Provincial authorities; geological map 1 : 500,000 of Austria Geological Survey 1997 (simplified)
Data analysis and graphics: Austrian federal environment agency, 1998
http://www.ubavie.gv.at

Fig. 10
Factors influencing spring water quality of karst and fractured aquifers (KRALIK, 1999b).

Tab. 5
Mean and other statistical data of springwater contaminants in karst and fractured crystalline aquifers. (1992-1997; KRALIK, 1999b).

Parameter	Mean	Std. Dev.	Median	Min*	Max	<10 (%)	<25 (%)	<75 (%)	<90 (%)	n	>MDL (%)
NO_3-Karst (mg/l)	3.8	4.16	2.7	<1.0	40.7	1.2	1.7	4.5	7.1	1919	95
NO_3-Fr. (mg/l)	4.8	4.21	1.7	<1.0	127	<1.0	1.2	3.5	10.5	594	88
1,1,1-Trichloroethane Karst a. Fr. (µg/l)				<0.1	0.6	<0.1	<0.1	<0.1	<0.1	1421	0.5
Tetrachloroethene (Per) Karst + Fr. (µg/l)				<0.1	0.8	<0.1	<0.1	<0.1	<0.1	1421	1.1
Tetrachloromethane Karst + Fr. (µg/l)				<0.1	1.4	<0.1	<0.1	<0.1	<0.1	1421	0.2
Trichloroethene (Tri) Karst + Fr. (µg/l)				<0.1	0.6	<0.1	<0.1	<0.1	<0.1	1421	0.8
Trichloromethane (Chloroform) K. + F. (µg/l)				<0.1	7.1	<0.1	<0.1	<0.1	<0.1	1421	3.0
Atrazine Karst + Fr. (µg/l)				<0.1	0.83	<0.1	<0.1	<0.1	<0.1	1765	1.7
Desethylatrazine Karst + Fr. (µg/l)				<0.1	0.88	<0.1	<0.1	<0.1	<0.1	1765	3.2
Desisopropylatrazine Karst + Fr. (µg/l)				<0.1	0.01	<0.1	<0.1	<0.1	<0.1	1765	0.1
Metachlor Karst + Fr. (µg/l)				<0.1	0.01	<0.1	<0.1	<0.1	<0.1	1711	0.1
Simazine Karst + Fr. (µg/l)				<0.1	0.01	<0.1	<0.1	<0.1	<0.1	1712	0.2

Std. Dev.: Standard Deviation; > MDL: Percentage of measured samples is above the given "Minimum Detection Limit" (FEDERAL LEGAL GAZETTE: BGBL 1991b); Fr: fractured crystalline rock aquifers.

* Min: Minimum (the official MDL are given here, although some laboratories had even lower detection limits);

** Percentile e.g. 10% of the measured values are below the 10. Percentile, 90% above etc.

(MDL) of chromium in many spring waters of Tyrol and of lead in many springs in Vorarlberg are unexplained so far (KRALIK et al., 1999).

Waste and Contaminated Sites

According to the 1998 Federal Waste Management Plan, the total estimated amount of waste generated (waste potential) in Austria is currently about 46.5 million t/a (about 5.7 t per capita). Excavation material (soil) accounts for roughly half of it. The mass potential of hazardous waste is estimated at 760,000 t/a or 1.6% of the total amount of waste. The major part is formed by ashes and slag from waste incinerators, obsolete vehicles, oil contaminated soils and waste oils.

In 1996 about 2.78 million tons of waste were generated by households and similar institutions (6% of total waste; about 340 kg/a and person) (DOMENIG et al., 1999).

Thermal Treatment of Waste

In total there are about 65 plants in Austria with an annual incineration capacity of some 1.8 million tons. Plants designed for thermal waste treatment exclusively make up about a third of the overall capacity of 1.8 million t/a. The emissions of these plants are subject to the Clean Air Act and its ordinances, which set limits for steam boiler installations of waste incinerators.

The rest is burned in industrial and commercial plants, most of which, however, are not subject to the Clean Air Act and the Clean Air Ordinance and their provisions for steam boiler installations of waste incinerators. Most of these plants are found in the non-metallic mineral processing industry (e.g. cement industry) or they consist of fluidized bed plants in the paper and pulp industry (DOMENIG et al., 1999).

More than 99% of the contaminant like heavy metals can be removed by state of the art treatment of the exhaust gas and waste water, however, still about 25% of the waste has to be deposited in the form of slag, ash, fly ash and fly dust.

Landfills

In Austria there are at the moment 60 (1997) landfills in operation for the disposal of residual waste and residues from the treatment of household waste. Apart from 11% of the landfills with unknown geology, 79% of the landfills in Austria are situated in sedimentary rocks and only four in crystalline rocks. However, 56% have been started at unsuitable sites, e.g. sand or gravel pits (k_f-value $>10^{-5}$ m/s). This situation arose, due to the lack of regulations about the geological barrier before 1975. Just 23% fulfill the regulation of a geological barrier with more than 5 m ($k_f > 10^{-7}$ m/s) or more than 3 m ($k_f > 10^{-8}$ m/s) thickness.

Nearly all landfills (93%) are equipped with a leachate collection and liner systems. Some of them (20%) have already been surrounded by a special containment. More than 60% meet the standard of the LANDFILL ORDINANCE (1996) with a 0.75 m mineral liner system covered by a >2.5 mm thick HDPE-foil. Four old landfills are in the status of improvement or will be improved in the near future.

In 1995, the disposal volume still available was about 26.7 million m^3 (not considering existing expansion plans). About 43.3 million m^3 were filled with waste in the past. Given the amount disposed in 1995 (2.15 million t), and assuming a disposal density of 1.1 t/m^3, the available disposal volume should last until 2009.

