Umweltbundesamt

Excursion Guide for the COST–65 Meeting in Austria/Slovakia

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Excursion Guide for the COST-65 Meeting in Austria /Slovakia
5th to 10th of October 1994

Part I, AUSTRIA

Contents:

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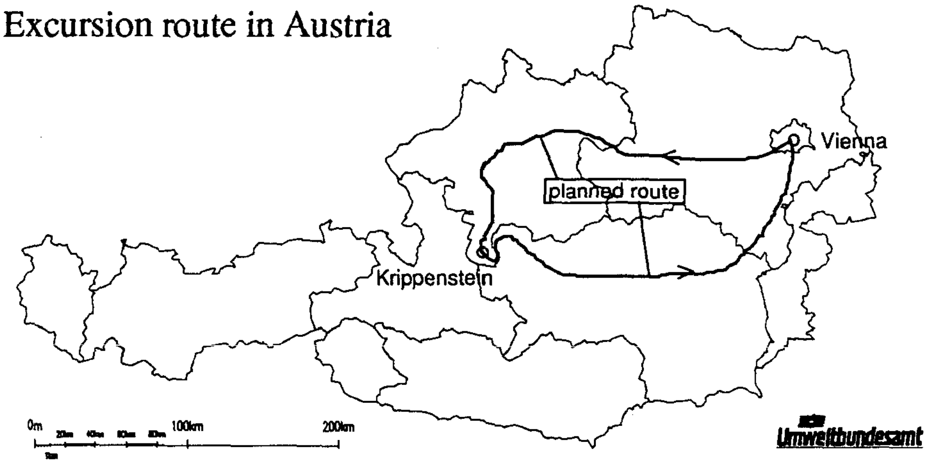
I. Route from Vienna to Hallstatt via Lower and Upper Austria

On our route we will start out of the Vienna Basin and head for Lower Austria across the "Wienerwald" (Viennese Wood), which forms a cross section through the "Flysch"-zone, consisting of marls and sandstones.

Fig. 1.1: Excursion route in Austria



The present excursion route leads us through the gravels and sands of the Molasse basin, the only exception is a small region near Amstetten, where the cristalline rocks of the Bohemian massif extend southwards from the Danube river. At Regau we turn south, directly towards the Northern Limestone Alps, passing through the morains of the ice age glaciers north of Gmunden.

The Austrian Limestone Alps are characterized by their nappe structure. After their sedimentation the nappes have been tectonically moved from the south over the Central Alps to their present position. During this movement the different limestone nappes were overthrusted. From Gmunden southwards we go through the Staufen-Höllengebirge-nappe and reach the Dachstein nappe at "Bad Ischl". The continue our way east of the edge of the Dachstein nappe and enter the nappe after crossing the river Traun along the "Hallstättersee" (Lake Hallstatt).

Hallstatt is one of the oldest villages in Austria (about 4500 years old). The first settlements reach back to the young stone-age. The importance and the wealth of Hallstatt had its origin in the presence of salt in the mountain. The word "Hall" is an old terme for salt. From findings in the salt mine - even a completely preserved miner was found in 1734 - and in more than 1000 graves on the "Salzberg" we know much about the living conditions of this time. The findings are so important that they gave this historic periode their name: Hallstatt age.

II. Karst water in Austria

The total area of Austria is 83 856 km^2, the carbonate rocks cover an area of about 23,7 % or 19.900 km^2. Approximately 25% of the whole precipitation of Austria falls in this area.

98% of thedrinking water supply in Austria is obtained from groundwater, one half of it is water from karst aquifers. Many big citys in Austria, e.g. Vienna, Salzburg, Innsbruck and Villach predominantly receive there drinking water from karst areas.

Fig. 2.1.: Karst in Austria (ÖWWV, 1984)

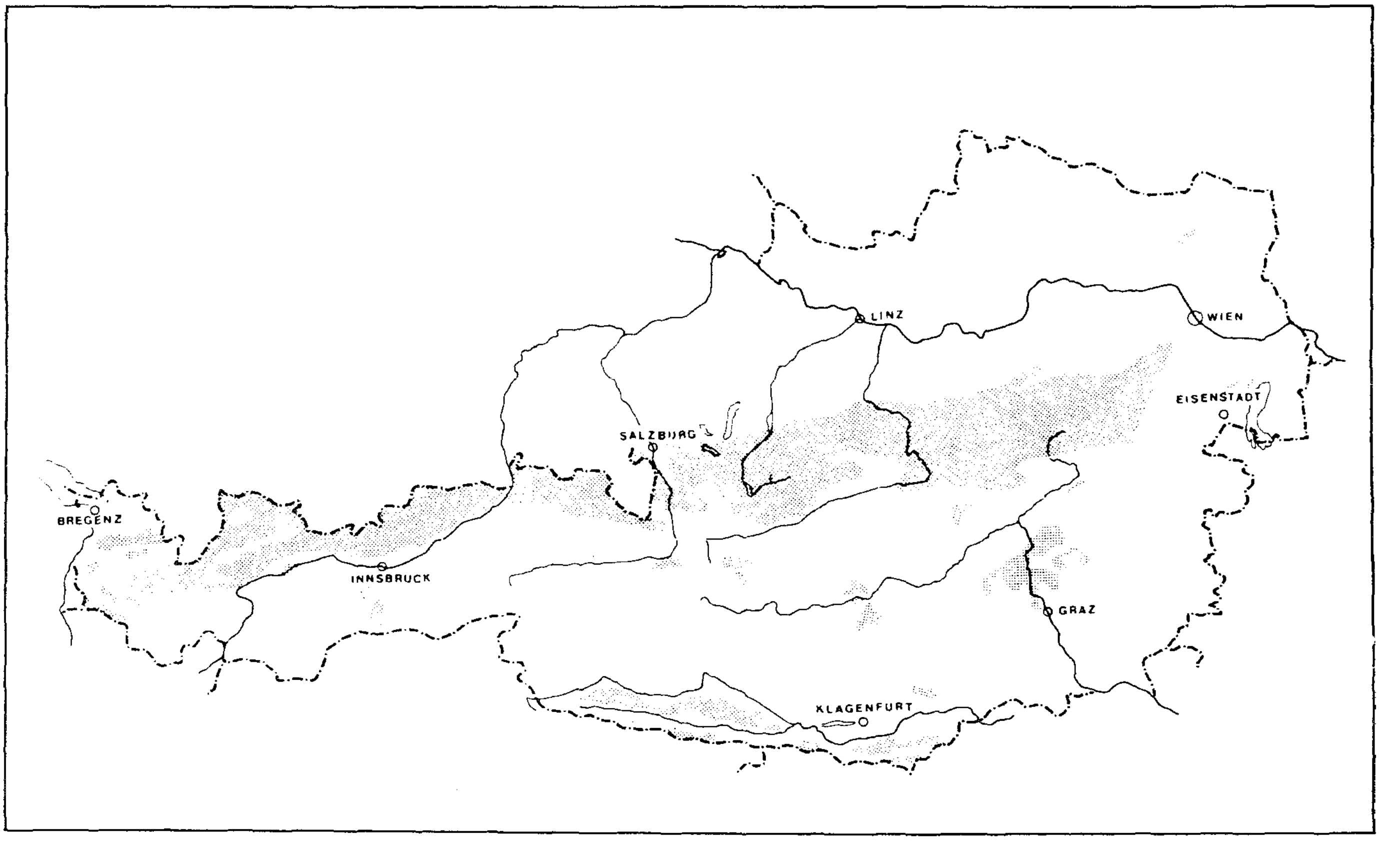


Fig. 2.2 : Western part of the Dachstein massif

(203, 206, 207....triangles mark springs under investigation during the present project)

III. Pilot Project „Karst Water Dachstein“
(preliminary version of the „National Report Austria“):

COST-65: National Report Austria

Pilot Project "Karst Water Dachstein"

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1 AIMS OF THE INVESTIGATION

1.1 Historical background

The Dachstein area has always been of vital importance to man. Whereas way back in the Hallstatt Age (3,000-2,000 before Christ) the saline deposits of Hallstatt drew many people into this area, it is today the scenic landscape, the recreational facilities and the numerous caves that form the main object of interest.

In the middle of the 19th century, the scientist Dr Friedrich Simony first documented his observations made on the Dachstein. In this area also spelaeological investigations have started very early; in 1910 the first cave was opened to the public on the Koppenbrüllerhöhe.

In the 1950s, the first investgations concerning the water resources of the Dachstein began and the first tracing experiments were carried out (ZÖTL, 1957; MAURIN & ZÖTL, 1959). Subsequently, Dr Bauer set up a research establishment in the plateau area of the Dachstein. In the 1980s as well as in the early 1990s further tracing experiments were conducted in order to receive information on the Dachstein catchment areas. A detailed survey of all karst hydrological investigations made so far is given in HERLICSKA & GRAF (1992).

Due to the wealth of available data, the Umweltbundesamt (Austrian Federal Environmental Agency) chose the "Karst Water Dachstein" project to serve as a pilot project for the Austrian Water Quality Register and as a contribution to COST-65.

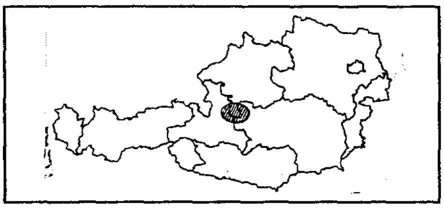
1.2 Preliminary aims and tasks

The objectives and tasks of the "Karst Water Dachstein" pilot project are as follows:
* large-scale determination of the karst water quality
* recording and quantification of the factors influencing water quality
* detection of the correlation between discharge, precipitation and karst water quality
* collecting information on the selection of springs, sampling times, parameters, the requirements for accurate analysis and treatment of samples to investigate the karst water quality
* checking the reliability of the different karst hydrological methods of investigation
* implementing the results of the investigations within karst groundwater conservation measures.

The scope of the investigation:
In the first phase of the project 42 springs, one stream and leachates in the area of a waste disposal site had been investigated in 5 sampling cycles. On the Krippenstein an automatic precipitation sampler was established, from which monthly mixed samples were taken. The snow cover in the area of the Hallstatt glacier was investigated chemically twice.

In the second and presently still running phase of the project isotope-hydrologically/hydrogeologically-oriented investigations are carried out.

Figure 1: Site of the Dachstein investigation area



2 DESCRIPTION OF THE INVESTIGATION AREA

2.1 Hydrography

In the Dachstein area the average annual precipitation amounts to about 1,600-2,500 mm. The absolute precipitation peaks are registered in summer (June-July), whereas in winter, from November through to January, the maximum precipitation rates clearly lie below those of the summer.

On the Krippenstein (2,050 m sea level) the average monthly temperatures lie between -5.7°C in January and +8.3°C in summer. In the valley (510 m sea level) the temperatures range between -1.6 and +16.9°C.

ABEL (1970) carried out intensive evaporation studies on the Dachstein plateau. He came to the conclusion that due to the high frequency of precipitation the soil never dries out and that the actual evapo-transpiration more or less corresponds to the potential one. In August 1969 the values measured by a lysimeter amounted to 1.38 mm during the day and 0.31 mm at night. In September 1969 the values were 1.22 and 0.40 mm, the evaporation rate lying at 38%.

2.2 Geology

In the Dachstein area the Limestone Alps generally consist of two macrotectonic units, the Tirolic and the Juvavic, which superposed the Tirolic.

The underlying tectonic storey, the Tirolic, reaches transgressively into the Lower Palaeozoic shales of the Greywacke zone. Its stratigraphic composition begins with the sandy-shaly series of the Lower Triassic Werfener layers, which, for tectonic reasons, may reach a thickness of several 100 m at the southern edge of the Limestone Alps (Werfener wedge zone). During the Middle and Upper Triassic periods great masses of carbonates from shallow sea water had been deposited (Wetterstein limestone and Wetterstein dolomite, Hauptdolomit, Dachstein limestone); thin shales of the Raibler layers may be interposed locally. The mountains Tennengebirge, Totengebirge, the Osterhorn group and the Traunalpen block are made up of these rocks and form the northern part of the area under investigation. This carbonate rock formation is superposed by a layer of limestones and marls dating from the Jurassic until the Lower Cretaceous periods. This layer is incomplete, which may be ascribed partly to tectonic movements, partly to erosion.

The upper storey, the Juvavic, forms a generally thin overthrust plane above the rocks of the Tirolic. As the topography of its deposition area was strongly subdivided during the Triassic period (mobile shelf), the Juvavic shows great lithological variety in its strata series. Out of the wide range of strata series two rock formations can be regarded as characteristic. On the one hand, there are the rocks with the alpine salt deposits dating from the so-called Hallstatt period. These very heterogenous, limey-marly strata are thin marine depositions between the carbonate platforms. In the course of Alpine orogenesis these layers were torn up into a mosaic of blocks and can be found as isolated fragments partly upon (Plassen/Hallstatt), partly below (Ischl - Aussee) and partly adjacent to the Dachstein nappe. On the other hand, as in the Tirolic, there are thick masses of carbonates from shallow sea water dating from the Middle and Upper Triassic. They form the main body of the Dachstein nappe and build the reservoir rock of the karst water body which is dammed up by the underlying Werfener layers and the Jurassic to Lower Cretaceous series of either the Tirolic or the Werfener layers, the Haselgebirge and the Upper Triassic-Jurassic marl series of the tectonically interstratified Hallstatt zone.

Between the individual tectonic movements in the Alps, deposition of more recent marine sedimentary rocks took place. These sediments would superpose the respective tectonic formation and served as "fillings" (Gosau layers, "neoautochthonous stratum") (see figure 2).

Toward the end of the Palaeocene, fluvial gravel was the last form of sedimentation in the area of the Limestone Alps. This fluvial gravel was the debris from one of the oldest river systems which had drained the Central Alps, they had already folded to form a mountain region, across the still low-lying Limestone Alps into the residual sea of the molasse zone in the north.

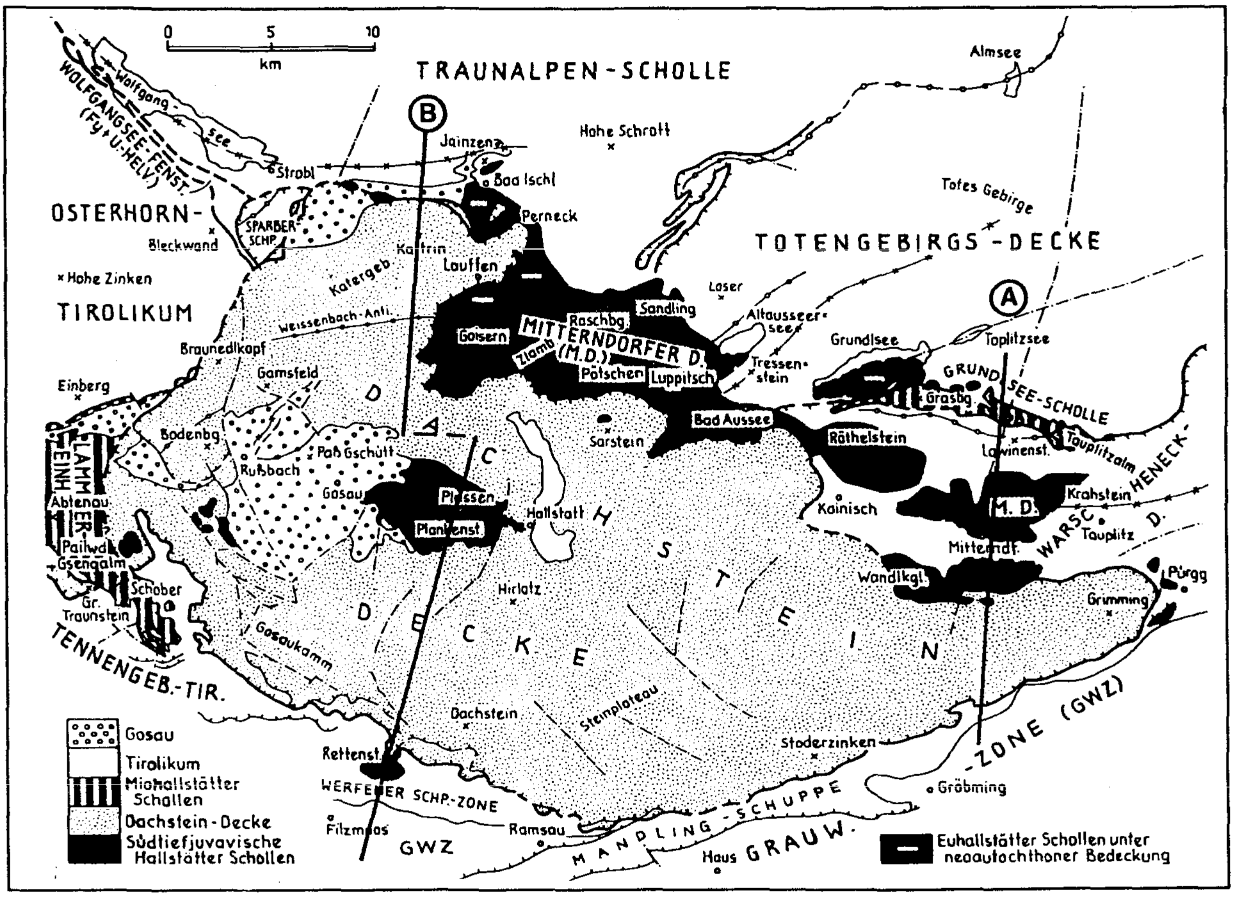
In the Neocene, the final folding and faulting of the Alps and the forming of the Alpine limestone plateaus took place. The karstification of the massive carbonate rock formations started when the climate was still tropical.

The old river debris and residual deposits were redistributed several times and washed into the newly forming relief.

In the Quaternary, the landscape received its final shape during the ice ages and the following climatic phases.

In summary, the tectonic overthrusting of a massive carbonate plate onto a more or less well-developed impermeable layer and the uplift to the present shape laid the foundation for a far-reaching karstic area with considerable drinking water reserves.

Figure 2: Tectonic survey map of the "Dachstein" (after TOLLMANN, 1985)



Tectonics

The Dachstein nappe, a thick carbonate plate, basically rests on a foundation of hardly permeable rocks. It is limited on all sides by tectonic lines. In the south the underlying Tirolic is made up of rocks of the Werfener wedge zone including the Mandling tongue, in the west it consists of Triassic carbonates of the mountain masses of the Tennengebirge and the Osterhorn group, which is covered by an impermeable Jurassic layer. In the Abtenau basin the massive Werfener layers have the same function. Tectonically, the Werfener layers belong to the Hallstatt zone of the Lammer unit and, in part, also to the marginal crustal block of the Dachstein nappe.

In the north, the Dachstein nappe is underlain by rock formations of the Ischl-Aussee Hallstatt zone with the Haselgebirge and the Zlambach marl and the Liassic mottled marl acting as impermeable horizon.