Landfilled waste is mainly organic waste with TOC values well above 20%. The disposal of this kind of waste (including residual waste, commercial waste, sewage sludge, etc.), after the year 2005 will only be possible in exceptional cases. According to the Water Act Amendment these exceptions will be stopped in 2009. Consequently, there is no need for further so-called reactor-type landfills or additional

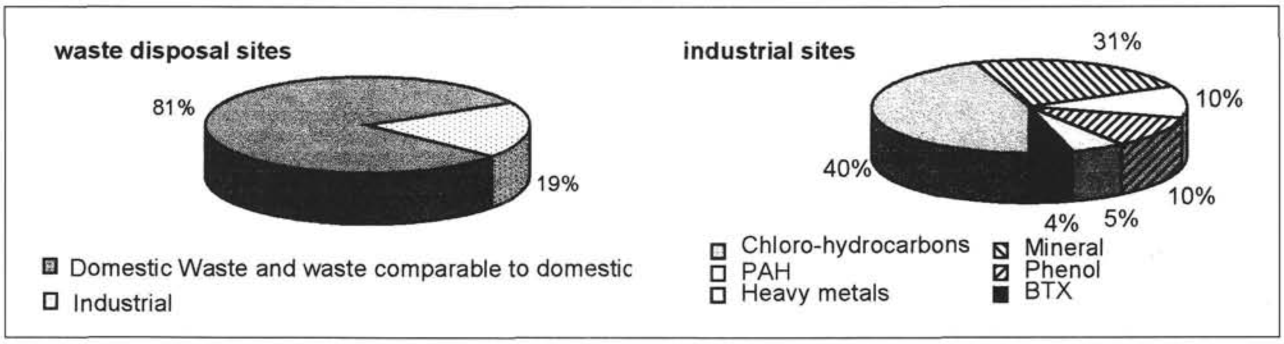


Fig. 11
Main contaminants found at 142 sites mentioned in the text (SCHAMANN, 1999).

disposal volume for residual and commercial waste (LUNZER, 1998; DOMENIG et al., 1999).

Contaminated Sites

Registration: In Austria currently 30,000 landfills and contaminated industrial sites are known, 2,470 of which have already been listed in the Register of Contaminated Sites. The total number of 2,470 is composed of about 2,300 landfills and about 170 industrial sites, mainly of metal or mineral oil processing enterprises, dry cleaners, chemical industries and gas works or terminals, where substances harmful to water are handled.

Analysis: For defining whether these sites represent a considerable danger to human health or to the environment, comprehensive studies (e.g. analysis of groundwater or soil samples etc.) are necessary. Analyses at about 190 sites have been initiated, 150 of which are currently going on, while about 40 have already been completed.

Remediation: In 142 cases, remediation measures were considered necessary, 34 cases of which were given top priority (see Tab. 6). 53% of the contaminated sites cited in the table below are landfills, 47% are industrial sites, the latter being mainly polluted with chloro-hydrocarbons or mineral oil (see Fig. 11). First remediation measures have already been taken at about 40 out of these 142 sites, while about 11 such sites have already reported the completion of such measures (SCHAMANN, 1999).

Case Study 2: Testing the long term behavior of a potential underground waste disposal site

Introduction

In addition to the traditional hydrogeological investigations, the long term evolution of pore-waters in the host rock of potential waste disposal sites has been studied. In this case, the potential host-rock, the granite of Wolfsthal (60 km East of Vienna; Fig. 12), has been tested with a combination of isotopic measurements (KRALIK et al., 1991). The investigation was complicated by the fact that no drip water was present even at small faults in a 100 m horizontal test-gallery. Groundwater that was easily obtainable, was from a spring on the surface.

The isotopes ^{3}H, D, ^{18}O, ^{87}Sr should be measured in the pore-water itself to determine the source, age (climatic changes) and potential pollution of the pore-water during the last decades. ^{238}U, ^{230}Th and ^{226}Ra was measured on the fault-gouges and the granite-rock to reveal large pore-water movements along faults and throughout the host-rock itself (disequilibria $^{226}Ra/^{238}U$ and $^{226}Ra/^{230}Th \neq 1$) during the last thousands of years up to now (0-1 my).

Sampling and analytical techniques

To overcome problems of contamination or evaporation of pore-waters, granite and fault gouge material was sampled immediately after blasting during the construction of

Tab. 6
Number of contaminated sites classified in Priority Classes I to III (PC I stands for highest priority to take adequate actions).

Province	PC I	PC II	PC III	not defined	Total
Burgenland	0	0	6	0	6
Carinthia	3	5	2	8	18
Lower Austria	6	9	7	5	27
Salzburg	2	3	3	0	8
Styria	2	8	1	5	16
Tyrol	2	5	3	2	12
Upper Austria	8	10	6	13	37
Vienna	11	5	1	1	18
Vorarlberg	0	0	0	0	0
Total	34	45	29	34	142

Not defined = priority class not yet defined (SCHAMANN, 1999)

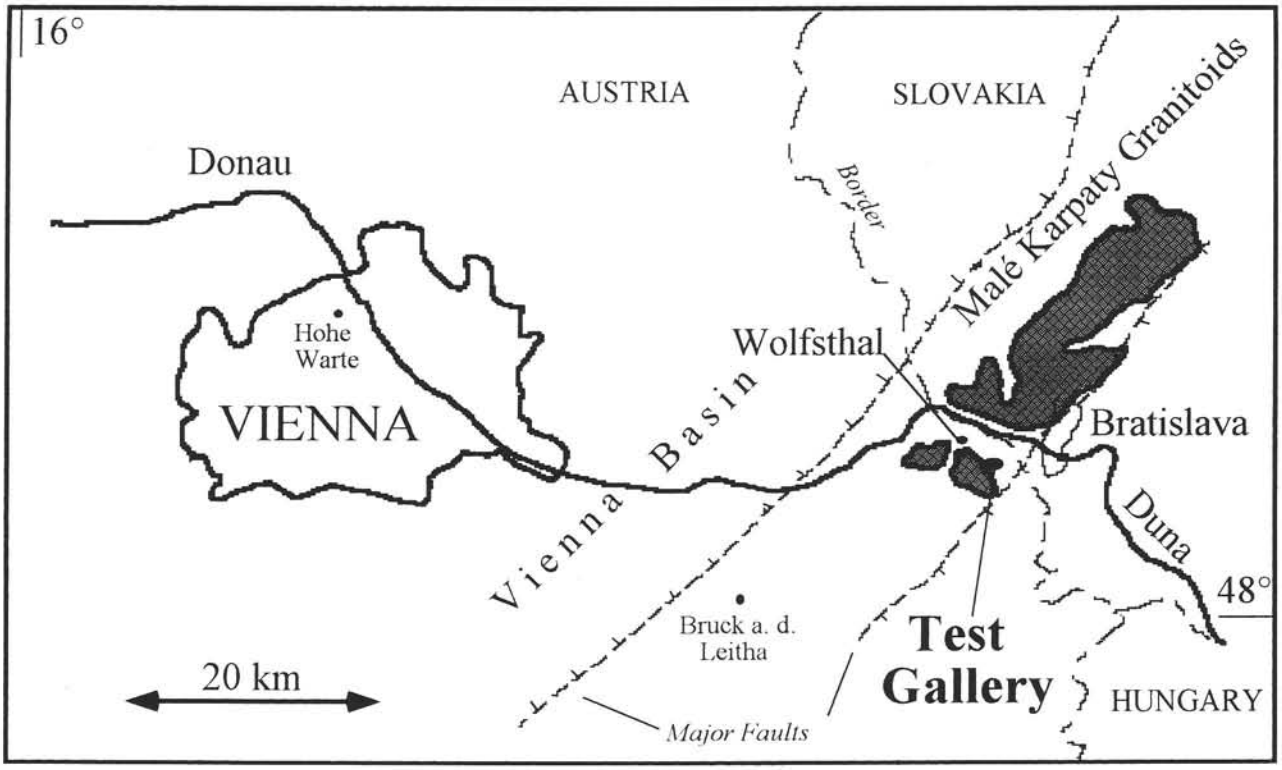


Fig. 12
Location of the Test Gallery in the Paleozoic Wolfsthal Granite at the very end of the Western Carpathian Granitoids (Austrian – Slovakian border).

the test gallery. In order to obtain enough pore-water for extraction, samples in amounts of several kilograms were collected. The samples were packed air-tight in plastic containers, transported (cooled ~ 4 °C), and deep-frozen (-20 °C) in the laboratory. The deep-frozen rock-fragments were heated up to 190 °C in a heating-cupboard (Heraeus VTR 5022) under vacuum to a pressure below 1 mbar. The quantitatively extracted pore-water was frozen in two glass traps in succession, cooled with liquid nitrogen, and consequently used for H-O isotope analyses. Tests with the heated fault-gouge material equilibrated with waters of known composition showed that the difference between the weight of water extracted and the weight loss in the fault gouge after heating is less than 3.5% at all temperatures used. The isotopic fractionation after vacuum extraction at 190 °C is about 0.3‰ towards lighter delta^{18}O values.

^{238}U, ^{226}Ra, and ^{230}Th activity was measured by gamma- (MARINGER et al., 1993) and alpha-spectroscopy (HRENECEK, 1994), respectively, on dried (60 °C) and powdered rock samples. The ^{87}Sr/^{86}Sr ratios were measured after leaching the smaller 40 micron fractions 100 hours with destilled water (ratio 1:100) with thermal ionisation mass-spectometry (KRALIK, 1984).

Results

Deuterium and oxygen isotopes of surface spring-water, close to the test-gallery, plot along the global meteoric water line (Fig. 13). Pore-waters, however, plot above *(0.53-0.83% water in granite)* and below *(4.5-9.6% water in fault gouges)* the global meteoric water line. The ^{87}Sr content of granite leachates is significantly higher (^{87}Sr/^{86}Sr=.7120-.7165) compared to leachates of the fault-gouges (^{87}Sr/^{86}Sr=.7089-.7107). ^{87}Sr/^{86}Sr ratios of the spring water is in the same range as in the fault-gouges.

Uranium-series disequilibria (^{226}Ra/^{238}U=0.2-0.7) in the fault gouges and granite in the first 50 m of the test-gallery are in contrast to equilibria (^{226}Ra/^{238}U=±1) in the granite samples deeper (>80 m) in the granite body (Fig. 14).

Discussion

Extracted pore-waters indicate host-rock exchange or meteoric water from old precipitation lines, plotting slightly above or below the present meteoric line. In any case, the extracted pore-water differ significantly (>1‰ δ^{18}O, >3‰ δ^{2}H) from the global meteoric water line. The pore-water of the granite samples plotting above the global meteoric water line indicate a low temperature exchange with the granite rock and probably mixing with old waters, similar to brines observed in the Canadian shield (FRAPE and FRITZ, 1987). A low temperature hydrothermal percolation of the granite rocks is in agreement with a noticeable clay mineral content (-1%) observed in these granites and the considerable rejuvenation of the Rb-Sr ages of the primarily Paleozoic granites. However, a purely experimental shift and a stronger fractionation than 0.3‰ delta^{18}O, observed during the extraction experiments, cannot be excluded. The tritium content of the pore-water of the first granite sample (<50 m) indicates a relatively young meteoric water seepage (KRALIK, 1999c) through the granite closest to the surface (Fig. 14).

A more extensive exchange at somewhat higher temperatures is suggested for the fault gouge samples with the formation of large amounts of clay minerals (10-70%). An experimental shift of the delta^{18}O values during extraction,

Fig. 13
Delta ^{2}H-^{18}O-plot for pore-waters of granite and fault-gouges obtained by vacuum-extraction and $^{87}Sr/^{86}Sr$ ratios of leachates. Bars represent standard error. Notice that the granite pore-water containing tritium (15 TU) is closest (<50 m) to the gallery entrance.