In the east, the Dachstein nappe is thrusted onto Dachstein limestone and the Jurassic rocks of the Warscheneck nappe. In the area of Bad Mitterndorf the Haselgebirge and the Werfener layers of the Mitterndorf nappe outliers are said to be tectonically wedged in. More recent findings indicate, however, that there might be a correlation between the Warscheneck and Dachstein nappes, but detailed studies will still have to be carried out.

Today, the Hallstatt block around the Plassen is seen as an outlier lowered by fracture tectonics above the Dachstein nappe. As outlined on the general map, the fracture tectonics follows two main directions, one running parallel to the Gosau lake groove from the north-west to the south-east, the other being almost vertical to it. Here, mention should be made of the Reißgang fault, which runs parallel to the Gosau lakes in the area of the Gosau ridge. In the south-east, this fault has transcurrent character, whereas in the north-western area it merges into the Zwieselbach overthrust, the marginal crustal block of the Dachstein mass secondarily or locally resting on the Gosau rocks. This example only serves to reveal the complex relationship between overthrust tectonics and fracture tectonics.

2.3 Hydrogeology

In the area under investigation the Dachstein massif consists amost entirely of karstifyable carbonate rocks. They are underlain by scarcely permeable up to impermeable layers which dam up water. Thus, with karstification of the Dachstein massif a thick karst water body could form. In the western part of the southward-facing Dachstein mass, the impermeable Werfener shales can be found at about 1,800 m sea level, toward the east (area of Gröbming) they reach right down to the valley basin. In the north, in the area of Gosau, Hallstatt, Bad Aussee and Bad Mitterndorf, the impermeable layers lie mainly below the valley bottom level. In general, the incline of the Dachstein mass or the underlying impermeable beds faces northward. Hence, for the most part, underground discharge is effected in this direction. It is also in the north that productive karst springs are found, the peak discharge rates lying over 10 m^3/s. In the south, however, at the southern drop of the Dachstein massif, the karst springs show peak rates which are well below the values encountered in the north. According to the investigations made so far, the karst watershed, i.e. the zone where discharge is possible in both directions, is situated in the southern part of the Dachstein massif, east of the Schladming glacier. So far, tracing experiments have revealed that the fracture tectonics with its two main directions (north-west to south-east and north-east to south-west) facilitates water routing (BAUER, 1989).

At present, further detailed investigations and mappings are being carried out by the Geologische Bundesanstalt (Austrian Federal Geological Centre). The results are expected to draw a modern picture of the geological situation in this area, which, together with hydrochemical and isotope hydrological investigations, will deepen the insight into the karst hydrological system.

2.4 Spelaeology

taken from the contribution by Dr PAVUZA in HERLICSKA et al., 1994

The Dachstein massif varies greatly in altitude, the scope reaching from 508 m (Lake Hallstatt) up to 2,995 m (Dachstein). The lowest-lying cave is the so-called Kessel at 512 m, the highest cave is the Nördliche Durchgangshöhle at 2,270 m sea level.

Spelaeological investigations started in 1910 with the discovery of the caves Dachsteinrieseneishöhle and Dachstein-Mammuthöhle. Few years later cave passages of about 9 km length were known, and already in the year 1950, which marked the beginning of a new era of intensive research activities in this area, some 25 km of cave passages had been documented. In the past decade, the breakthrough in the upper levels of the Hirlatz cave in 1983 (since then the passage length has grown from about 8 km to more than 75 km), the constant investigations carried out in the Dachstein-Mammuthöhle (in 1959 the cave passages reached a length of 10 km, in 1993 some 49 km) and the research work done in the Schönberg cave led to entirely new findings with regard to the courses of the giant cave systems at the northern edge of the Dachstein. Now underground passages of a length of already 140 km are known in this area.

When looking at the distribution pattern of the caves, a clear accumulation can be observed in the northern part of the mountain range. A short glimpse underground confirms this impression, as the extensive cave systems of the Dachstein are entirely placed in its northern drops and extend about 10 km from west to east and approximately 3 km from north to south.

Whereas most of the inactive parts of the cave systems, they vary in size, run from north-west to south-east and from north-east to south-west and, in part, from west to east, massive and frequently water-bearing canyons head northward in steep gradient and very often reach the phreatic zone, the average overlappings measuring only 200 to 500 m; in special cases they reach a maximum of 800 m. Apart from the 75-km-long Hirlatz cave (longest cave in Austria), the Dachstein-Höhlenpark with its 49-km-long Mammut cave (it shows a total difference in altitude of 1,180 m and is, therefore, also one of the deepest caves in Austria) is of major importance.

With respect to their altitudes, the ice and water caves show a very characteristic distribution pattern: for climatic reasons ice caves are mainly found between about 1,250 and 2,250 m sea level, whereas most of the water caves are located in the valley bottom area.

3 FACTORS OF INFLUENCE AND RISK POTENTIAL

3.1 Land use and cultivation

One of the most important factors of land use in the Dachstein area is forestry.
The vegetation at low altitudes is characterized by mixed forests of beech, fir and spruce, which are to be found up to about 1,450 m sea level. With increasing altitude the beech population disappears, giving way to spruce forests which grow up to about 1,850 m. From approximately 1,950 m to ca. 2,100 m sea level mountain pines and shrubs prevail.

Forests can be found up to approximately 1,700 m (KILIAN, 1959).

After a longer time if decreasing, the number of livestock on Alpine pastures is increasing in the last decade again. Mention must be made, however, that too great a density of stock grazing may lead to the pollution of spring water. The grazing of sheep, in particular, may contribute to rapid soil destruction on steep slopes, as sheep leave sharp hoof marks and nibble the grass almost down to the roots.

Statistics show a marked growth in game hunting in the Dachstein area between 1951 and 1990, which, with regard to the nationwide trend, points to an increase in game stock.

3.2 Tourism

In the area of the Dachstein massif tourism is of great economic importance.

Analysis of the total annual overnight stays in the Dachstein communities between 1973 and 1991 reveals only minor fluctuations, the average figure of overnight stays being 2.5 million per year. Only the tourist centres Ramsau and Filzmoos show a slight upward trend.

The annual distribution pattern of overnight stays is characterized by strong seasonal changes; whereas there are peak rates in the summer and winter seasons, the low seasons are marked by significant slumps.

3.3 Buildings in the alpine mountain regions

In the Austrian alpine mountain regions there are approximately 760 huts run by Alpine Clubs. Half of these mountain huts can be found in the Northern and Southern Limestone Alps, the rest being located in the Central Alps. In the 460 huts of the Austrian and German Alpine Clubs, 1 million mountaineers stay overnight annually; the figure for day-time guests amounts to ca. 1.5 million per year. As regards the amount of waste water produced by refuges in the Tyrolean mountains, the detailled figures are as follows (HOFER, 1990):

In the Tyrol there are about 160 refuges of the German and Austrian Alpine Clubs. All private buildings such as mountain restaurants, ski huts, etc. taken into account, the number of buildings situated in the high mountain regions reaches 1,000 in the Tyrol alone. The amount of waste water from these buildings (including lift companies) is estimated to be about 150,000 population equivalents of which, however, only a maximum of about 5,000 to 6,000 population equivalents is likely to come from the mountain refuges. In comparison, the total waste water volume in the Tyrol is assumed to be 1.6 million population equivalents. Considering the figures known for the Tyrol, the total waste water load for the high mountain areas of Austria as a whole would be 430,000 population equivalents half of which are applicable to the Limestone Alps.

This volume of sewage imposes a heavy burden on the karst aquifers. Thus, it is desirable that the waste waters from buildings located in highly sensitive alpine areas are either treated biologically or transported into the valley, if there is no adequate receiving stream for the treated waste water.

There are about 25 refuges and hotels in the high mountain area of the Dachstein. Only the sewage from the buildings located near the two main cable railways is transported down to the valley. The introduction of sewage into dolines, a practice which can still be observed today, inevitably affects the groundwater and, subsequently, represents a danger to drinking water springs. No detailed information can be given on the number of small private huts and hunting lodges.

3.4 Waste deposits

In order to gather information on the waste deposits in the area under investigation, the responsible provincial governments were contacted for data. It was found that many waste disposal sites are situated mainly in the marginal zones of the investigation area. Due to their location, however, a contamination of the springs in the investigation area can be levelled out. Seepage water sampling was carried out in an abandoned waste disposal site located in the mountain area (see 4.4).

3.5 Radioactivity

The nuclear accident at Chernobyl, which took place on 26 April 1986, has clearly shown the extent to which the groundwater in karst aquifers is affected by such an incident. In Austria, the main fallout of radioactive nuclides (mainly iodine-131, caesium-137 and caesium-134) was registered between 29 April and 8 May 1986. Thereupon, the water of all drinking water supply plants was investigated. The Austrian limiting value for the total activity, which is laid down in the Austrian Food Code (BUNDESKANZLERAMT, 1989) is set at 0.122 Bq/l. If this value is transgressed, the values of the Radiation Protection Ordinance (1972) will apply. For mixtures of any nuclides except radon the limit for the annual mean value is 1.22 Bq/l. The following table gives the results of the drinking water analyses (data provided by the UMWELTBUNDESAMT, 1986; HEINTSCHEL, 1986). The investigations showed that at Hallstatt, a community which is situated in the Dachstein area, the exposure of the drinking water to radiation was comparatively high.

Springs	Nuclide	Activity Bq/l	**Transgression of the Food Codex**	**Transgression of the Radiation Protection Ordinance**
Hallstatt	Jod-131	111,0	910	91
1. Wiener Hochquellenleitung	Gesamt-β	1,9	15	1,5
2. Wiener Hochquellenleitung	Gesamt-β	3,9	32	3
Fürstenbrunn/ Salzburg	Gesamt-β	13,0	106	10,7

Karst aquifers are much more sensitive to the introduction of radioactive substances than pore aquifers. As the nuclides introduced into a karst system are hardly retained or adsorbed, the drinking water supply from karst aquifers is seriously endangered by a nuclear accident. This problem can only be met by exact knowledge of the discharge regime.

3.6 Air pollution

The alpine regions (predominantly the southern edge of the Alps and their northern ridge with barrier effect, where the Dachstein massif is located) are characterized by high annual precipitation rates. This results in very high annual depositons of air pollutants even though the individual pollutant concentrations may be relatively low. In this context, the long-distance transport of air pollutants plays an important role (KOVER & PUXBAUM, 1992). In Austria not only sulphur compounds but also nitrogen compounds, which are largely caused by motor vehicles and, in part, by agricultural emissions, are another major cause for acid precipitation. In view of a predicted upsurge in the volume of motorized traffic, a further rise in nitrogen compounds cannot be ruled out. The volatile organic compounds (VOCs) belong to another group of substances whose impact on both groundwater and ecosystems are as yet hardly known. SCHLEYER (1992) states that the emitted amount of VOCs recorded for the Federal Republic of Germany, 2.45 million tonnes per year, is altogether comparable with the volume of inorganic compounds.

As regards the impact of air pollution on the bodies of groundwater in alpine areas, dynamic processes are of major significance. For example, forests act as air filter and the snow cover serves as a kind of reservoir over a longer period of time (ULRICH, 1989; ECKER, et al., 1990). The pollutants accumulate and are then occasionally deposited in large concentrations, which leads to strong intermittent acidification of soils and groundwater.

The Austrian karst areas exhibit a high natural buffer capacity. However, as already mentioned, the amount of pollutants deposited in this area is particularly high, and it is mainly the rendzina soil type which is highly susceptible to chemical decomposition and erosion. Furthermore, it is in the karst areas that there are extended forests already gravely affected by pollution (FBVA, 1993). As hardly any studies with regard to the impact of pollutants on the bodies of groundwater have been made so far, the results of the present investigations in the Dachstein area will provide first insights into this matter.

4 MONITORING OF KARST WATER QUALITY

4.1 Methods of investigation

In April 1991, a sampler was set up on the Krippenstein (2,050 m) in order to carry out qualitative analyses of precipitation samples (2 WADOS sampler).

The springs were chosen according to the following criteria: if possible, discharge throughout the year; easy access also during winter; size of the spring; importance (drinking water supply); if possible, representative distribution of springs in the investigation area; registration of potential emitting sources.

For qualitative water analysis a wide-ranging list of parameters was compiled, which can be subdivided into: main substances and inorganic contamination indicators; metals and inorganic trace elements; organic parameters; organic micropollutants; bacteriological and radiological parameters.

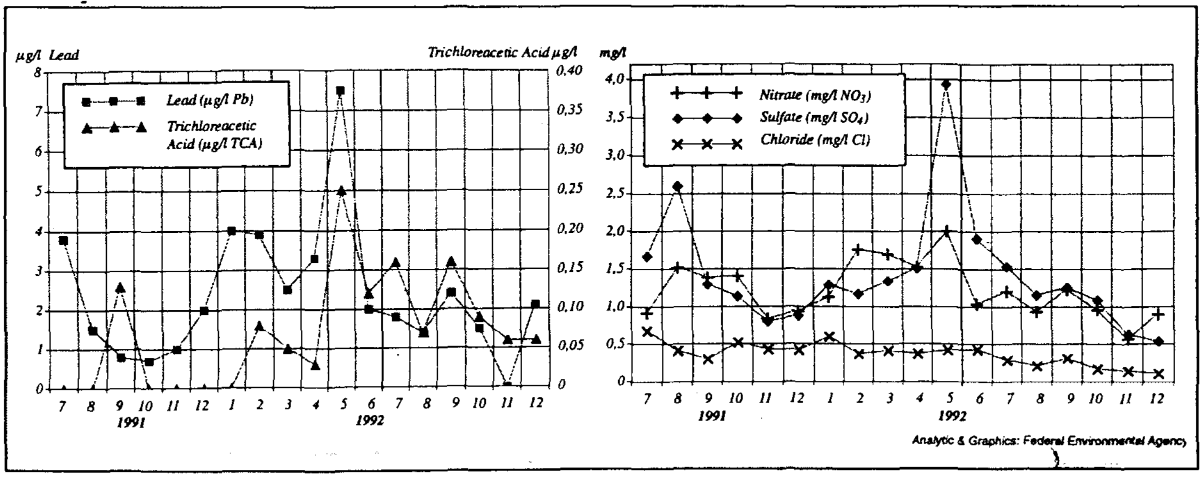
4.2 Precipitation and glaciers

The amount of inorganic substances traced in precipitation is well in line with the results of other investigations in neighbouring areas (KOVAR & PUXBAUM, 1992). For example, the nitrate concentrations measured between 0.57 and 2.01 mg/l, those of sulphate ranged from 0.57 to 3.94 mg/l, and the values for chloride lay between 0.11 and 0.68 mg/l. The pH values were between 3.8 and 6.4.

In comparison, the concentrations of lead (up to 7.5 µg/l) and cadmium (up to 0.35 µg/l) were surprisingly high. The organic micropollutants detected in the precipitation samples were trichloroacetic acid (TCA), lindane and, in one case, atrazine and desethylatrazine, the TCA being a reaction product of highly volatile chlorinated hydrocarbons. Furthermore, trichloroacetic acid is a substance which is allowed to be used as agent in herbicides in the Federal Republic of Germany; in Austria, however, it is forbidden. In view of the precautious limiting values for pesticides of 0.1 µg/l, the concentrations of up to 0.25 µg/l measured in the Dachstein area can be regarded as strikingly high.

As revealed in figure 3, the seasonal fluctuations in concentration rates are high for both inorganic and organic substances, with the peak concentration values for most pollutants occurring in May 1992. Similar observations with regard to seasonal fluctuations were also made by KOVAR & PUXBAUM, 1992.

Figure 3: Pollutants contained in precipitation - Krippenstein July 1991 to December 1992



The snow samples taken from the Dachstein glaciers at 2,600 to 2,700 m sea level in September 1988 and August 1990 showed nitrate and sulphate concentrations which lay clearly below the values recorded for the precipitation samples. The lead content of the snow, however, was the same as measured in the precipitation samples. In addition, various chlorinated hydrocarbon compounds were detected in the snow cover, the concentrations lying above the values registered in the spring waters (see 4.3).

By means of organic screening phosphoric esters and alkanes were detected in the snow.

4.3 Appearance and distribution of (chemical) substances in springs

The investigated springs show remarkable differences with regard to their catchment areas and the mean residence times of the karst groundwater. Nevertheless, as expected, the individual hydrological conditions had a profound impact on the total amount of data gained during the qualitative investigations.

The first sampling cycle with regard to the springs took place in August 1991; the results were influenced by a strong summer flood. In most cases, the concentrations of the substances contained in the water were below those of the other samplings. The occasional increase in sulphate and chloride concentrations can be ascribed to geogenic factors (salt deposits, Werfener layers). Greater water turbidity as well as higher concentrations of total and dissolved organic carbons (TOC and DOC) were due to the turbulence and entry of soil into the water (from the surface or through the disturbance of cave sediments) caused by the flood. Analyses of chlorinated hydrocarbon compounds indicated background levels caused by ambient pollution. These levels were higher than the values obtained from the other samplings, which was presumably due to the strong karst water dynamics during the flood (which resulted in a strong direct entry of precipitation waters). As in the case of the other samplings, it was not possible to detect pesticides and polychlorinated biphenyls even though the detection limits in spring water had been set very low.

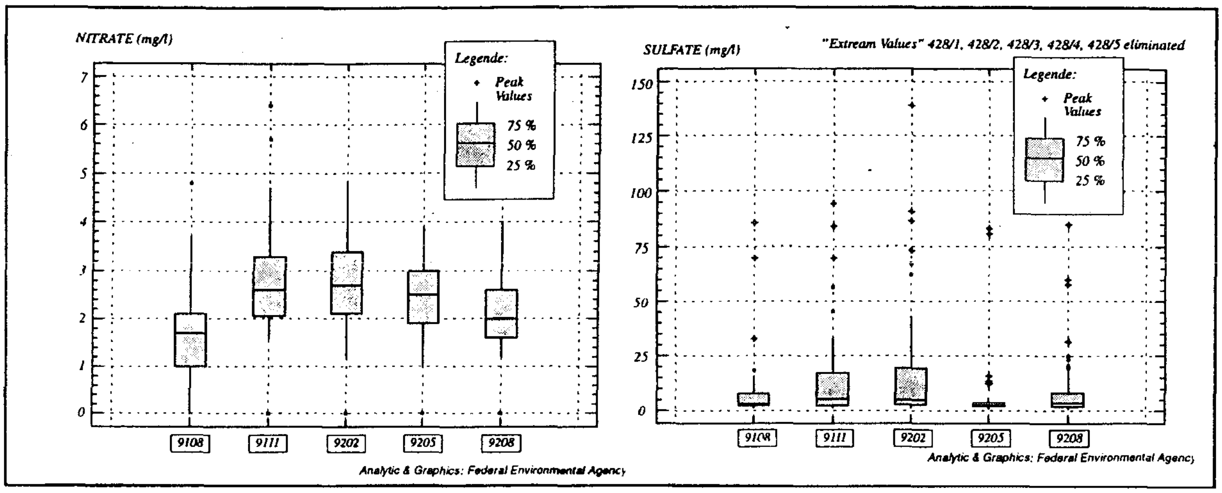
The results of the sampling activities in November 1991 and February 1992 basically present the same picture due to the prevailing winter conditions. In the absence of a direct precipitation influence (fast flowing water component), the geogenic influence on the chemical water properties was particularly prominent during the winter period. Above all, the concentrations of chloride and sulphate, but also those of boron and copper, lay clearly above the concentrations of the samples taken during the other sampling cycles.