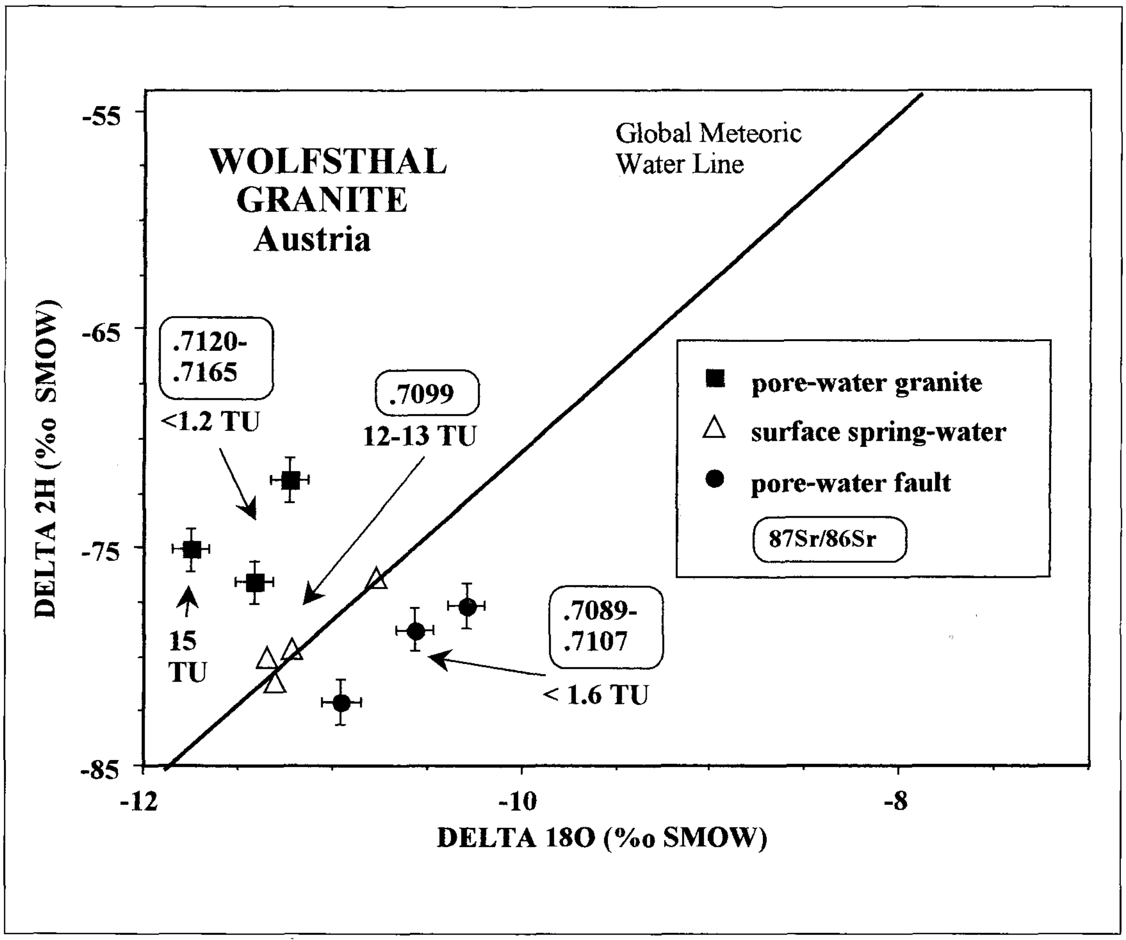
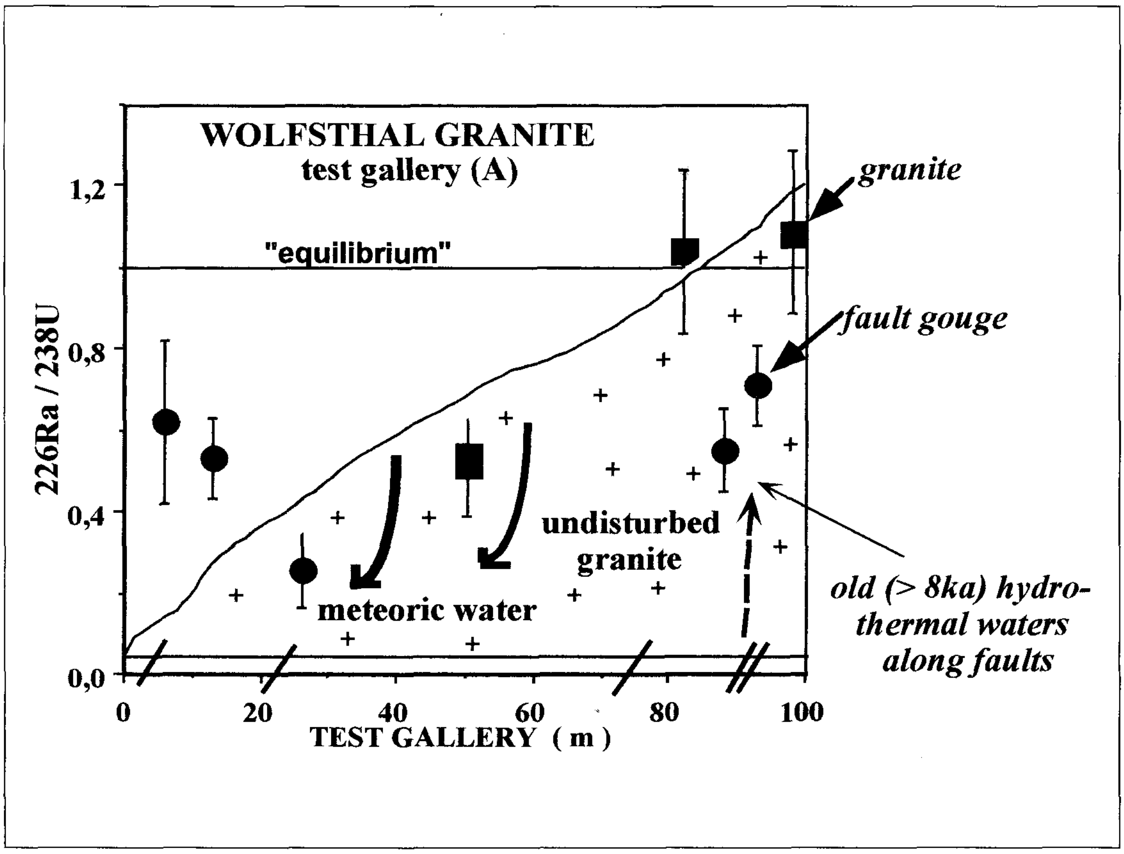


Fig. 14
$^{226}Ra/^{238}U$ ratio for fault-gouges and granites vs. test-gallery meter and interpretation of meteoric water seepage based on ^{3}H, D, ^{18}O, ^{87}Sr isotope measurements. Filled dots: Fault gouges left and right of the gallery. Filled squares: granite samples. The bars represent standard error.



as mentioned above, would indicate an even stronger exchange. Both explanation suggest old waters, supported by the afore mentioned lack of tritium (older than 40 years) in the fault gouges. The higher ^{87}Sr content in pore-waters of granites compared to fault-gouges supports their different evolution. The ^{87}Sr/^{86}Sr ratio of the surface spring-water (.7099) is in the range of the fault-gouge leachates (.7089-.7107), suggesting its recharge mainly along faults.

U-series disequilibrium in the fault gouges and granite in the first 50 m of the test-gallery confirm meteoric water seepage (Fig. 14) already shown by ^{3}H measurements. A ^{226}Ra/^{238}U equilibrium was preserved deeper into the granite body, suggesting no major movements of pore-waters during the last 2 million years. ^{226}Ra/^{238}U-disequilibrium and ^{226}Ra/^{230}Th-equilibrium (HRENECEK, 1994) in the fault-gouge at the end of the test-gallery (90 m) may be interpreted as a fairly old (>8 thousand to 2 million years) hydrothermal pore-water circulation event (KRALIK et al., 2000).