The results of the analyses carried out in May 1992 were characterized by the onset of snow melting. Compared to the other samples, there were relatively modest differences between the values of electrical conductivity as well as between the concentrations of calcium and magnesium. The results obtained for aluminium were remarkable: at six of the 41 springs, the groundwater threshold value (Federal Legal Gazette No. 502/1991) of 0.06 mg/l was transgressed.

In August 1992, samples were taken at the end of an extremely dry period. It was most striking that the concentrations of cadmium were particularly high in the springs strongly influenced by the glaciers. However, the groundwater threshold value was never exceeded.

The bacteriological investigations conducted in February, May and August 1992 provided the following results: out of the springs sampled in February, 77% fulfilled the drinking water standards of the Austrian Food Code for untreated water (BUNDESKANZLERAMT, 1993). In May only 44% of the springs met these drinking water standards, in August the figure dropped to 21%. Especially at the sampling in August 1992, the correlations between bacteriological contamination and concentrations of dissolved organic carbon and orthophosphate were evident.

Figure 4: Distribution of concentrations of nitrate and sulphate at the different springs - sampling cycles Dachstein (Multiple Box & Whisker Plot)


NITRATE (mg/l)

SULFATE (mg/l)

"Extream Values" 428/1, 428/2, 428/3, 428/4, 428/5 eliminated

Analytic & Graphics: Federal Environmental Agency

Analytic & Graphics: Federal Environmental Agency

4.4 Additional samples

In the course of the investigations, samples were also collected from a stream which flows into Lake Hallstatt and which is subject to anthropogenic influences. Especially in the winter months, high salt loads were recorded. These can be traced to the "Salzberg" region. The samples taken in November 1991 revealed a very high nitrate content of 127 mg/l, apparently due to the introduction of sewage into the stream.

Several leachates were detected below an already abandoned waste dump in the karst mountain area. The results of the qualitative water investigations, which were only conducted at random, revealed that the concentrations of a number of parameters were higher than those measured in the surrounding area. Further investigations would be necessary to determine if the waste dump represents a possible threat to the groundwater.

In August 1992, the waste water disposal of several buildings in the mountian area was investigated at random and sewage samples were taken at two sites. The site inspections indicate that, in many cases, sewage disposal is still a problem. Among other things, the introduction of waste water into dolines and dried out stream beds was observed. Without doubt, from a bacteriological and virological perspective, this can result in an impairment of groundwater quality in the karst mountain regions. The waste water analyses showed high values especially for the parameters ammonium and phosphate as well as for organic sum parameters and bacteriological parameters. In several cases concepts to improve the situation are being worked out by either the communities or the commercial operators.

4.5 Karst dynamics

Between 13 August 1992 and 8 October 1992 as well as from 22 March 1993 to 6 July 1993, water samples were taken daily from the Klausbrunn spring, which is used for the water supply of Hallstatt. This spring is located in the headwater area of the Waldbach stream and, like the stream itself, is strongly influenced by the Dachstein high mountain and glacier areas. The parameters analysed were nitrate, sulphate, chloride, electrical conductivity and pH. During the entire investigation period also isotope samples of the spring water as well as isotope samples related to the individual precipitation events were collected. At present, only part of these samples have been evaluated. Thus, further information on these parameters will be expected at a later date.

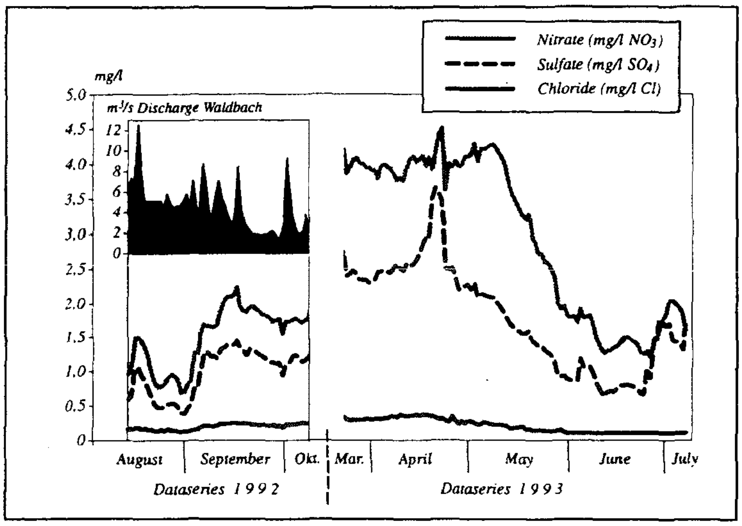
From the period of investigation discharge data of the neighbouring Waldbach (the chemical composition of the discharge of this stream strongly correlates with that of the Klausbrunn spring) and precipitaton data collected on the Krippenstein are available.

In autumn, the hydrological situation is characterized by a relatively high water level in the karst aquifer, which already begins to sink due to reduced water supply. Frequently, heavy autumn precipitation, which is manifested in discharge peaks occurring slightly deferred in time, reverses this trend temporarily.

As depicted in figure 5, the concentrations of chloride lie far below those of sulphate and nitrate during the entire observation period. The values are comparable with the precipitation data on the Krippenstein. Until the end of 1993 the data curves for nitrate and sulphate are almost parallel in their course. At the end of July, however, the sulphate concentrations rise and in some cases even exceed the nitrate values. In precipitation water, the concentrations of sulphate are generally higher than those of nitrate, and the sulphate concentrations measured in the spring water largely correspond to the precipitation values. The nitrate concentrations for spring water, however, are often about twice as high as the maximum precipitation values, which may be due to soil leaching.

Due to the high temperatures in the summer of 1992, a great melt off was registered in the glacier area of the Dachstein. This may have been the cause for the low concentrations of nitrate and sulphate, which rose again at the end of the year. This basic curve is characterized by minor fluctuations and peaks which correlate with the fluctuations in the discharge rates of the spring due to precipitation. In March 1993, the concentrations of both substances reach a level that exceeds the concentrations measured in September 1992 by the factor 6 to 7. Peak concentrations are registered in April 1993, but the values decrease again in summer.

Figure 5: Klausbrunn spring/Hallstatt - daily sampling



SPRING WATER ANALYSIS DURING THE SNOW MELTING PERIOD:

Until 18 April the discharge of the Waldbach stream remains fairly constant. Then it rises very rapidly and reaches a rate ten times that of the winter period. This increase correlates strongly with the onset of thawing at 2,000 m sea level. The melting of the snow cover below 2,000 m obviously does not affect the discharge of the Waldbach. The direct influence the snow melting process exerts on the discharge pattern is also reflected in the immediate reduction in discharge when the average day-time temperature drops (e.g. 22 May).

There are only minor fluctuations in the concentrations of nitrate, sulphate and chloride before the onset of snow melting, which is marked by a short rise in values for nitrate and sulphate, followed by a sharp decrease. With chloride the peak is less pronounced and occurs slightly later (fig. 5). These peak values may be ascribed to the fact that the first snow water carries a high concentration of dissolved substances (see also ECKER, et al., 1990). The snow cover acts as reservoir for the winter precipitation. All substances stored in this reservoir in dissolved form are set free as soon as the snow begins to melt. Later, however, further melting dilutes the basic geogenic concentration.

Until snow melting sets in the ion concentrations detected in the spring samples lie clearly above the precipitation values. These concentrations reach their lowest level in the middle of the snow melting process (mid-June) and amount to 1.3 mg/l for nitrate and 0.7 mg/l for sulphate. The average winter precipitation values are 1.16 mg/l for nitrate, 1.17 mg/l for sulphate and 0.37 mg/l for chloride.

In general, spring water investigations conducted by using daily sampling intervals reveal considerable seasonal fluctuations as regards the concentrations of chemical substances. This is confirmed by the first findings gained from the analysis of the isotope data (see 6). However, as opposed to the considerable seasonal fluctuations, there are hardly any prominent short-term changes in the daily concentrations of chemical substances, which proves that the fluctuation pattern of the spring can be satisfactorily traced with daily sampling intervals.

5 ARTIFICIAL TRACER STUDIES

Due to the incline of the mountain mass on the north side of the Dachstein massif, the most productive springs can be found there. In order to study the spatial discharge pattern, 28 tracing experiments have been carried out since 1953. In the beginning, undyed and dyed spores were used as tracers, which, as we see it today, proved to be highly problematic. The samples were most probably contaminated as they were taken by the very person who had added the tracers to the spring before. The discharge was then found to be radiating in all directions. Since 1984 only fluorescent tracers have been used. This brought about a drastic change in the understanding of the drainage regime (BAUER, 1989). The radial discharge could no longer be confirmed. On the contrary, clearly favoured directions of discharge were detected, which made it possible to distinguish roughly between areas that would discharge to the north and those that would discharge to the south.

More recent tracer studies in the western part of the Dachstein area were carried out in 1990, both at high and low water levels in the karst aquifer. These studies indicate that there is a considerable change in the way karst groundwater is discharged in the different seasons. They also reveal a clear overlapping of the catchment areas of the Gosau and Hallstatt springs (HERLICSKA & HOBIGER, 1991).

6 ENVIRONMENTAL ISOTOPE TRACER STUDIES

Between the Umweltbundesamt Wien (Austrian Federal Environmental Agency with seat in Vienna) and the GSF München (Munich-based German Research Centre for Environment and Health) a research agreement has been concluded to collect, analyse and interprete the isotope data gathered in the Dachstein investigation area. The samples are mainly analysed for the stable isotopes deuterium and oxygen-18 and, to some extent, for tritium. The final objective is to establish a correlation between the data of the hydrochemical spring water analyses, the hydrological and hydrogeological information and the isotope data in order to receive information on the source and residence time of karst water and its fluctuation characteristics. In addition, it is important to gather experience with regard to applicability and reliability of isotope studies when investigating water quality.

In the early 1970s, a sampling network for precipitation isotope analyses was established in Austria. It is run by the Umweltbundesamt Wien in cooperation with the BVFA Arsenal (Austrian Federal Research and Testing Institute) and currently operates 72 sampling sites. From 20 sites the current results for tritium are reported, which are measured by the BVFA Arsenal. 33 stations deliver the measurement results for the concentrations of deuterium and oxygen-18, analysed by the GSF München (HUMER et al., 1994).

Out of this measuring system 3 stations are situated in the Dachstein area. In 1991 another site was established on the Krippenstein. The precipitation samples from these measuring sites are analysed for their content of stable isotopes (deuterium and oxygen-18) by the GSF München. First results from the Krippenstein have already come in, the results from the other 3 sites are still awaited.

So far, the GSF München has analysed 265 spring water samples from the area under investigation for the stable isotopes deuterium and oxygen-18. The treatment of the remaining samples, which will mainly comprise the analysis and interpretation of data from isotope samples related to individual precipitation events, is expected for the near future.

So far, the evaluation results suggest that there is a clear differentiation between springs of similar characteristics (pronounced or minor fluctuation patterns). It seems that a distinct fluctuation pattern is mainly displayed by those springs which are strongly influenced by glaciers.

7 RESULTS OF THE DIFFERENT TRACING METHODS - COMPARISON AND CONCLUSIONS

As indicated in section 6, the full results have not yet been obtained: they will be published at a later date.

8 PROTECTION OF THE KARST GROUNDWATER IN THE DACHSTEIN AREA - SITUATION AND PERSPECTIVES

In the late 1950s, the protection of the karst groundwater in the area of the Dachstein massif gave rise to numerous hydrologically/hydrogeologically-oriented investigations in this particular area.

Today, a multitude of water protection zones for local supply with drinking water (mainly on a municipal level) can be found in the Dachstein area. In most cases, these protection zones only include the immediate tapping area of the springs and very often do not meet today's requirements as defined by VILLINGER, 1991. Furthermore, the areas around the tapped springs are frequently not protected from game and alpine livestock.

Even though there have been considerable and manifold improvements with regard to groundwater protection in the Dachstein area, one major problem remains. Several lifts and the "Dachstein" glacier skiing area itself are located within an ecologically sensitive nature reserve established in the high mountain region of this area as early as in 1963.

Preparations for establishing a special water preservation area which is to cover the entire Dachstein massif with participation of the Federal provinces of Styria and Upper Austria have been under way for several years. For the realization of this project, however, a series of utilisation conflicts will have to be resolved first; the final ordinance will most likely be still long in coming.

IV. The geological situation of the Dachstein massif (G. W. Mandl)

The text of this presentation is identical with the parts 2.2. and 2.3. of the „Preliminary National Report Austria" (see part 3 of the excursion guide).

Afterwards there are enclosed some geological maps used during the presentation:

Fig. 4.1: Tectonical overview of the Dachstein nappe and of its frame

Fig. 4.2: Geological map of the Dachstein area 1: 200 000

Fig. 4.3: Triassic depositional realms of middle part of Northern Calcareous Alps (Austria)

Legende zur Geologischen Übersichtskarte des Dachsteingebietes

QUARTÄR

G	Gletscher	Holozän
☐	Talfüllungen	
⁘	Hangschutt, Blockwerk	
⟋	Schwemmkegel	
▒	Grund- und Endmoränen	Pleistozän
°	Terrassen, fluviatile Ablagerungen	

TERTIÄR

⁘	Inneralpines Tertiär

GOSAU-GRUPPE

▧	Mergel und Sandsteine (Oberkreide - Alttertiär)
∘	Konglomerate

JURA

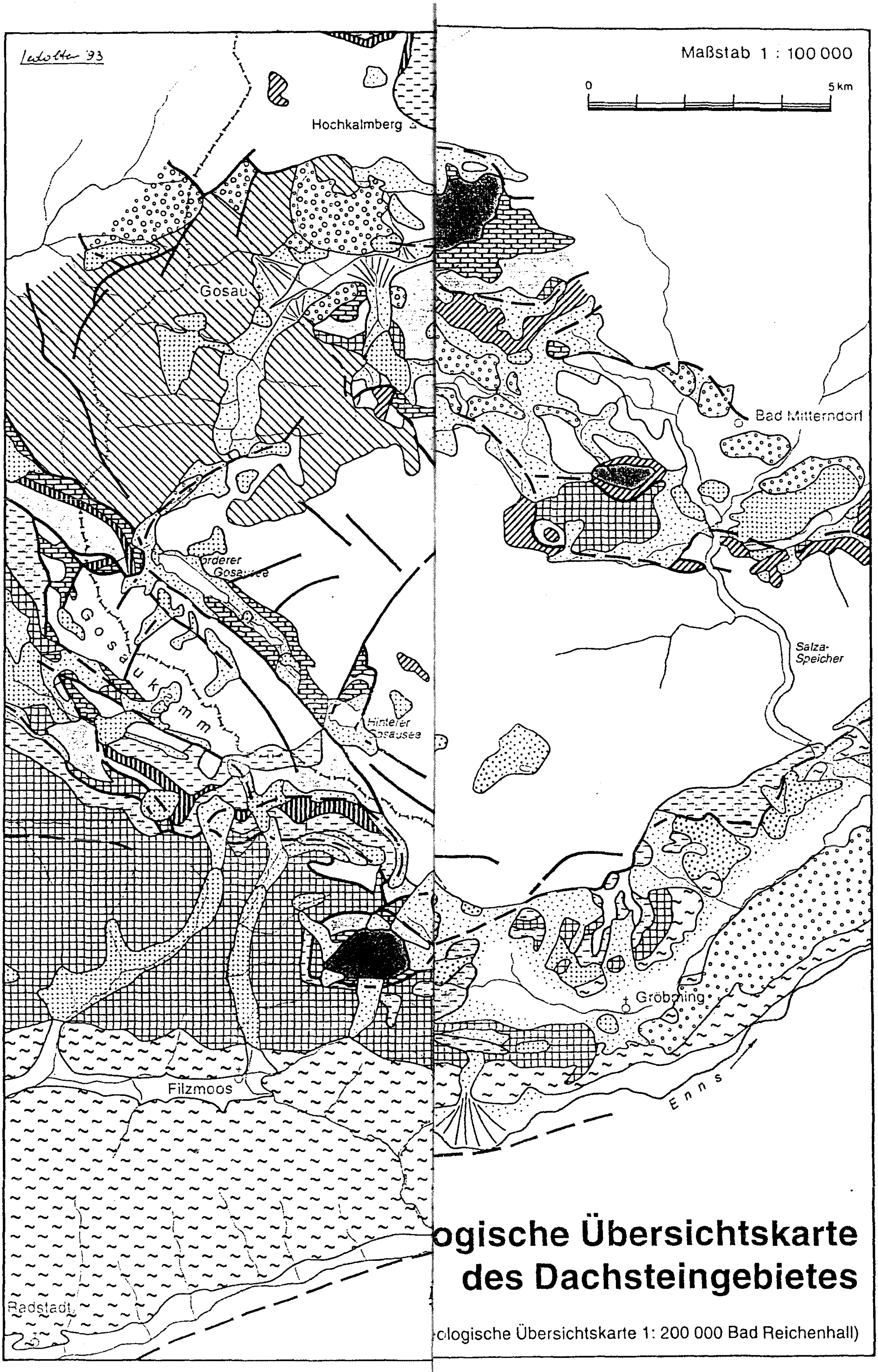
▓	Kalke des Oberjura (Malm)	
▨	Radiolaritgruppe inclusive Breccien, Allgäuschichten, untergeordnete Rotkalke	"Mergelige und kieselige Gesteine" des Lias und Dogger

(PERMO-) TRIAS

▤	Hallstätter Gruppe (Kalke, untergeordnete Mergel)	
☐	Dachsteinkalk	
┄	Hauptdolomit	
▥	Raibler Schichten	
▒	Wetterstein- und Steinalmdolomit, Gutensteiner Dolomit	"Karbonatgesteine der Mitteltrias" (überwiegend Dolomite)
▓	Wetterstein- und Steinalmkalk, Gutensteiner Schichten	"Karbonatgesteine der Mitteltrias" (überwiegend Kalke)
▦	Werfener Schichten, Präbichl Schichten, Haselgebirge (Ton, Gips, Salz)	"Siliziklastisch/evaporitische Gesteine" des Permoskyth