Conclusions

Several isotope techniques are useful in mapping host formations with old pore-waters or to detect areas, which have been flushed by larger amounts of younger or older waters during the last 2 my. The technique of pore-water extraction is a valuable tool in order to obtain information about pore-water in rocks without dripping waters. This is especially valuable for evaluating long term behavior of host rocks and to investigate rock formations and fault gouges around potential waste disposal sites.

Air

Particulate Dust Pollution in Vienna

Due to improved filtering techniques, industries reduced the coarse dust emission considerably in Central Europe, while the very fine grained (<10 µm) and more dangerous dust emission stayed constant or has even increased. Because of their small size, as well as their shape, dust particles may be particular harmful to the human respiratory system. High concentrations of some minerals themselves (asbestos, quartz etc.) or the high heavy metal content, as well as carcinogenic organic compounds (PAH's) frequently attached to them, have noxious effects.

The most important natural and manmade particle sources in urban environments are materials eroded by wind (soils, construction materials), as well as industrial and traffic emissions. Speculation about their sources is accomplished on the basis of chemical information only. Very little is known about their mineral and organic phases. In order to interpret the physical properties of particles, their environmental behavior and the health risks they may pose in future, the combined information of chemistry and mineralogy is essential.

The very fine-grained particles have been collected on "low blank" cellulose nitrate and glassfiber filters in a high volume sampler (Stroehlein) or in a cascade impactor (CMI) at several places in the capital city of Vienna. In order to observe long term changes, samples have been taken from the filter of an air conditioner in intervals of 3-5 month from 1991-1995. These samples have been dry-screened <20 µm in order to make them more comparable to the PM10 filter samples. Mineralogical composition was analyzed by X-ray diffraction, FTIR and SEM. The trace element and Pb-isotope composition was obtained by dissolving parts of the filters and subsequent analysis with ICP-MS. Glassfibre filters were extracted with supercritical CO_2 and the PAH were analyzed with GC-MS.

Source apportionment by trace metals, lead isotopes and PAH's

The dust samples consist of calcite, dolomite, quartz, organic matter (+soot) and gypsum as major phases, whereas illite-mica, chlorite and feldspar are minor phases (<5%). Magnetite, goethite, brushite and epsomite were detected as well. Winter sample are more enriched in calcite, dolomite and gypsum compared to samples collected during summer (Fig. 15).

The considerable enrichment in As, Cd, Pb and Zn, compared with the mean crustal composition, as well as the lead isotope-ratios (^{207}Pb/^{206}Pb), indicate a fair mixture of emissions from heating and gasoline combustion during winter. The considerable stronger mean enrichment of Sb, Cd and Pb (Fig. 16) during the summer month is caused by the dominance of automobile emissions and the missing dilution effects by carbonates caused by winter maintenance in the form of carbonate grit (Fig. 15).

The higher concentrations of benzo[a]pyrene in the winter dust samples indicate a higher contribution by fossil fuel burning compared to higher concentrations of coronen in summer, indicative of burning hydrocarbons in car engines (Fig. 17).

The most prominent change during 1991-1995, is the considerable decrease in lead content in Viennese dust samples, due to the legal ban on leaded gasoline in 1993 during this period, causing a continuous shift in lead isotope ratio. This ratio is a mixture between exhaust lead derived from leaded gasoline (mainly Australian lead) and the lead naturally occurring in Vienna represented by Danube sediments (Fig. 18).

Transport and deposition of dust particles into remote Alpine areas

Objective

Dust and aerosols have been mainly monitored in urban areas. In order to obtain information about the nearly uncontaminated background and the impact of long-range transport, sites in remote areas without any local contaminants have to be sampled on a regular basis.

In the Reichraminger Hintergebirge (Northern Calcareous Alps, Upper Austria), 'Zöbelboden', the first Austrian Integrated Monitoring site on air pollution effects on ecosystems was established by the Austrian Federal Environment Agency. The input on long range trans-boundary air pollutants on this Integrated Monitoring site is observed and the long term influence on the ecosystem is recorded.

Methods

Sampling of the particulate deposition was done weekly over a seven months period in 1997, on the Zöbelboden plateau. Airborne dust samples (<10 µm) were collected

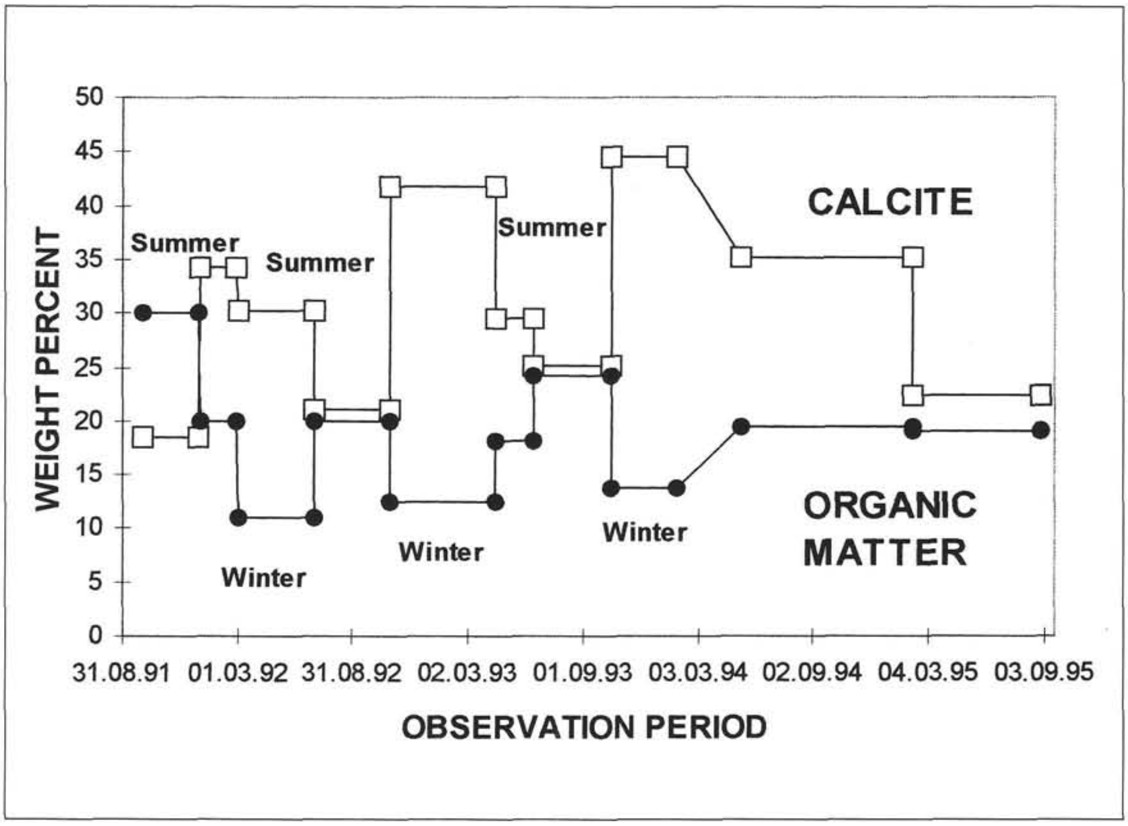


Fig. 15 Seasonal changes of the mineral composition in the city dust of Vienna (<0.02 mm).

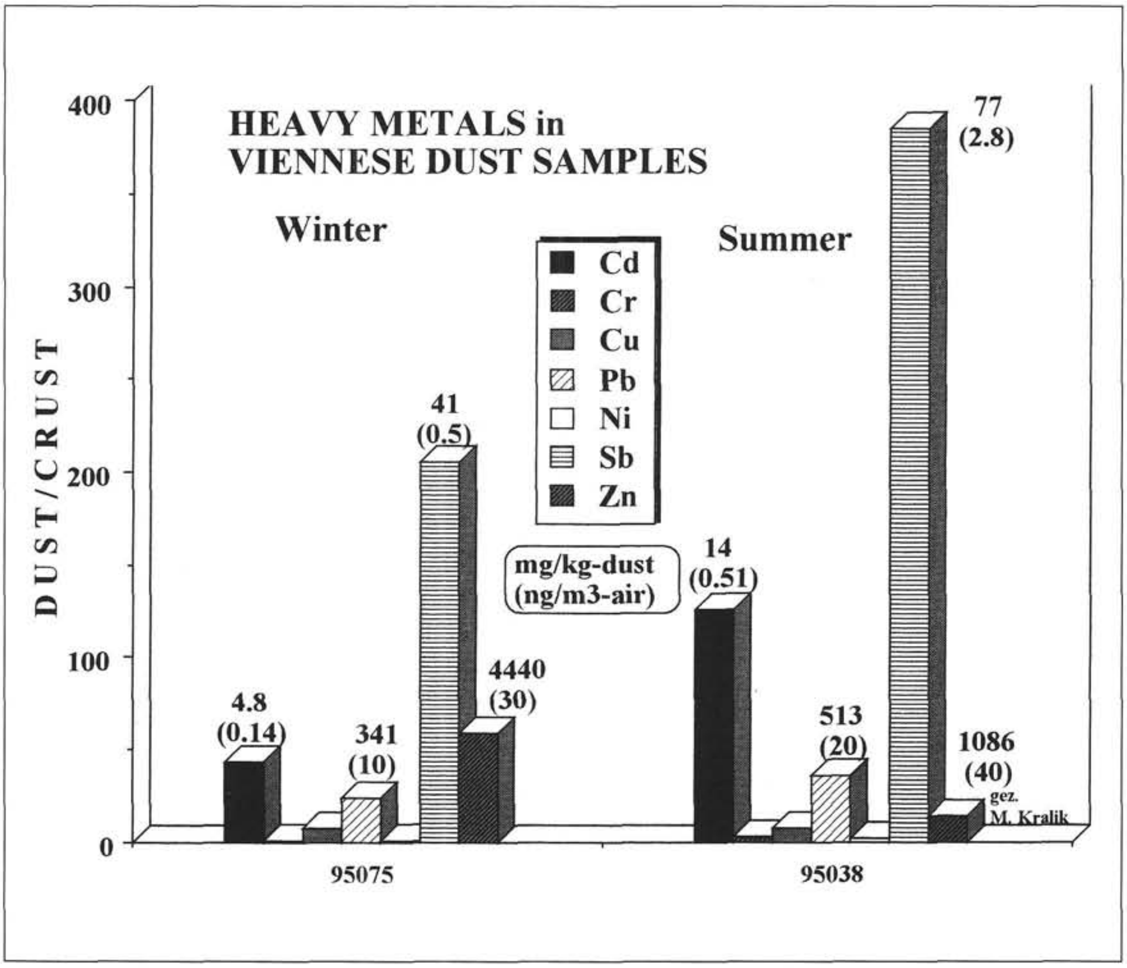


Fig. 16 Enrichment of heavy metal concentrations in Viennese dust samples (mean of 5-6 winter and summer samples each) compared to crust concentrations. Numbers show concentrations based on dried dust samples and concentrations per cubic meter air (in brackets).

Fig. 17
Mean concentrations of PAH's in Viennese dust samples (mean of 5-6 winter and summer samples each 1995). Remarkable is the stronger enrichment of Benzo[a]pyrene and coronen during the winter and summer month, respectively. Numbers in brackets indicate concentration in the air (μg/m³).