PALÄOZOIKUM

∼	Phyllite und Schiefer der Grauwackenzone



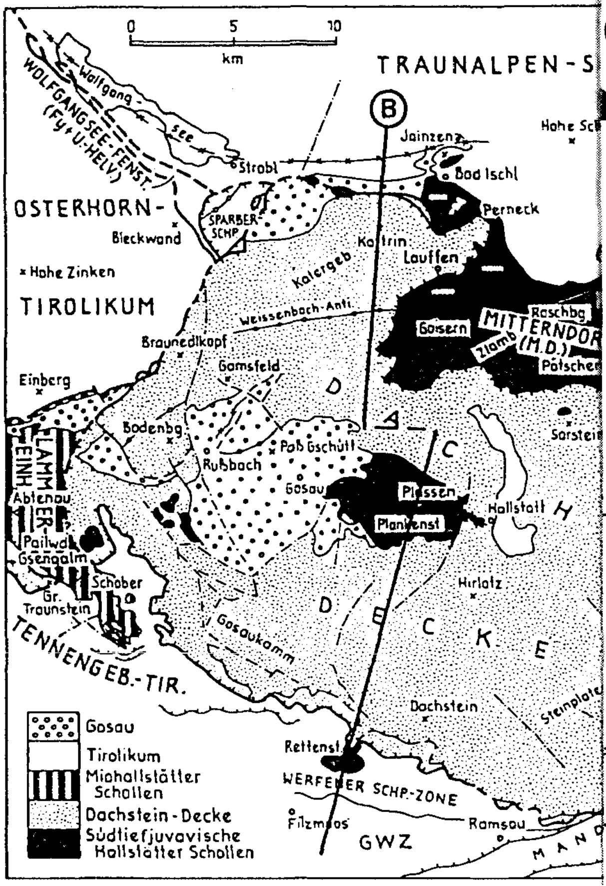
ogische Übersichtskarte des Dachsteingebietes

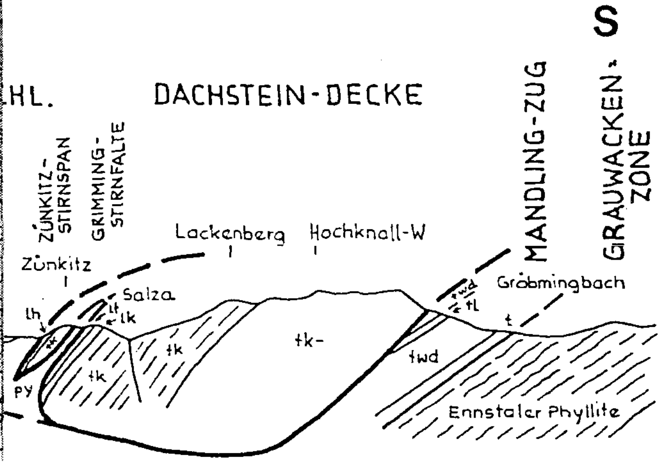
ologische Übersichtskarte 1: 200 000 Bad Reichenhall)

Dachstein nappe and of its frame

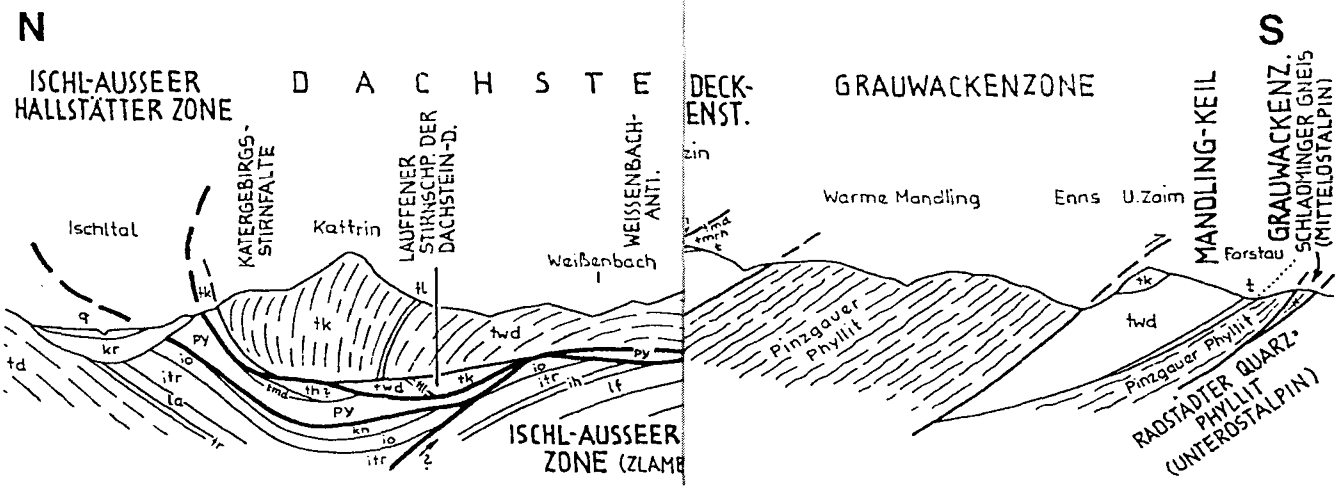
der Dachsteindecke
nens (mit 2 Profilen)

Nach A. TOLLMANN 1976, 1985





Schnitt B



QUARTÄR

q .... Quartär i. a.

KREIDE

kr .... Gosau
kn ... Schrambachschichten

MALM

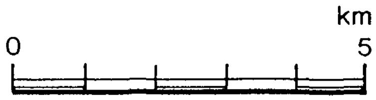
ip .... Plassenkalk
itr .... Tressensteinkalk
io .... Oberalmerschichten
ih .... Ruhpoldinger Radiolarit

LIAS

lf .... Allgä
(Lias
la .... Adne
lh .... Hierl

RHÄT

tr .... Köss
trz ... Zlam



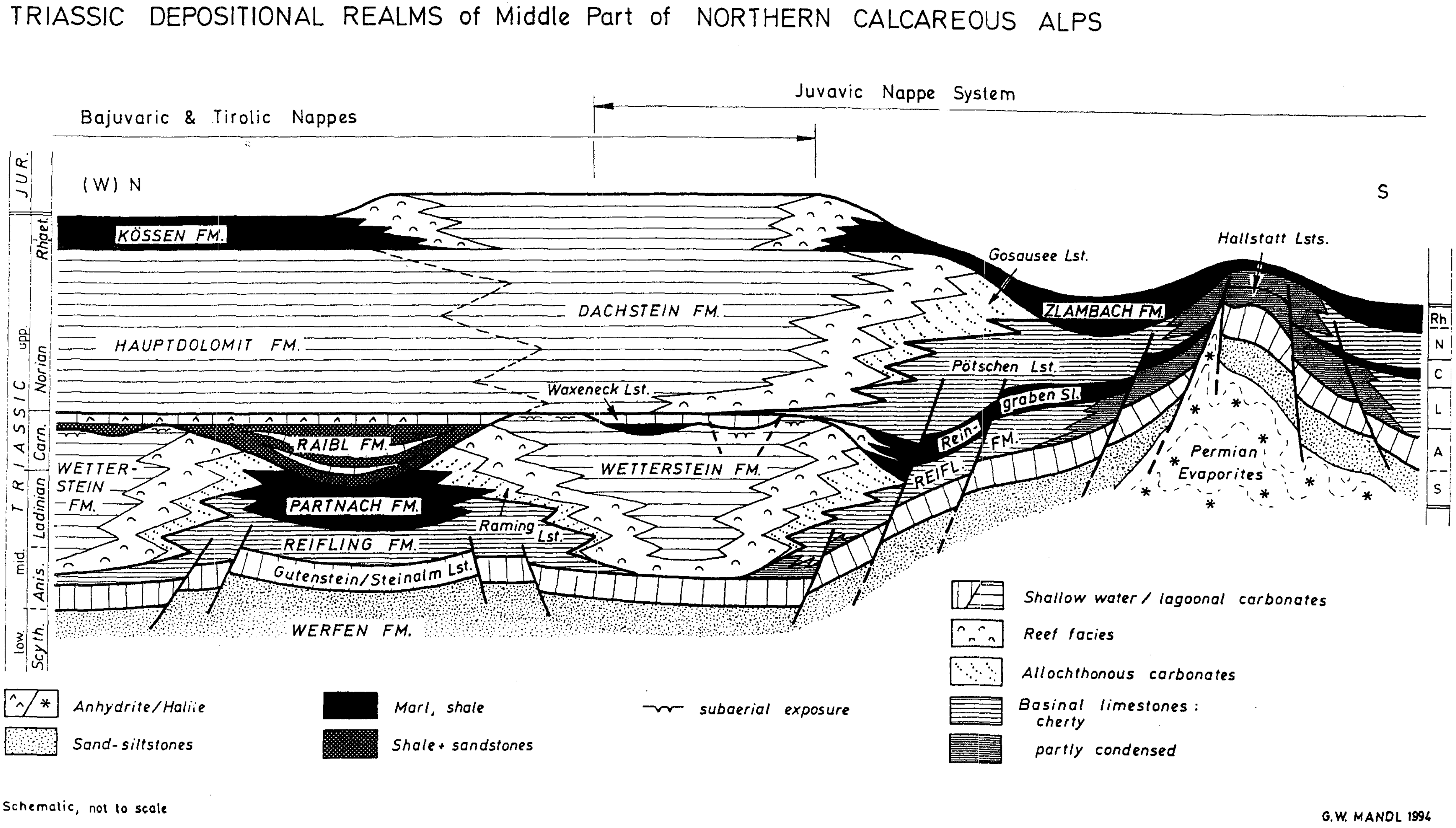


Fig. 4.3: Triassic depositional realms of middle part of Northern Calcareous Alps (Austria)

V. Present situation of water use and the realisation of protection and preservation zones in the area of the Dachstein-massif (H. WIMMER)

The planned preservation area Dachstein

The provincial governments of Upper Austria and Styria have been planning to delimitate a water-preservation-area in the massif of Dachstein since the early eighties. This area in the size of about 480 km^2 should cover the southernmost region of Upper Austria (46 % of the whole area) and the northwestern region of Styria (54 %).

Region features

The region ist wellknown as the heart of the Salzkammergut and includes beneath the Dachstein-massif sights like the lakes of Gosau, the skiing- and hiking-areas of the Zwieselalm, the rough mountain-chain of Gosaukamm, the valley of Gosau, the village of Hallstatt and its salt-mines, the impressive karstic-spring Kessel, the Krippenstein-area with the large caves Rieseneishöhle and Mammuthöhle, the nature-protection-area of Koppenwinkel, the Koppenbrüllerhöhle and the glaciers of Dachstein with areas for summer-skiing; all of them in Upper Austria. In Styria the preservation area will include sights like the rafters paradise of the narrow canyon of the river Traun, the lovely Ödensee, the gorge and storage lake of Salza, the magnificent overlook from the Stoderzinken, the mountainous scenery of Ramsau and last not least the steep walls of the Dachstein-Südwand which are ascended by climbers as well as by passengers of the cableway.

Hydrologic situation

There are about 350 karstic springs within the planned water-preservation-area. Most of them are little ones with periodically discharges. Such types of springs are also represented in the little group of the big springs up to 1000 l/s and more. Due to the geological situation the main runoff can be located in the northern part of the Dachstein massif.

Compared with other karstic regions in Austria the Dachstein area ist the leader in precipitation with 2000 to 2500 mm per year. As there are glaciers which are able to store much of the precipitation for a long term of the year the hydrological characteristics are very different from those of karstic regions without glaciers (e.g. the catchment areas of the Wiener Hochquelleitung in the eastern part of Austria).

Water supply situation

Three communities in Upper Austria and seven communities in Styria obtain drinking-water from the region described before. Most of these waters are from karstic springs, but there are some wells delivering water from post-glacial sediments and landslips, which are invisible dotated by karstic waters from the Dachstein massif. All of these waters are protected only nearby the springs or wells. In contrast to groundwaters in porous media these karstic waters cannot be protected on the whole by their small and isolated protection-areas.

Water power plants

Big springs attracted electricity companies long before water supplly institutions: Since the early beginnings of this century a lot of karstic water has been used for producing electric power.

Scientific investigations

The waters of the Dachstein area have not only been attracting planners of power plants in former days and tourists nowadays but also scientists like hydrologists, spelaeologists or geologists as well as the water-supply- and protection authorities of Upper Austria, Styria and Salzburg.

There have been many questions to be answered by the scientists engaged.

Which springs or wells are preferentially suitable for supplying the local communities or, at least, whole regions?
Where are the catchment areas of those karstic waters?
What ist the minimum and average storage time?
Which paths are leading from the catchment areas to the springs and wells?
What´s about the influence of the geological and geotectonical situation on the hydrological and the hydrochemical characteristics of those waters?
What are the potential threats to karstic groundwater?
Under which conditions will it be possible to avoid bacteriological or chemical pollutions of drinking waters like it happened to those of Hallstatt?

A lot of investigations were done. Some are just going on, and many have to be made in future. For example, we don´t know very much about the infiltrations of karstic waters into the porous groundwater systems as well as about the hydrological and ecological riscs of extracting water from this area in a big extent. Or: The fallout of Chernobyl accident caused a high radioactivity load of the karstic waters within the first days after the fallout. Which duties for the water supply managment should result from this?

Aims of the regulation of the planned preservation area

Due to the present usage of waters their quality and quantitiy should not be affected or threatened. Groundwater and karstic water should be used primary as drinking water. Insufficient wastewater conditions should be cleared. The natural hydrology of the ground- and karstic water should be preserved. Forest cultivation as well as touristic development should be done carefully.

Many actions like the storage and transportation of mineral oil and chemicals, the usage of pesticides, the clearing of woodland, the construction of roads and cableways or the storage of waste waters are to be reconsidered by the authorities for water legislation.

Some actions like drilling- or blasting-operations have to be reported to the authorities before starting them.

The following actions will be prohibited:
Construction and operation of waste deposits;
Application of sewage sludge;
Treatment and deposition of radioactive materials;
Oozing or sinking of waste water;
Exploitation of sediments if the distance to the groundwater-surface is less than 10 meters;
Chemical preparation of snow on ski-tracks;
Storage of old cars;
Usage of mineral oils and fuels in the forest culture if substitutes are available.

In cases of endangering the ground- and karstic water system the authorities for water legislation are to be informed immediately.

Outlook

The restrictions listed beforde imply, that they have to be compensated - in most cases with money.

So the authorities are in search for representatives of preservation-areas which are prepared for these cases. As the number of restrictions is according to the size of the area, it is evident, that there is only little willingness to representate a preservation-area Dachstein. And as long as the authorities have to wait for this moment, the preservation-area will exist only on the paper. Well designed, but as a project.

VI. The subterranean discharge in the Dachstein area

The subterranean discharge in the Dachstein area and the consequences for the karst water preservation
(BAUER, F. (1989); UBA- Report UBA-89-28)

Short summary:

To investigate the catchment areas of the springs and the subterranean karsthydrological phenomena nineteen injections with fluorescent tracers were carried out by the Dept. Water Resources of Karst Areas of the Federal Environmental Agency in 1984, 1985 and 1986, thus continuing earlier injections of the years 1953-1960 with lycopodium spores. In the report special attention was paid to a comparison of the results obtained with this two different tracing methods.

Added you find some maps of spore and dye tracer experiments, which have been carried out in the Dachstein area between 1956 and 1990.

As short additional information to the maps you can use part 5. of the „Preliminary National Report Austria".

Fig. 6.1: Spore tracer experiments 1956 in the eastern Dachstein area (carried out with lycopodium spores) (ZÖTL, 1957)

Fig. 6.2: Spore tracer experiments 1958 in the Dachstein area (lycopodium spores) (BAUER, ZÖTL & MAYR, 1958)

Fig. 6.3: Revised results of the spore tracer experiments in the Dachstein area (1953 - 1960) (BAUER, 1989)

Fig. 6.4: Situation of the subterranean discharge and necessary protection areas in the Dachstein massif (BAUER, 1989)

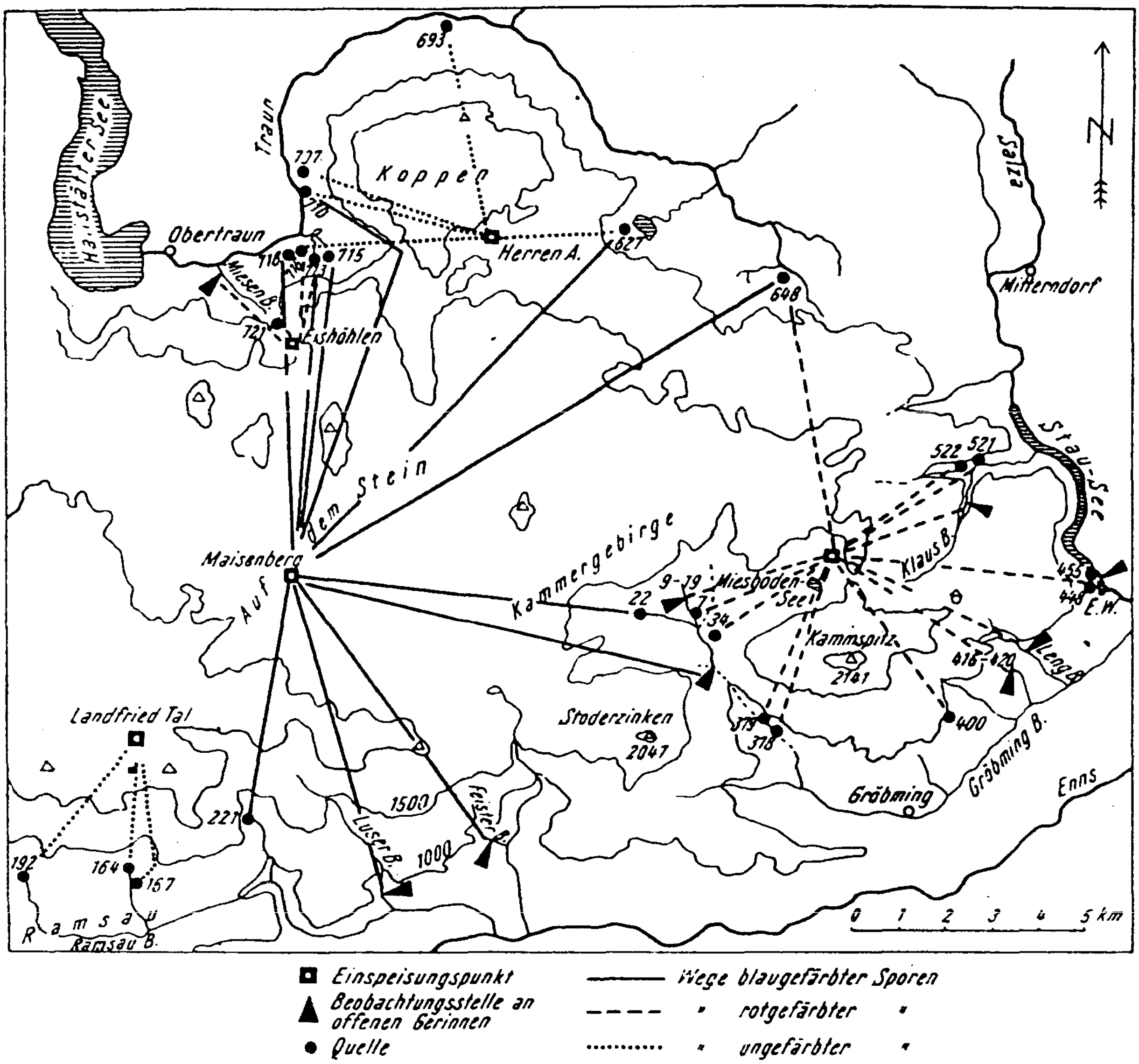


Fig. 6.1: Spore tracer experiments 1956 in the eastern Dachstein area (carried out with lycopodium spores) (ZÖTL, 1957)

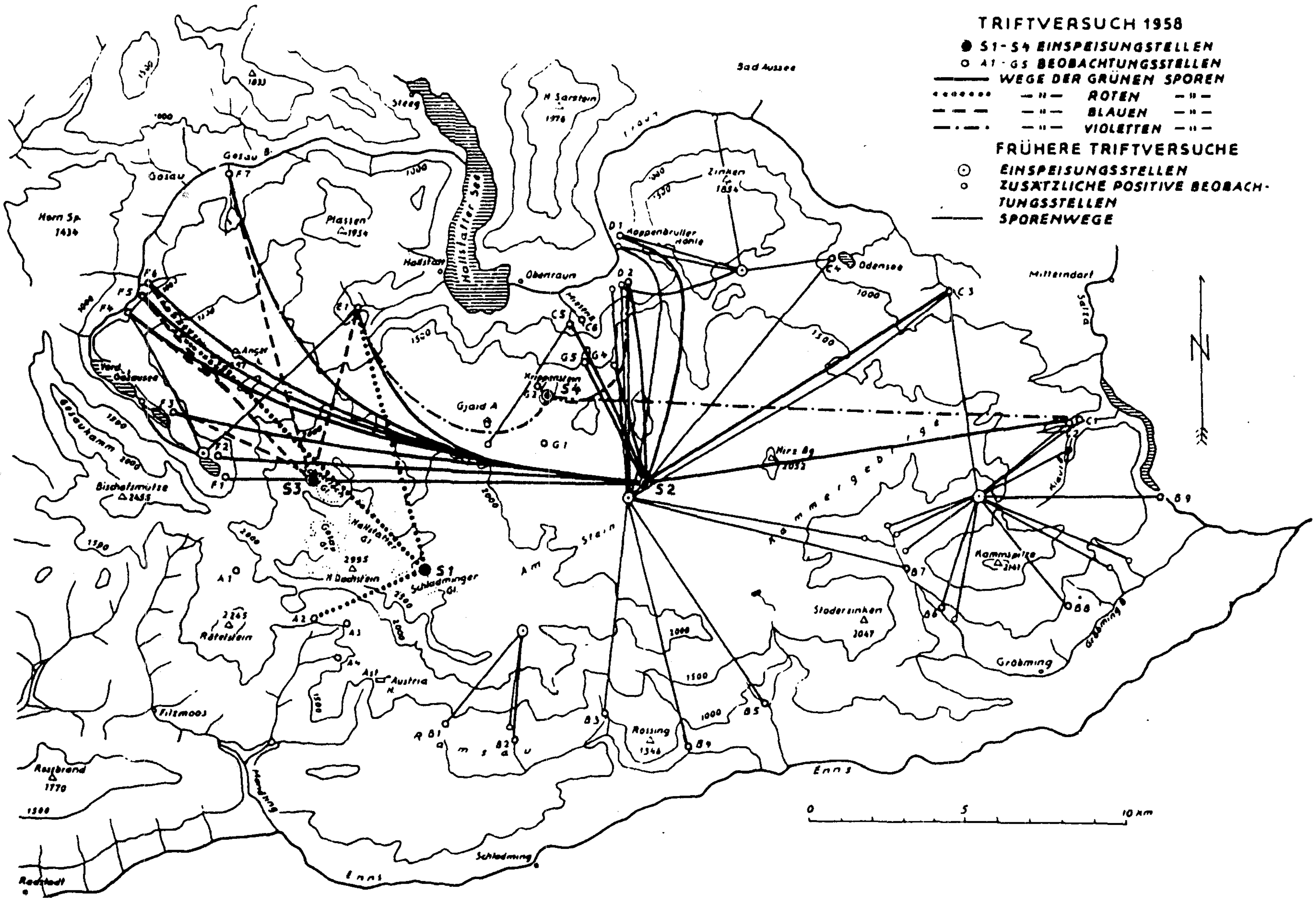


Fig. 6.2: Spore tracer experiments 1958 in the Dachstein area (lycopodium spores) (BAUER, ZÖTL & MAYR, 1958)

Kopierverzerrung nur für die Ost-West-Richtung.
Für die Nord-Süd-Richtung entspricht die mit 10 km angegebene Strecke einer Entfernung von 8,9 km.

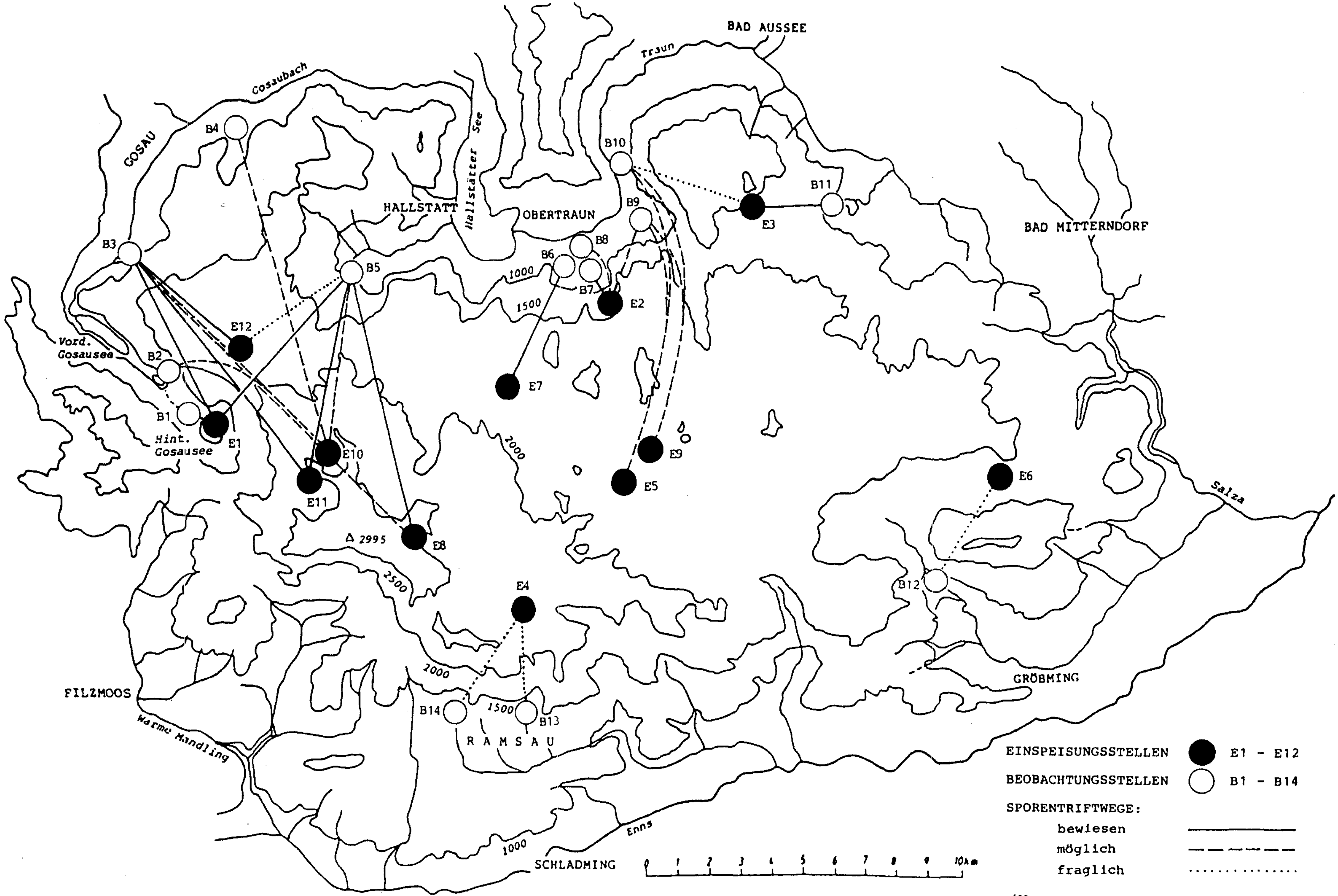


Fig. 6.3: Revised results of the spore tracer experiments in the Dachstein area (1953 - 1960) (BAUER, 1989)

Der angegebene Maßstab stimmt infolge einer Kopierverzerrung nur für die Ost-West-Richtung. Für die Nord-Süd-Richtung entspricht die mit 10 km angegebene Strecke einer Entfernung von 8,9 km.

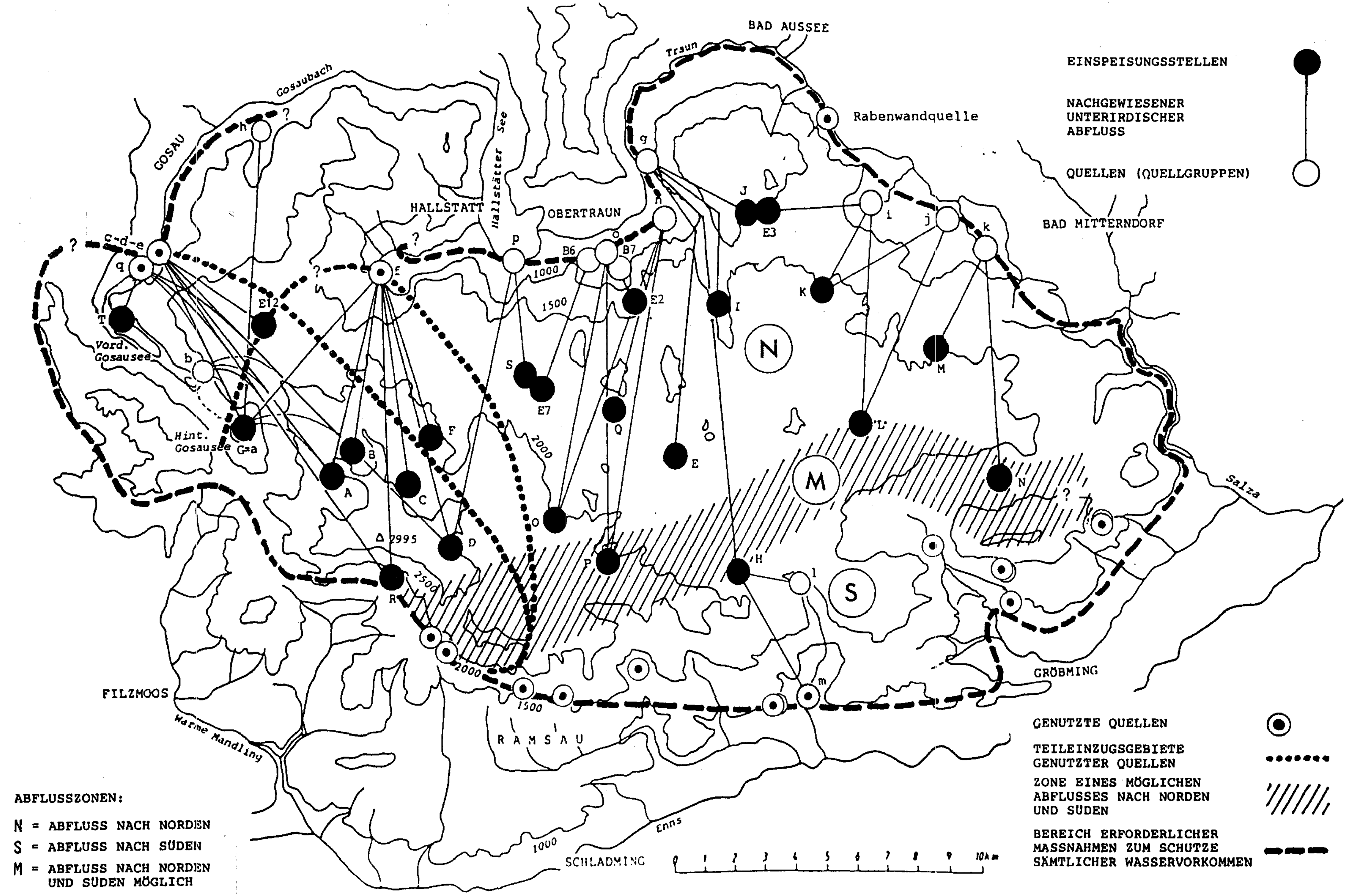


Fig. 6.4: Situation of the subterranean discharge and necessary protection areas in the Dachstein massif (BAUER, 1989)

Karsthydrological investigations in the western part of the Dachstein massif with regard to the delimitation of water protection area (HERLICSKA, H., HOBIGER, G. (1991); UBA-Report UBA-91-056)

Short summary:

In 1990 the Austrian Federal Environmental Agency conducted two additional tracer experiments in the western part of the Dachstein region.

The investigations were made on account of a demand by the planning department of the provincial government of Upper Austria. The results of the study are to provide a basis for the delimitation of a water prevention area.

One of the main purposes was the investigation of the subterranean discharge at times of high and low water levels inside the Dachstein massif, in order to justify the necessary delimitation of a groundwater prevention area.

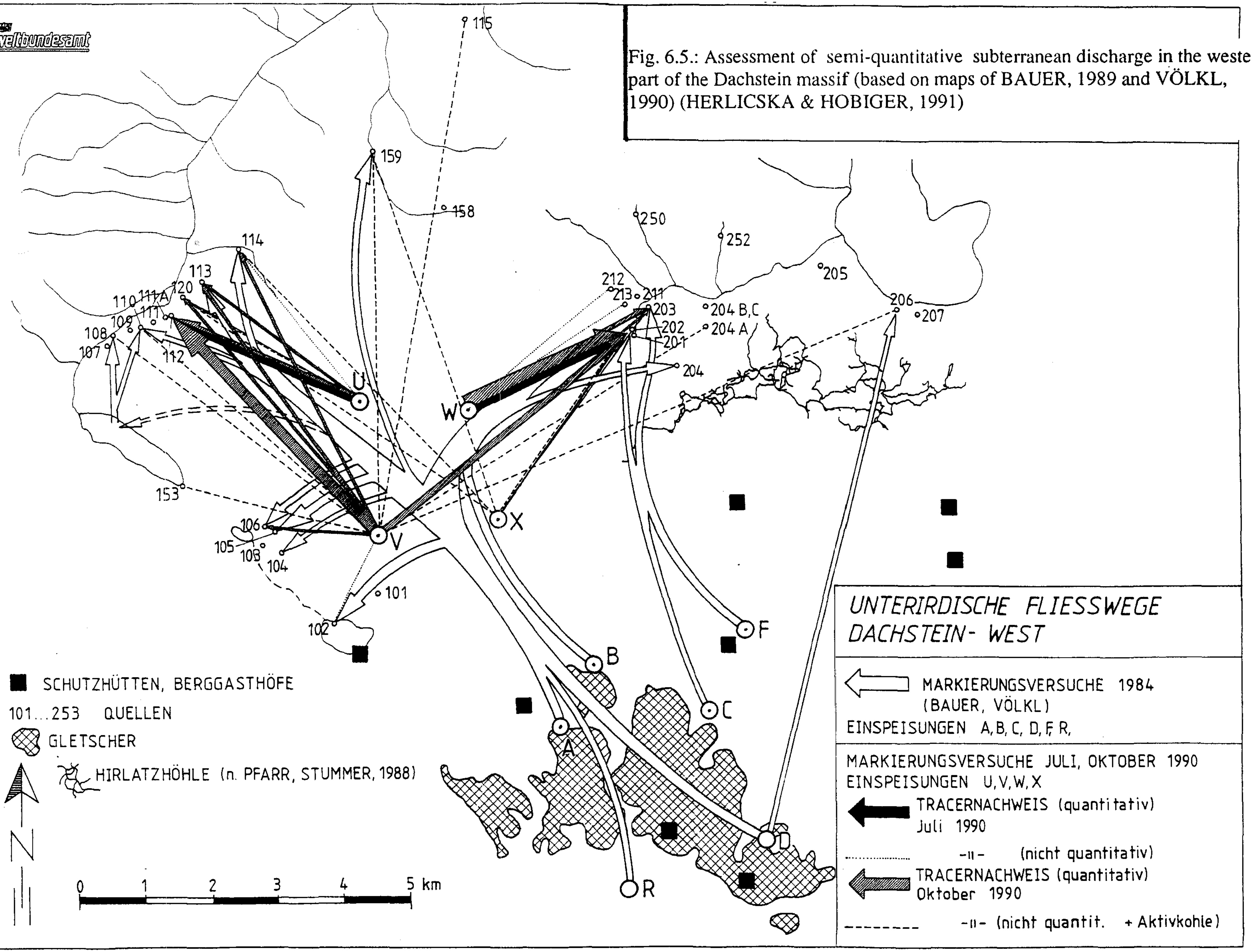
The results of the investigations indicate a high variability of the karst subterranean discharge at different seasons; it has also been proven that the catchment areas of the drinking water springs in the communities of Gosau and Hallstatt overlap each other.

For this reasons, a groundwater prevention area for the communities of Gosau and Hallstatt must include the whole western part of the Dachstein massif.

Due to the possibility of a fast discharge to springs, dolines and sinkholes within the investigated area - like catchment areas of drinking water springs - should be made subject to special protection.