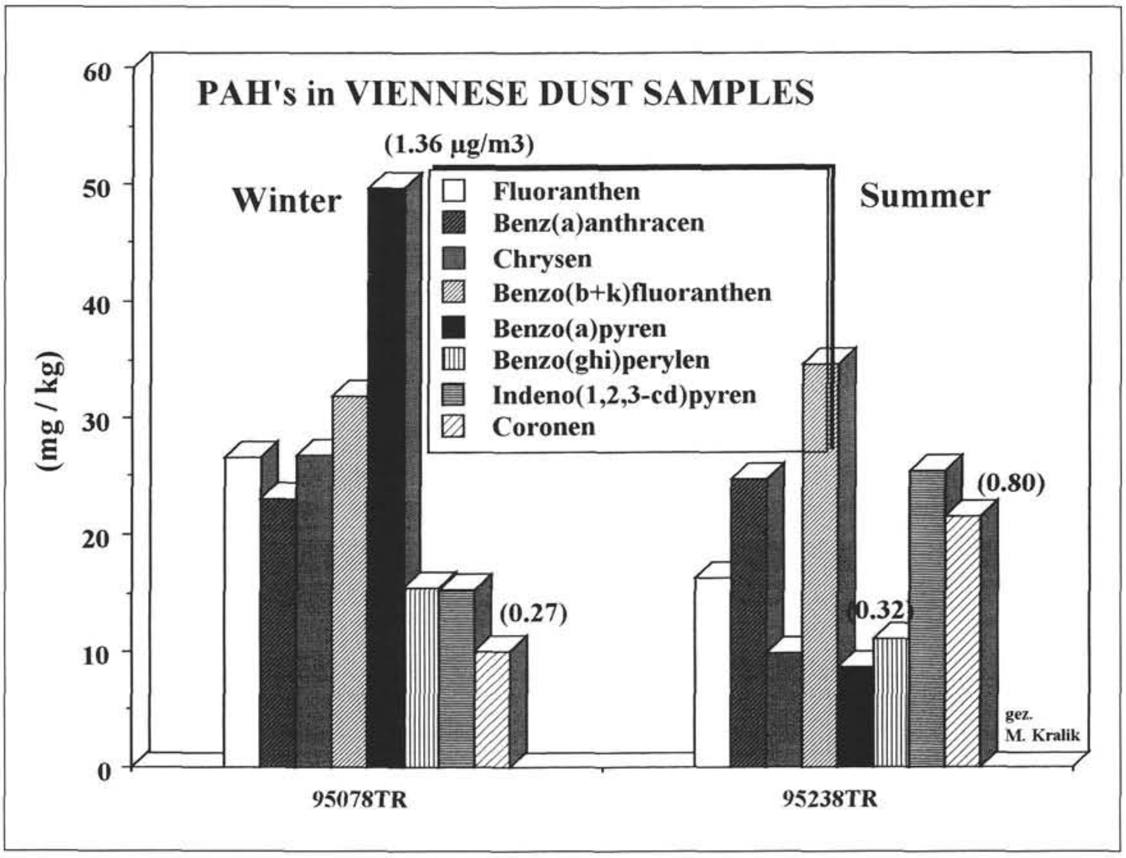
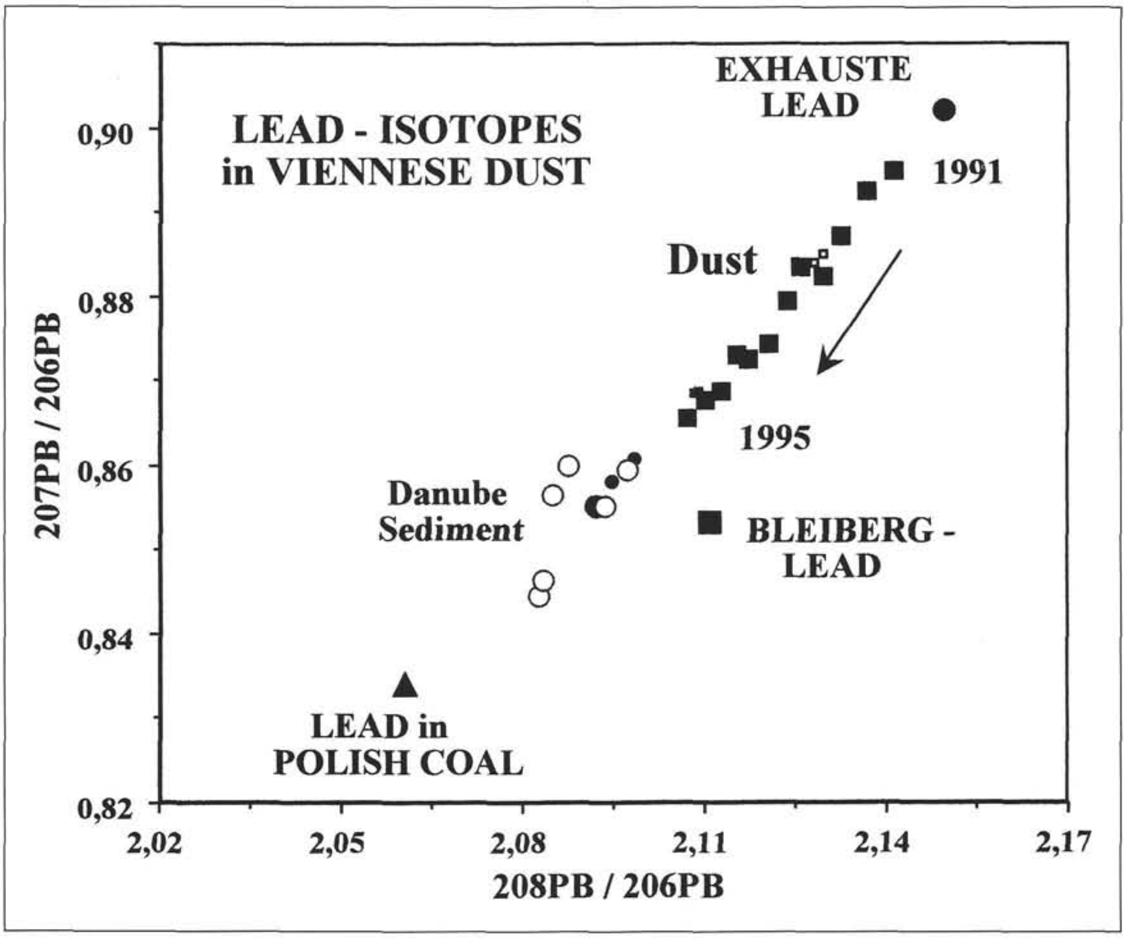


Fig. 18
Decreasing influence of gasoline lead changed the lead isotope composition in Viennese dust samples considerable during the period of 1991-1995.



twice on polycarbonate filters in a low volume sampler (Gent). The deposition samples were dry-screened $<20\ \mu m$ in order to adjust them for comparison with the PM10 filter samples.

Mineralogical composition was analyzed by X-ray diffraction and SEM. The chemical composition was obtained by analysis with total-reflection x-ray fluorescence. The content of organic matter was determined by loss on ignition (360 °C).

Results

The average particulate bulk deposition is 24 $mg/m^2\ d^{-1}$ and does not exceed 100 $mg/m^2\ d^{-1}$. The PM10 concentrations are in the range of 8-9 $\mu g/m^3$ – typical for a rural area like Zöbelboden. The dust samples consist of about 60% organic matter. The main mineral phases in the dust are carbonates (calcite and dolomite), gypsum and quartz. Illite-mica, chlorite, kaolinite and feldspar are only present in small quantities. In the airborne dust samples slag glasses which are formed by industrial combustion processes were identified. The main elements Si, Al, Fe, Mn, Ca and K are not enriched compared to the mean earth crust content. The content of S and heavy metals (As, Cd, Cr, Cu, Ni, Pb, Sn, Zn) are relatively enriched by anthropogenic activities.