Fig. 6.5.: Assessment of semi-quantitative subterranean discharge in the western part of the Dachstein massif (based on maps of BAUER, 1989 and VÖLKL, 1990) (HERLICSKA & HOBIGER, 1991)

Fig. 6.5.: Assessment of semi-quantitative subterranean discharge in the weste part of the Dachstein massif (based on maps of BAUER, 1989 and VÖLKL, 1990) (HERLICSKA & HOBIGER, 1991)



VII. Caves in the western part of the Dachstein area

The following map (Fig. 7.1) shows the most important big caves in the north-western part of the Dachstein massif (PFARR & STUMMER, 1988):

1546/7: Hirlatz cave (Hirlatzhöhle)

1547/9: Dachstein Mammut cave (Dachstein-Mammuthöhle)

1547/17: Dachstein Ice cave (Dachstein-Rieseneishöhle)

1547/70: Schönberg cave (Schönberghöhle)

As short text you can use part 2.4 of the „Preliminary National Report"

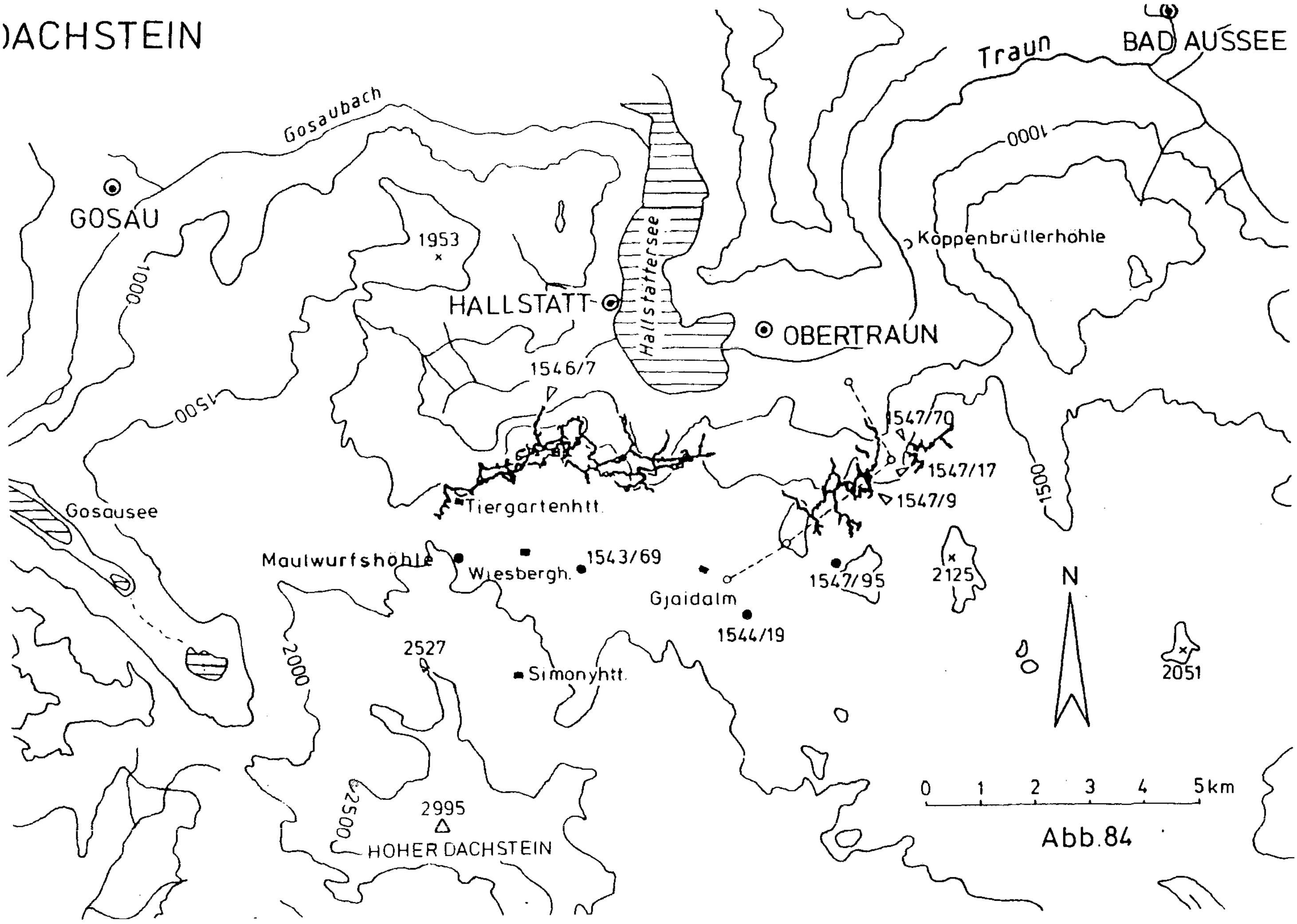
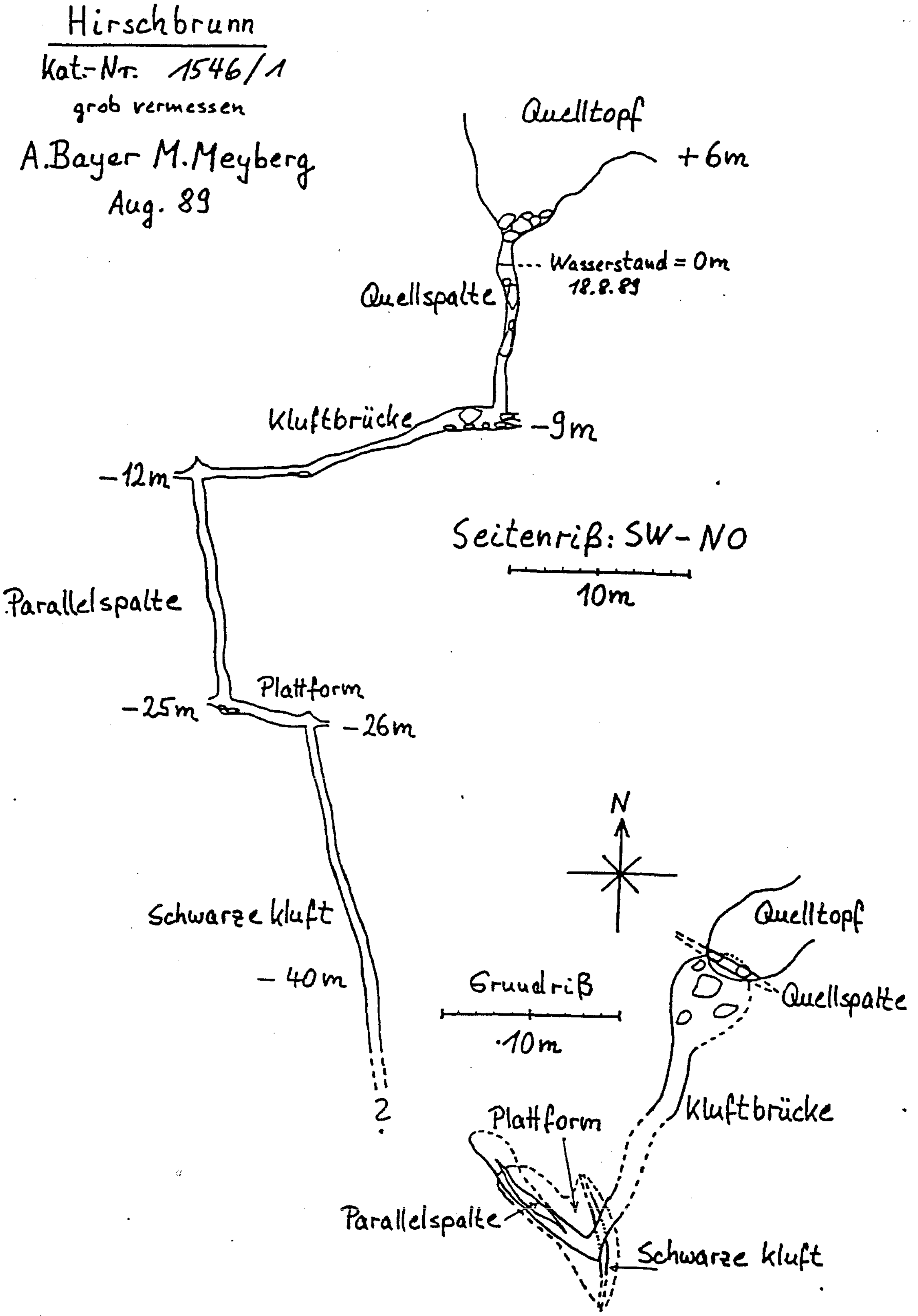


Fig. 7.2: Cross-section of the siphon „Hirschbrunn" (spring „206" in Fig. 2.2) (MEYBERG, 1991)



REFERENCES

ABEL R. (1970): Klima und Wasserhaushalt einer Hochkarstfläche; Dissertation an der philosophischen Fakultät Wien.

BAUER, F. (1989): Die unterirdischen Abflußverhältnisse im Dachsteingebiet und ihre Bedeutung für den Karstwasserschutz; Report UBA-89-28, Wien.

BUNDESKANZLERAMT (1993): Österreichisches Lebensmittelbuch (Lebensmittelkodex), Kap. B1 "Trinkwasser"; Wien.

BUNDESMINISTERIUM FÜR LAND- UND FORSTWIRTSCHAFT (1991): Wassergüte-Erhebungsverordnung. BGBl.Nr.: 338/1991

ECKER, F.J., HIRARI, E., CHOHJI, T. (1990): The release of heavy metals from snowpacks on the Japan Sea Side of Japan; Environmental pollution 65.

FORSTLICHE BUNDESVERSUCHSANSTALT (FBVA) (1993): Ergebnisse der terrestrischen Kronenzustandserhebung für 1992. Österreichische Forstzeitung 2/1993.

HEINTSCHEL, G. (1986): Wasserversorgungs- und Umweltsituation nach dem Unfall von Tschernobyl am Beispiel Wiens; in: Symposium Radioaktivität und Trinkwasser. ÖVGW Bericht SW 2, 149-176.

HERLICSKA, H., HOBIGER, G. (1991): Karsthydrologische Untersuchungen im westlichen Dachsteinmassiv im Hinblick auf die Erlassung einer Wasserschongebietsverordnung; Report UBA-91-056, Wien.

HERLICSKA, H., GRAF, K. (1992): Dokumentation karsthydrologischer Untersuchungen in Österreich; UBA-Reports-92-057; Umweltbundesamt Wien.

HERLICSKA, H. (1993): Wasserqualitätsuntersuchungen in Karstgebieten - Grundlage für den vorbeugenden Gewässerschutz; Österr. Geol. Ges.; Exkursionsführer 14, Österr. Hydrogeologentag 1993.

HERLICSKA, H., LORBEER, G., BOROVICZENY, F., MANDL, G. W., PAVUZA, R., STUMMER, G., LASSNIG, M. (1994): Pilotprojekt „Karstwasser Dachstein", Band 1: Karstwasserqualität; Monographien Bd. 41, Umweltbundesamt Wien.

HOFER, V. (1990): Anforderungen an die Abwasserreinigung im Hochgebirge; Vortrag im Rahmen des ÖWWV-Seminars "Wasser, Abwasser, Müll im Hochgebirge", 12./13. Juni 1990, Fulpmes/Tirol.

HUMER, G. (1994): Isotopenmessnetz Österreich; UBA- Reports; Umweltbundesamt Wien; (in press).

KILIAN, W. (1959): Vorschlag zu einer Karstbestandsaufnahme Österreichs; Dissertation an der Universität für Bodenkultur Wien.

KOVAR, A., PUXBAUM, H. (1992): Nasse Deposition im Ostalpenraum. Institut für Analytische Chemie, Technische Universität Wien, 1-33.

MANDL, G.W. (1984): Zur Tektonik der westlichen Dachsteindecke und ihres Hallstätter Rahmens (Nördl. Kalkalpen, Österreich);-Mitt.österr.geol.Ges., 77, Wien.

MANDL, G.W. (1987): Das kalkalpine Stockwerk der Dachsteinregion; in: Arbeitstagung der Geol. B.-Anst. 1987, Blatt 127 / Schladming, Wien.

MANDL, G.W. (1988): in: HEJL, E. et al.: Geologische Übersichtskarte 1:200.000, Bundesrepublik Deutschland CC 8742 Bad Reichenhall, Hannover.

MAURIN ,V., ZÖTL, J. (1959): Die Untersuchung der Zusammenhänge unterirdischer Wässer mit besonderer Berücksichtigung der Karstverhältnisse. Steirische Beiträge zur Hydrogeologie, JG 1959, Graz 1959

MAYBERG, M. (1991): Tauchvorstoß im Hirschbrunn. Höhlenkundliche Vereinsinformation, Jahrgang 17, Verein für Höhlenkunde, Hallstatt, Obertraun.

ÖSTERREICHISCHE STRAHLENSCHUTZVERORDNUNG, 1972

ÖWWV (1984): Leitlinie für die Nutzung und den Schutz von Karstwasservorkommen für Trinkwasserzwecke. ÖWWV, Regelblatt 201, Wien.

PFARR, T., STUMMER, G. (1988): Die längsten und tiefsten Höhlen Österreichs. Wissenschaftliche Beihefte zur Zeitschrift „Die Höhle" Bd. 35, Wien.

PLÖCHINGER, B. (1980): Die Nördlichen Kalkalpen.; in: OBERHAUSER, R. (Ed.): Der geologische Aufbau Österreichs, Wien.

SAAR, R. (1951): Die Geschichte der Entdeckung, Erforschung und Erschließung der bundesforsteigenen Höhlen nächst Obertraun, Denkschrift, Österreichische Bundesforste, Wien 1951.

SCHLEYER, R. (1992): Gefährdung der Grundwasserqualität durch Deposition atmosphärischer organischer Schadstoffe; DVGW-Schriftenreihe; Wasser Nr.73, 75-90.

TOLLMANN, A. (1985): Geologie von Österreich, Band 2.

ULRICH, B. (1989): Waldökosystemforschung, Konzepte und Wege; in: Immissionsbelastung des Waldes und seiner Böden - Gefahr für die Gewässer ? Mitteilungen des deutschen Verbandes für Wasserwirtschaft und Kulturbau e.V., Heft 17, 7-22.

UMWELTBUNDESAMT WIEN (1986): Tschernobyl und die Folgen für Österreich; UBA- Monographien Bd. 1, Wien.

VILLINGER, E. (1991): Hydrogeologische Kriterien für die Abgrenzung von Wasserschutzgebieten in Baden- Württemberg; Informationen des Geologischen Landesamtes Baden- Württemberg, 2.

ZÖTL , J. (1957):Hydrogeologische Untersuchungen iim östlichen Dachsteingebiet, Mitt. naturwiss. Verein Steiermark, Graz .

Slovak part of the 10th COST 65 Management Committee Meeting

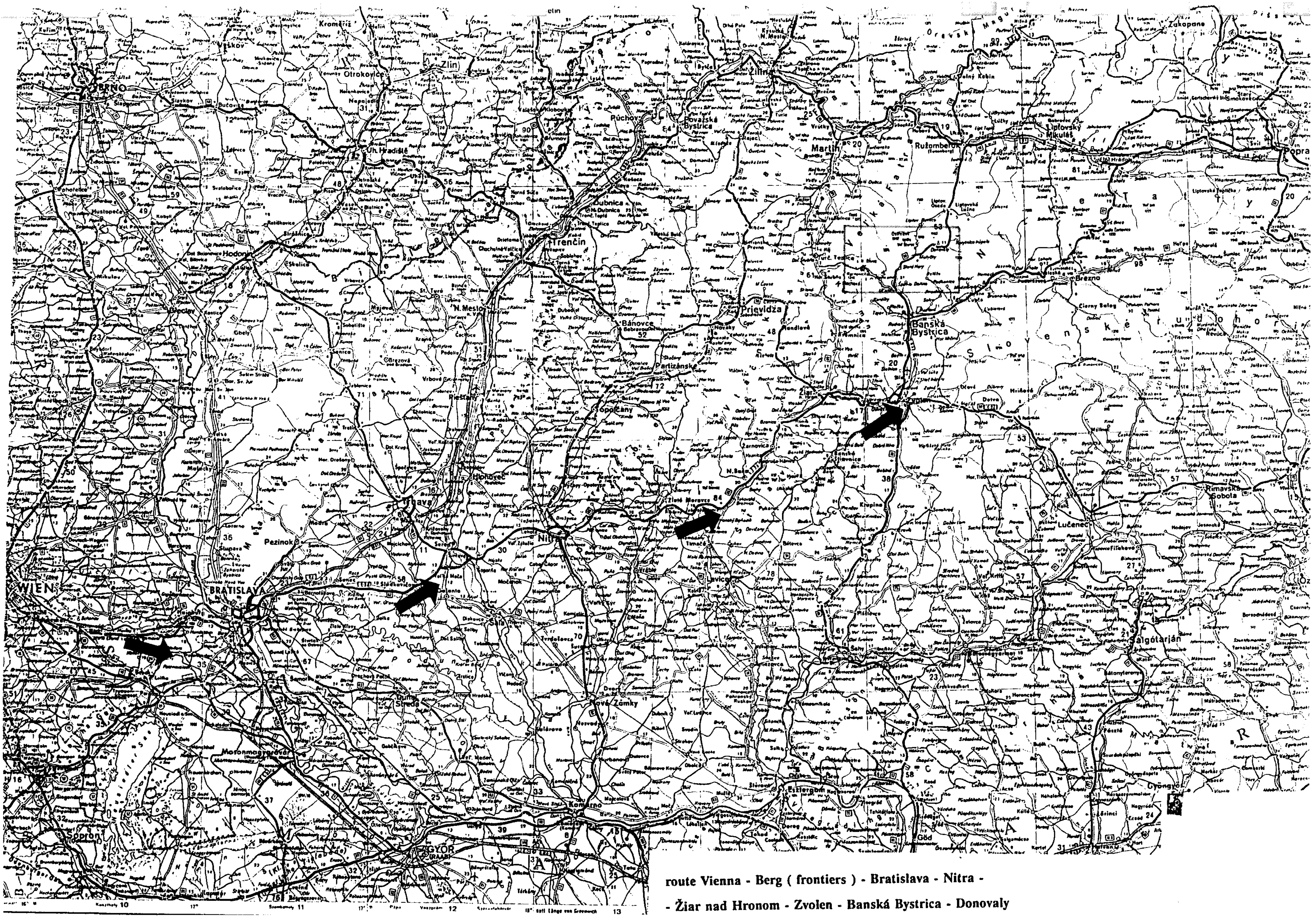
Donovaly, Oct. 8 - 10, 1994

EXCURSION

GUIDE

Compiled by Peter Malík, 1994

CONTENT:



route Vienna - Berg (frontiers) - Bratislava - Nitra -
- Žiar nad Hronom - Zvolen - Banská Bystrica - Donovaly

I. Šalaga

INGEO a.s. Žilina

HYDROGEOLOGICAL FEATURES OF THE KARST TERRAINE IN SLOVAKIA

Introduction

Karst aquifers represernt important and irreplaceble groundwater resources in Slovakia. In respect to their significance for water management the karst-fissure waters come on the second place behind resources and reserves in Quaternary sediments. With the increasing pollution of Quaternary water their significance grows and their research and exploration should be intensified. Due to their specific character and vulnerability to the pollution a particular approach is necessary to their study, evaluation utilization and protection.

Brief geotectonic review of the West Carpathians

The greater part of Slovak territory belongs to the young orogenic system of the West Carpathians which is a part of the vast Alpino - Carpathian Arch running across Europe.

Geotectonic structure of the West Carpathians is similar to those, known from the Alps or East Carpathians, but certain differences are striking. Comparison with the Central Alps having a massive continuous crystalline core, for the West Carpathians is typical morpho-tectonic complexity of crystalline core emerging from sedimentary crust as isolated mountain ranges or hills resulting in pronounced morphological variability with high mountain ranges contrasting with low depressions on the inner side and an intermontane basins. Typical for the West Carpathians is also an extensive young volcanic activity (Neogene) on the inner side of the system.

The West Carpathians consists of two parts:

- *The Inner Carpathians* belongs to late Mesozoic geosyncline folded by the Alpine orogenic events in Cretaceous, and
- *The Outer Carpathians* better known as the *Flysh Belt* originated from outer geosyncline with predominantly flysh Paleogene sedimentation and orogenic events in early Tertiary.

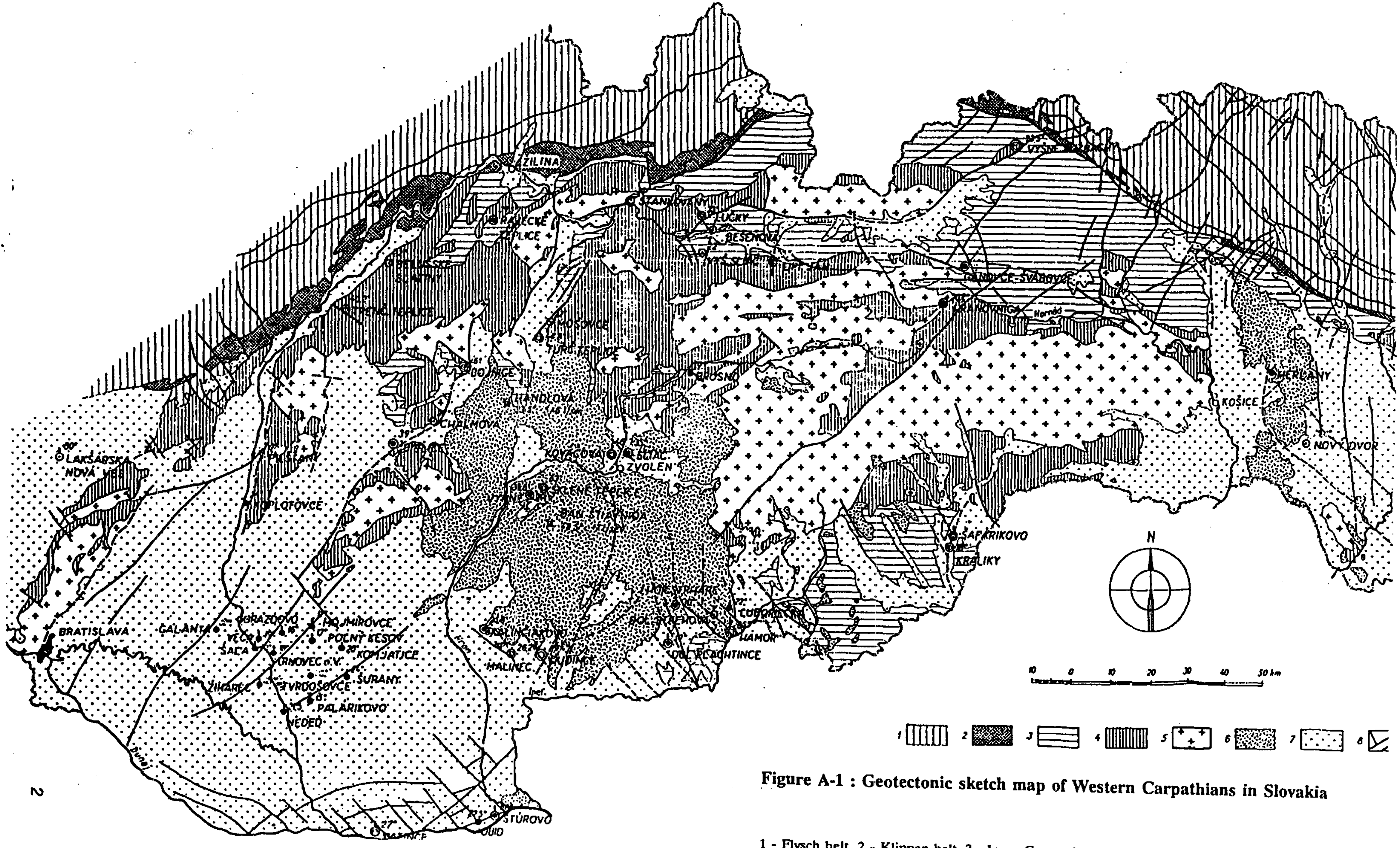


Figure A-1 : Geotectonic sketch map of Western Carpathians in Slovakia

1 - Flysch belt, 2 - Klippen belt, 3 - Inner-Carpathian Paleogene, 4 - Mesozoic complexes,

5 - Crystalline core, 6 - Volcanic sequences, 7 - Neogene and Quaternary sediments, 8 - fault lines

On the contact of the Inner Carpathians and Flysh Belt occurs a narrow zone of the **Klippen Belt** of flysh sequences of Upper Cretaceous and Paleogene with isolated blocks of Jurassic and Lower Cretaceous carbonatic rocks.

The Inner Carpathians forms a wide belt consisting of 11 morphostructural elevations dissected by intermontane depressions filled with Paleogene and/or Neogene sediments. On the Crystalline cores lay a complex folded and faulted system of the Mesozoic sedimentary formations sometimes with several nappes one on top of the other. In Eastern Slovakia this system transits to the huge megasyncline of the Slovenské Rudohorie Mts. formed by Pre-Mesozoic mainly metamorphic rocks and overlaid by flat - laying nappes of the Mesozoic carbonatic rocks of considerable thickness.

Geotectonic sketch map of West Carpathians in Slovakia is shown in Figure A-1.

Typical features of karst terrains in the West Carpathian

Due to the different character of the geomorphological elements in the West Carpathians the development of the karst phenomenon has distinct features. The original Cvijic's concept of the karst typology had not reflected specific aspects of the West Carpathian. Therefore several typologies have been suggested by some Slovak authors. A generally recognised typology of E. Mazúr - J. Jakal (1969) divides West Carpathian karst into two main groups with subsequent sub-divisions:

1. Middle European karst of temperate climate
2. High mountain karst.

The first group is divide to two sub-types:

1.1 Plateau karst with a typical features of the holokarst.

1.2 Karst of the folded and faulted structures - merokarst.

This comprises: - karst of the monoclinal ridges (fluviokarst),
- horst karst,
- karst of the basins - covered karst,
- isolated karst of the Klippen Belt.

The plateau karst is developed only in eastern and south - eastern Slovakia (Slovenské Rudohorie Mountains) and it forms three separated areas : Slovenský Kras, Muránsky Kras and Slovenský Raj with the total area over 800 km^2. The Middle and Upper Triassic carbonates lay nearly horizontally on the Lower Triassic clayey shales and Pre - Mesozoic substratum. Their thickness varies from several hundred metres to more than 1000 metres. The relatively flat surface of the plateau is dissected by deep canyons (some of 400 - 500 m depth). The karst phenomenon is well developed including polje, uvala, sinkholes, karrens, chasms, dry valleys, ponors, karst springs and caves (The cave Domica with an underground river is 26 km long). Recharge of groundwaters is mainly from precipitation (mean rainfall is about 700 mm). Groundwater discharge is via karst springs at the foot of the plateau often on contact with impervious clayey sediments (Neogene). Typical for karst springs is a yield fluctuation from several litres per sec. to more than 1000 $l.s^{-1}$.

Slovenský Kras is one of the pilot areas of the COST - 65 and some research results will be a part of the Slovak national report.

Karst of the folded and faulted structures is typical for Central, Northern and Western Slovakia. Though the conditions for karst development here were not as favourable as in South - Eastern Slovakia and surficial karst phenomenon is less frequent, underground karst is well developed e.g. deep chasms and extensive caves (There are nine cave levels with a rich stalactite and stalagmite decoration in the Demänová caves - Low Tatras), ponors and karst springs.

Recharge of groundwaters is directly from rainfall and often also from morphologically higher situated older formations e.g. from crystalline rocks and their weathered mantle via ponors or sinkholes which occur frequently at the contact of carbonatic rocks with outcropping older formations. Groundwater flow in the saturated zone is mainly subhorizontal with high velocity 0.01 - 0.1 m.s-1 (Kullman, E. 1990). Groundwater discharge is usually performed on the margin of the structure (base level) but often also inside the structure to the deep - eroded valleys via karst springs or hidden affluents to the fluvial deposits.

In the case where carbonate complexes submerge underneath the Tertiary sedimentary formations of the basins or volcanic sequences, part of the groundwater percolates to the depth and then becomes part of the circulation of "the Basin karst" or covered karst. Some case studies from the karst of monoclinal ridges will be presented during the field trip.

2. High mountain karst forms a distinct type mainly from the point of view of the climate. It is usualy territory over a forest boundary e.g. over an altitude of 1400 m. High rainfall (about 1800 mm), low temperature (mean annual temperature about 0 °C) and high contents of CO_2 in the water increase limestone dissolution. An intensive mechanical weathering together with a poor vegetation cover create a favourable condition for karstification. Some forms of karst phenomenon are well developed - e.g. karrens, sinkholes, chasms and vertical caves. High mountain karst is limited to some small areas in the High and Low Tatras and in the Veľká and Malá Fatra Mts.

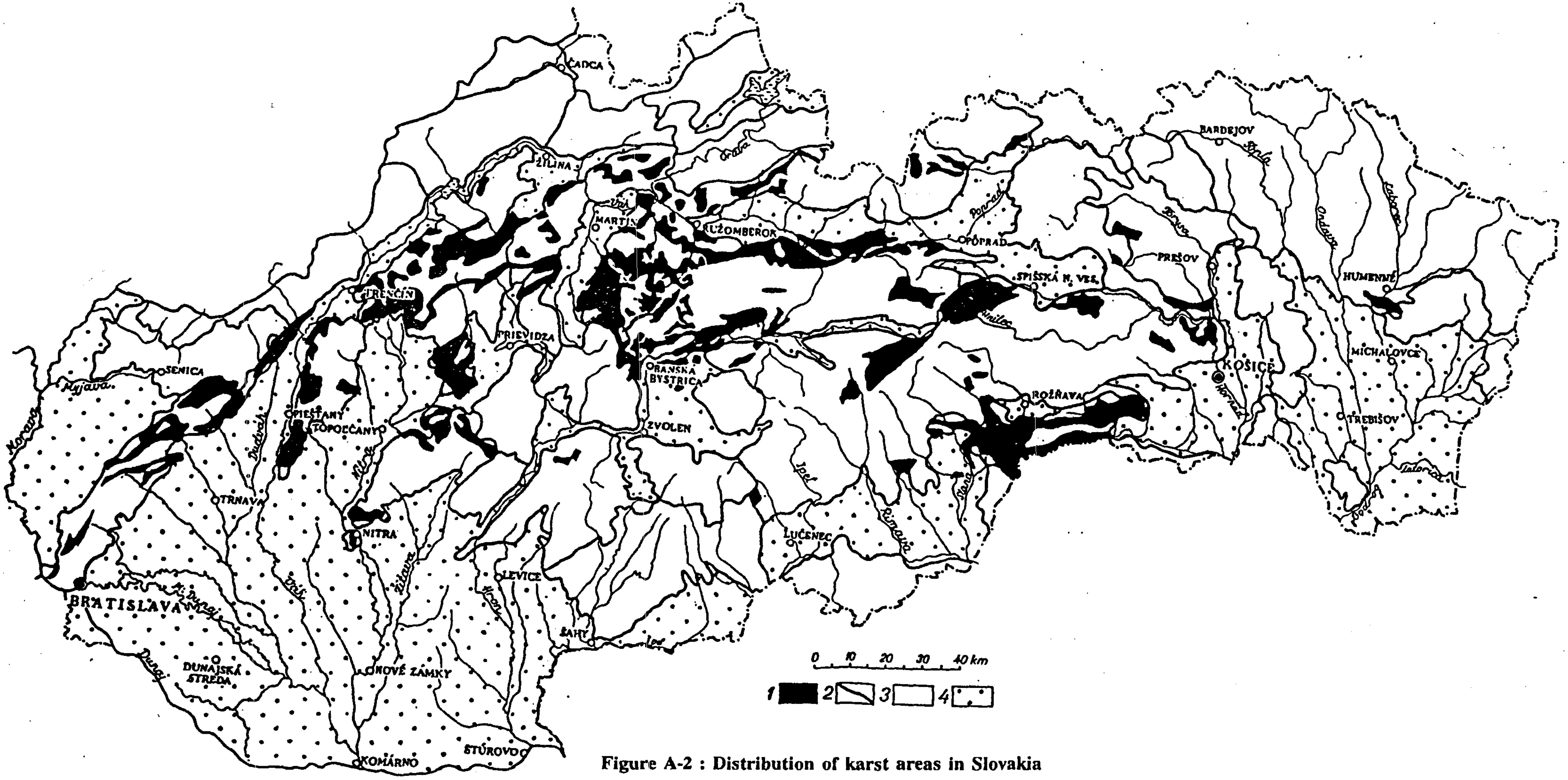


Figure A-2 : Distribution of karst areas in Slovakia

1 - carbonate complexes, 2 - morphological boundaries of mountain ranges, 3 - mountain ranges, 4 - basins and depressions

Karstic aquifers of Slovakia

The karstic aquifers in the West Carpathian occur generally in carbonate complexes represented by Middle and Upper Triassic limestones, dolomites and dolomitic limestones. A limited number of karst aquifers exists in water - bearing Jurassic and Lower Cretaceous limestones, Paleogene carbonate conglomerates and Carboniferous limestones.

The karst areas in Slovakia do not cover a vast territories as we know from Croatia, France or Spain. These are dispersed to about 80 rather smaller structures or groups of hydrogeologic structures. The sketch map in Figure A-2 shows the distribution of karstic areas in Slovakia.

The total areal extent of exposed karst carbonate formations in Slovakia is 3280 km^2. In evaluated 80 hydrogeologic structures with total area 3 082 km^2 the expected natural groundwater resources represent 27 474 - 31 523 $l.s^{-1}$ (Hanzel, V. et al. 1989). This in average corresponds to the specific groundwater runoff of 8.9 - 10.2 $l.s^{-1}.km^{-2}$. The specific runoff increases with the altitude of hydrogeologic structure. In low situated structures (average altitude 500 m) it is about 8.01 $l.s^{-1}.km^{-2}$, in medium altitudes (625 m) about 12.0 $l.s^{-1}.km^{-2}$ and in high situated hydrogeological structures (960 - 1100 m) 14.0 - 17.0 $l.s^{-1}.km^{-2}$ (Kullman, E. 1990).

In the above mentioned 80 structures 12 996 - 21 236 $l.s^{-1}$ of documented groundwater resources were calculated (see table A-1).

Groundwater chemical composition is mostly of $Ca\text{-}HCO_3$ or $Ca\text{-}Mg\text{-}HCO_3$ type, rarely $Mg\text{-}HCO_3$ (circulation in dolomites). T.D.S. range from 100 to 1000 $mg.l^{-1}$ with the maximum frequency 56% from 300 to 500 $mg.l^{-1}$. Groundwaters associated with lithofacies comprising gypsum and anhydrite (mainly Permian and Lower Triassic, less Carpathian Keüper) have chemical composition close to the $Ca\text{-}SO_4$ type.

In respect to the Slovak standard for drinking water the majority of the carbonatogenic groundwaters in West Carpathian represent high-quality drinking water resources.

Besides Quaternary sediments the Mesozoic sediments with karst and karst-fissure aquifers contain most part of the groundwater reserves utilizable in Slovakia.

A graph of documented groundwater resources in individual geological formations in Slovakia is shown in Figure A-3.

A hydrogeological research and groundwater exploration of the karst aquifers commenced in the late fifties and up to now an evaluation (to a certain degree) of the majority of the karst structures have been completed. The aim of all researchs besides the understanding the function of the karst

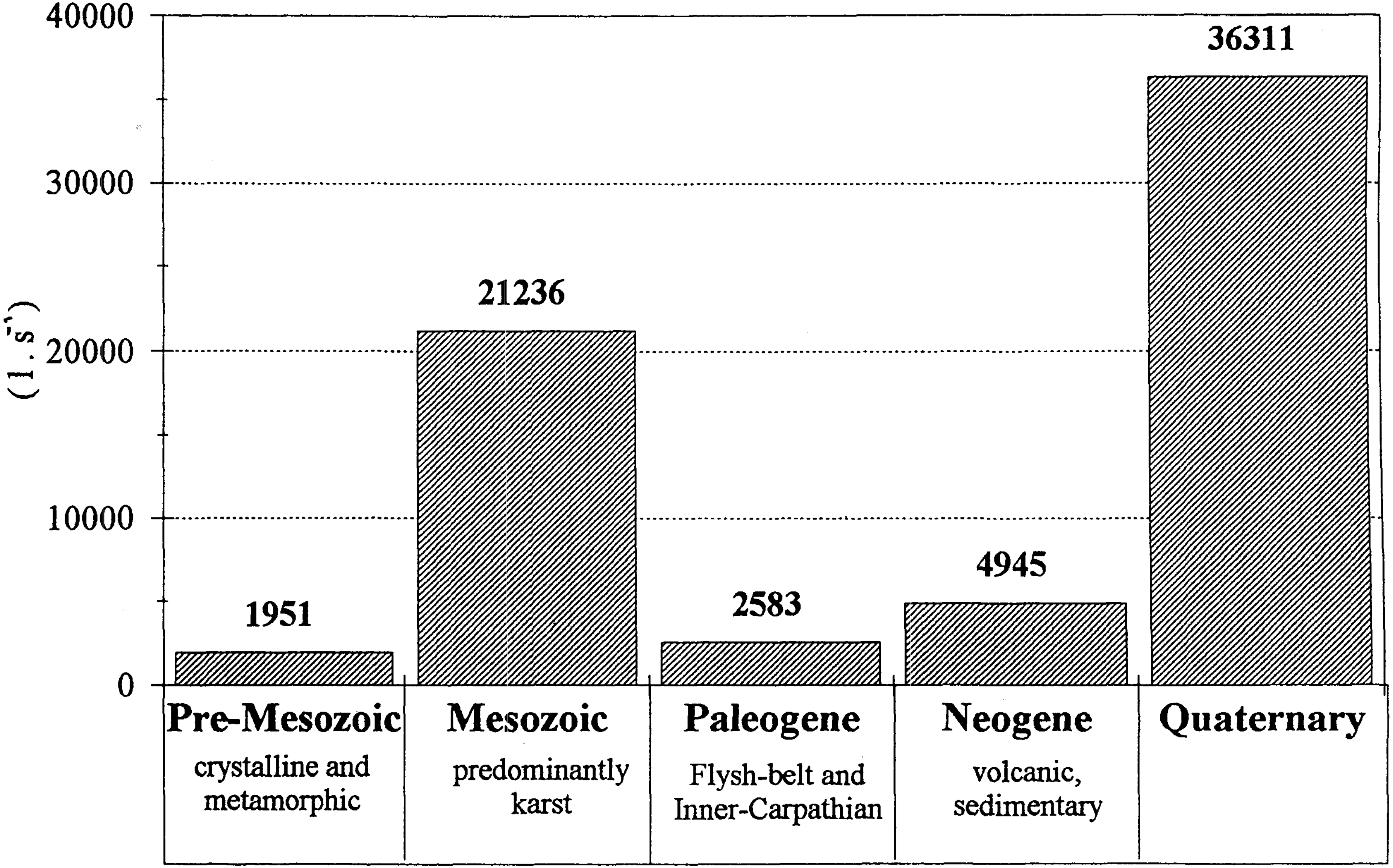


Figure A-3 : Documented groundwater resources in individual geological formations in Slovakia

Table A-1 : *Expected natural groundwater resources and documented groundwater resources in Mesozoic hydrogeologic structures (Hanzel V. et al. 1989)*

Orographic unit	Area (km^2)	Expected natural groundwater resources ($l.s^{-1}$)	Documented groundwater resources ($l.s^{-1}$)
Pezinské Karpaty Mts.	115,	917-1627	651-1361
Brezovské Karpaty Mts.	116,0	950	645-918
Čachtické Karpaty Mts.	53,6	450	337
Inovec Mts.	131,5	814-888	412-504
Tribeč Mts.	110,7	614-654	397
Žiar Mts.	19,2	180-190	108-224
Strážovské vrchy hills	378,0	3580-3780	1643-2146
Malá Fatra Mts.	119,4	1396-1506	484-1590
Veľká Fatra Mts.	361,7	4330-4480	1724-3088
Nízke Tatry Mts. - sev. časť northern part	397,5	2980-3070	1523-4242
Nízke Tatry Mts. - juž. časť southern part	130,6	1175-1313	1073-1115
Zvolenská kotlina basin	50,5	400-500	139-271
Veporské vrchy hills	10,0	80-100	15-30
Chočské vrchy hills	71,4	924	618
Belianske Tatry and north. slopes of Vysoké Tatry Mts.	99,0	3100	551
Branisko Mts.	19,2	187	142
Čierna Hora Mts.	90,0	397	106
Muránska planina plateau	148,1	1826	629-1787
Slovenský raj Mts.	224,6	1767	745
Galmus Mts.	40,7	304-394	188-198
Slovenský kras (groups of hg. structures)	389,0	3420	866
Total	3081,7	27474-31532	12996-21236

aquifers was the determination of **the expected natural groundwater resources** as well as assessment of the documented groundwater resources in the particular hydrologic structure or area.