Conclusions

- The main particulate phases are organic matter, carbonate and quartz.
- Slag glasses and the growth of gypsum on filters indicate a long range transport of dust particles and pollutants from an urban or industrial environment far off from the monitoring area.
- 10-40% of heavy metal content deposited stayed in particulates and did not dissolve in precipitation, whereas only small portions of aluminum and iron went into solution (<20%).

Case Study 3: Radon Hazards in Ötz-Valley, Tyrol

Radon is a naturally occurring radioactive gas formed from decaying uranium or radium. It escapes from the earth's crust through cracks and crevices in bedrock and either dissolves in groundwater or seeps through foundation cracks into basements and homes. Radon can also be emitted from the soil. Once produced, radon begins to move toward the surface and decays to a series of elements. These radon decay products or "daughters" move less freely in the air than radon. As a result, they eventually attach to dust particles in the atmosphere. Any particle not filtered out by the nose, thus becomes a health problem.

Recent studies of uranium and lava rock miners have shown that inhalation of radon daughters increases the chances of lung cancer. The extent of these effects and the risk estimates involved are difficult to determine.

The significance of radon (^{222}Rn) in houses has only been realized over the last 10-20 years. Current assessments indicate that ^{222}Rn contributes approximately half (43%) of the mean average effective dose received by a member of the Austrian population (BUNDESKANZLERAMT, 1997). Therefore, the Austrian Radon Project (ARP) currently investigates the distribution of the indoor radon concentrations on a statistical basis (FRIEDMANN, 1999) and 1521 groundwater and drinking water samples were measured all over Austria (DITTO et al., 1999) providing annual mean values of 54-138 Bq/m^3 and 18 Bq/l, so far respectively.

However, the little village Umhausen in the Ötz-Valley in the western Austrian Province of Tyrol (Fig. 19), to the knowledge of the author is the only place in the world where a radon hazard was recognized primarily by the higher mortality (40% higher than normal) due to lung cancer, as compared to the Austrian mean values (ENNEMOSER et al., 1993). The Austrian Radiation Protection Commission has introduced a current action level of 400 Bq/m^3 air in existing buildings. Measurements in winter revealed that concentra-

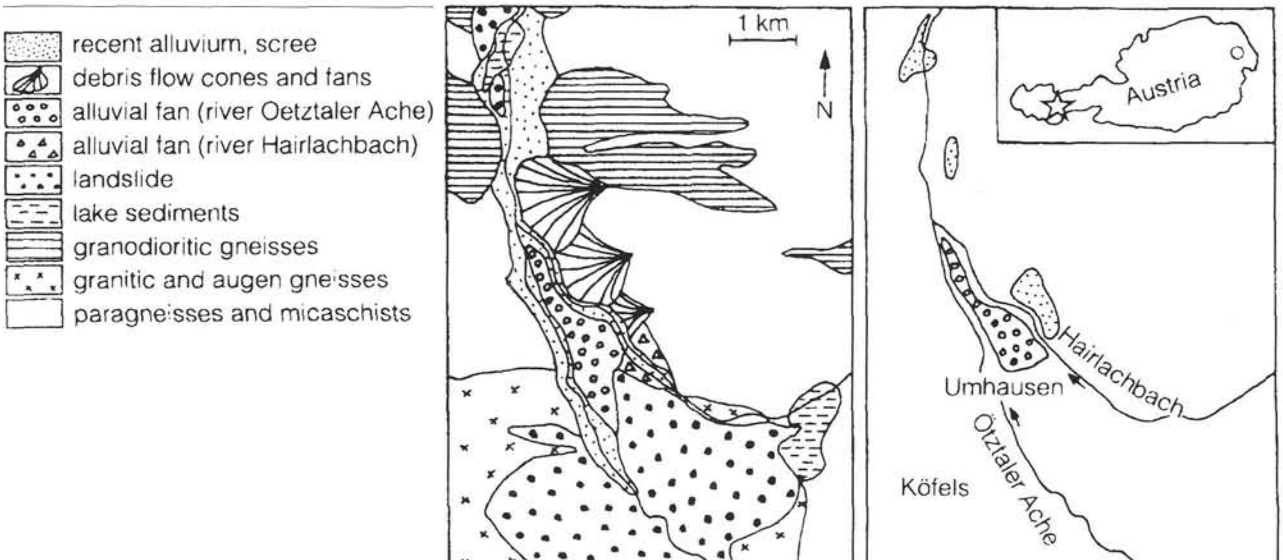


Fig. 19
a) Geological map of the Ötz Valley adjacent to the village of Umhausen (Tyrol, Austria). b) Average radon concentrations in the basements of the houses of the village of Umhausen (Note the relation of Rn-concentrations with the geology) (PURTSCHELLER et al., 1995).

tions in basements of the houses in Umhausen are exceeded in 71% of the houses with a remarkable maximum of 274,000 Bq/m^3 (Purtscheller, et al., 1997).

In contrast to U-mineralisations and fault zones in granitic rocks in other areas the elevated soil gas ^{222}Rn values in Umhausen are related to the Koefels landslide and to alluvial fans reworking the landslide material (Fig. 19). Its high permeability yields circulation pathways for underground air with radon. Buildings situated at the adjacent impermeable debris flow fans are not affected by this health hazard. Intensive crushing and fracturing in the lower part of the landslide and good air circulation in the upper part are prerequisites for high emanation rates, despite the only slightly enriched uranium (1-65 mg/kg U) and radium (125 Bq/kg ^{226}Ra) content of the granitic gneiss involved (Purtscheller, et al., 1997).

Recent studies revealed that a major aquifer (>40 m vertical dimension) in the alluvial continuously removed debris fan with its coarse components transport ^{222}Ra and ^{222}Rn (up to 1127 Bq/l) below of Umhausen (Hacker and Mostler, 1999). Therefore, ^{222}Rn emanates out of the aquifer through the coarse debris fan (150-200 kBq/m^3). In the houses in Umhausen, built on this debris fan, ^{226}Rn values in the range of 0.1-40 kBq/m^3 were measured. Various ventilation installations in the basements of these houses brought the concentrations down to considerably lower concentrations.

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