The expected natural resources represent the total groundwater amount circulating in the structure. They can be determined by hydrological balance, by evaluation of groundwater discharge, derived by analogy or determined by a qualified estimation.

The documented groundwater resources represent the total yield of significant springs, pump tested yield of the wells and measured groundwater affluents to the streams and rivers.

For complete evaluation groundwater quality was monitored and evaluated, protection zones delineated and protection principles stated.

The data for hydrological balances (meteorological and hydrological were used from the long-term or short-term monitoring of the Slovak Hydrometeorological Institute.

Optimal groundwater exploitation and groundwater protection are the most important issues for all researchers in Slovakia.

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Dionýz Štúr Institute of Geology, Bratislava

HYDROGEOLOGICAL INVESTIGATION WITHIN THE FRAMEWORK OF COST 65 ACTION

PILOT AREA 2 - VEĽKÁ FATRA MOUNTAINS

A 606 km^2 area of the Veľká Fatra Mountains, ranges from 410 to 1592 m a.s.l. in the centre of Slovakia. It is - according to the geological point of view - composed from the crystalline core, its Mesozoic envelope overlain by a system of nappes. This is complicated by later folds and overthrusts. Generally, each nappe including envelope is built by an underlying Middle and Upper Triassic karstic carbonate aquifer, Jurassic carbonate semipervious rocks and Upper Jurassic - Lower Cretaceous marls concluded as an isolator (Fig. B-1).

Due to the complicated geological conditions the recharge area of some of the important springs, captured and used as a source of piped drinking water supply for the surrounding region, which can be considered as the outer protection zone, are until now unknown. In fact the groundwater discharge of these springs is much greater than the effective infiltration indicative of the surrounding area of outcropping limestones and dolomites.

The first step in the very beginning of the compilation of the rough hydrologic balance scheme in the Veľká Fatra was to determine hydrogeologic structures and units in Triassic carbonate rocks of the envelope unit and Krížna nappe. The determined structures were drawn at scale 1 : 25 000 or were divided into smaller sections which better reflect groundwater circulation in a given hydrogeologic structure characterized by a united circulation. In these hydrogeologic structures and smaller sections we assessed mainly their relationship to surface streams. Gauging stations to measure total discharge from a unit (structure) were established below the lowest limestone and dolomite outcrops in each unit. If a unit was recharged by surface streams flowing from relatively more elevated areas, these streams were gauged as well. Concealed recharges and discharges were evaluated through the compilation of the balance scheme. About 270 such sites were selected on surface streams. Of course, it was impossible for technical and economic reasons to build a regularly-monitored gauging station in each such place. Flows of surface streams were therefore measured occasionally by hydrometric wing. The

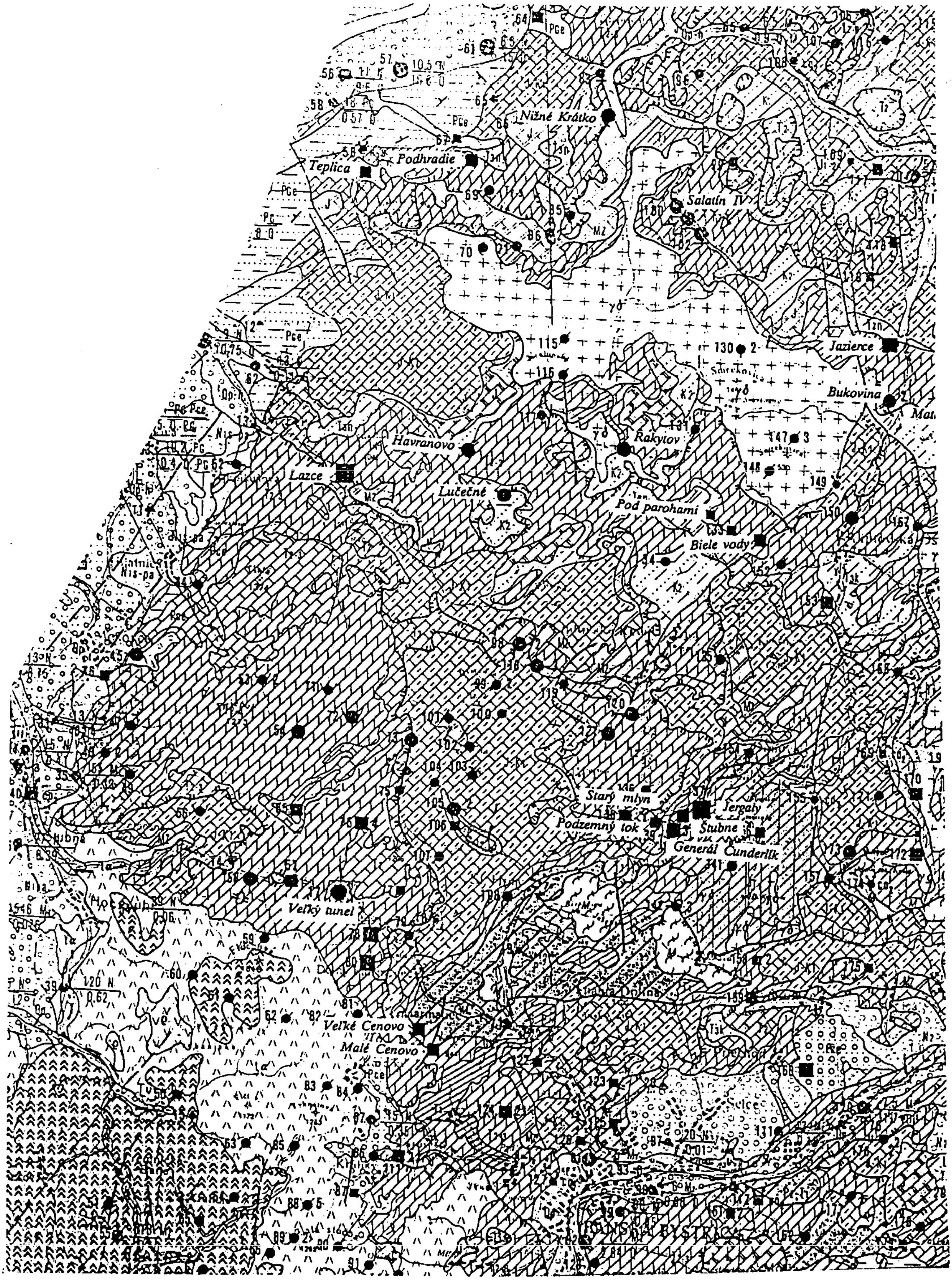

Fig. B-1 : Some important sampled karstic springs in Veľká Fatra Mts., Slovakia

0 1 2 3 4 5 6 km

values obtained in this way, however, cannot be used for calculations in their original state because they were measured in different periods of different weather (rainfall controls discharge by springs as well as from the whole structure). As we did not have 270 permanent gauging stations to calculate average annual discharge, we attempted to apply the method of analogy and inferred the average annual values from one-time observations. For this purpose we used the results of gauging carried out in 1991 and 1992 on 11 springs dewatering Krížna nappe limestones and dolomites in the Veľká Fatra. Likewise, we employed average daily flows determined by gauging on 23 surface streams in this mountain range.

As far as springs are concerned, single average annual discharge turned out to be suitable for the characterization of an annual average, i.e. the resulting adjustment coefficient to determine an average annual groundwater discharge was calculated for each day and for each spring as an average of 11 values of average-annual-discharge/immediate-discharge ratio. The one-time gauging of a surface-stream flow (spring discharge) was then adjusted to its assumed annual value by relative comparison of the discharge (flow) by gauged springs (surface streams) on the day gauging was done to the average annual value.

Flows on individual days relative to 330-day flows on 21 surface streams in the Veľká Fatra were inferred in an analogous way. That is how we got a set of adjustment coefficients. The regime of surface streams, however, is more sensitive to recent rainfall (large areas in some drainage basins are underlain by igneous and metamorphic rocks or poorly permeable marly limestones) than karst-fissure springs and therefore adjusted flows of surface streams are less reliable. For surface streams it is much more difficult or even impossible to calculate the adjustment coefficient from the average annual flow because it overestimated average specific discharge by about 150 % in comparison with adjustment coefficients for springs which realistically reflect possible specific discharge from a given area. That is why the adjustment coefficients for surface streams were based on 330-day flows. An evaluation of such adjustments later indicated that they slightly underestimated actual specific discharge but still their accuracy was acceptable for our comparisons and also as an indicator of minimum discharge values (the application of 300-day flow may have yielded better results).

An average adjustment coefficient to an average annual value was then determined for each day in 1991 and 1992 when the discharge (flow) was gauged. The coefficients were determined separately for springs and surface streams.

The adjusted flows (adjusted to the day of gauging) of individual streams were added together to get a resulting absolute surface discharge from individual hydrogeologic structures and units. As the majority of them are not closed and their groundwaters may flow unseen from *one structure (unit) to another, in further comparative assessments of the units we also employed calculated values of specific discharge according to Kullman's (1980) formulae for representative karst-fissure structures in the Veľký Choč outlier and Harmanec syncline. The former is situated about 15 km northeast of the investigated area and the latter lies directly in the southern Veľká Fatra. This comparison may indicate an approximate discharge (recharge) of groundwaters from (into) the studied structure to (from) its neighbourhood and/or another structure or unit.*

The Veľký Choč limestone and dolomite hydrogeologic structure makes up an extensive outlier of the Choč nappe in the western tract of the Chočské vrchy Mts.

Its impermeable substratum consists of the highest formations of the lower Krížna nappe - marly limestones and marls of Tithonian-Neocomian age. The Veľký Choč outlier itself is composed of Middle Triassic limestones which occupy an area of 19.45 km2. Its average altitude is 1096 m (E.Kullman, 1989). Equation 1 - an empirical relationship between precipitation and effective precipitation based on ten-year monitoring from 1971 to 1980 was published by Kullman (1990) for the Veľký Choč outlier :

$$Q_z = 0.4743248 \quad Z + 11.644437 \qquad (1)$$

where

Z - total annual precipitation (mm)

Q_z *- effective precipitation or effective discharge (mm).*

The Harmanec syncline occupies the southern section of the vast Choč nappe carbonatic complex. The impermeable substratum along with an overlying carbonatic complex were folded to form synclines and anticlines whose axes run NE-SW to ENE-WSW. The hydrogeologic structure consists of Middle and Upper Triassic formations of the Choč nappe. The structure's area is 27.9 km^2 *and average elevation is 963 m above sea level. Equation 2 - an empirical relationship between precipitation and effective precipitation based on ten-year observations from 1971 to 1980 was published by Kullman (1990):*

$$Q_z = 0.65911 \quad Z - 206.29721 \qquad (2)$$

The two equations can ony be used if the average altitude and average precipitation in the investigated territory are known and therefore we had to determine them in detail by planimetric measuring of areas between altitude contours with a 50-m step on 1 : 25 000 maps (determination of average altitude) or by planinetric measuring of areas between isohyets interpolated for total precipitation in individual hydrologic halfyears at scale 1 : 50 000 (determination of average precipitation). We failed to obtain input data for the equations (1) and (2) for the hydrologic year 1993 and so approximate values of effective precipitation and potential specific runoff for that year were calculated through a third, general equation (3) expressing an empiric relationship to the average altitude of a given carbonate hydrogeologic structure.This equation gives a ten-year average of five monitored hydrogeologic structures and is biased by their different locations and different frequency of readings. Although these results are obviously less reliable than those calculated through the equations (1) and (2), they are applicable for approximate calculations in equivalent climatic conditions.

$$q = 0.0141 \quad H + 1.9016 \qquad (3)$$

where

q - specific runoff ($l/s/km^2$)

H - average altitude (m).

By the compilation of the approximate balance scheme, the value of recharge potential was measured with measured actual runoff. Our efforts in the compilation of the balance aimed at finding a potential balance equilibrium between potential recharge calculated from precipitation and actual measured discharge from all investigated structures and units. We made some measurements during a fairly stable climatic period in autumn of 1992 (September - October) when the immediate total and specific discharges were extremely low, which allowed us to compare these discharges with one another using actual autumn 1992 discharges and/or adjusted average discharges by springs regardless of precipitation and recharge potential.

The isotopic composition of oxygen in rainwater depends on several factors including the altitude of the site. The higher the site, the more abundant light oxygen isotope is. For the sake of comparison we give data by D.Rank et al. (1990) on average isotopic composition of rainfall in 1976-1985 which indicate $\delta^{18}O$ content of - 10.45 ‰ in the Vienna-Hohe Warte station (203 m above sea level), - 9.11 ‰ in Graz Universität (366 m) and - 13.59 ‰ in the Obervermunt station (1986 m). Of course, the differences in the above contents in these mutually distant places may result from different times of readings and different geographic-climatic conditions. The values determined by us are essentially identical with the contours of $\delta^{18}O$ global distribution in precipitation published by Y.Yurtsever - J.R.Gat (1981). In addition, a comparison *between rainfall isotopic compositions in Slovakia and Austria reveals that the gradual increase in the average heavy-oxygen content is caused by the substantial increase of its contents in summer rainfall. The pattern of oxygen isotopic composition in precipitation displays a seasonal effect when winter precipitation is systematically much lighter than summer one. The precipitation distribution in Slovakia also seems to be affected by altitude, although variations in* $\delta^{18}O$ *content calculated from annual averages for stations Chopok, Stará Lesná and Mochovce (which together form a sort of a profile) are only 0.03 - 0.06 ‰ per 100-m change in elevation.*

As Veľká Fatra groundwaters are normal, not thermal ones, and are recharged by precipitation, we can assume that their isotopic composition was not affected by water-rock interaction. Oxygen shift towards the heavy isotope when oxygen in the water is replaced by much heavier oxygen from carbonates is typical of thermal waters. Pearson Jr. et al. (1991) give an equation expressing the relationship between the altitude and oxygen isotope composition in groundwaters from nine Swiss regions and note that the change in $\delta^{18}O$ *content with altitude varies from 0.17 to 0.28 ‰ / 100 m. The solution to their parametric equations was based on oxygen-isotopic composition and precipitation data, which allows to check these calculations. The value calculated by us for waters from Veľká Fatra springs (0.1 ‰) is similar to data from northern Switzerland where Pearson Jr. et al. (1991) determined a change in the oxygen isotopic composition around 0.2 ‰ per 100 m. As the duration of the measurements was relatively long and its frequency short, the calculated average isotopic composition of waters from individual sources could fairly reliably indicate the reality.*

Nevertheless, variations in oxygen isotopic composition in investigated springs suggest considerable stability of the otherwise variable values in karst structures probably due to extensive mixing of waters from large water-bearing regions. Moreover, their average composition corresponds to the average altitude of known springs and/or their recharge areas.

Oxygen isotopic compositions in the Veľká Fatra were monitored on 30 springs and one brook which represented all major karst-fissure springs and hydrogeologic structures in each part of the mountain range. The regime monitoring lasted from December 1991 to July 1993, the sampling frequency being roughly two months (a total of 9 samples were collected). Isotopic composition of sulphatic sulphur from these springs was also analysed (in sample collected on March 1 - 5, 1993 along with a sample for the isotopic analysis of oxygen). The average $\delta^{18}O$ *contents from all analyses were then added into the altitude/* $\delta^{18}O$ *relationship. We thus resolved a parametric equation expressing the linear relationship between* $\delta^{18}O$ *and altitude of the recharge area, the correlation coefficient being 0.873 (4):*

$$\delta^{18}O = -0.00097\ H - 9.975 \qquad (4)$$

where

$\delta^{18}O$ - $\delta 18O/\delta^{18}O$ ratio in water (‰)

H - altitude (m).

This technique allowed us to rule out or confirm some potential recharge areas of certain groundwater sources (springs Jazierce, Hradská - Podhradie, Salatín 1 and 4, Malá and Veľké Cenovo, Rakytov) or indicated that some springs were recharged from surface streams (Lazce, Pri starej priehrade, Havranovo).

As most sulphur in groundwaters of the area concerned came from Werfenian and Keuper sediments, we decided to verify this fact by isotopic analyses of dissolved sulphatic sulphur. Kartesian diagrams were employed to indicate how sulphate content in spring water depends on sulphur isotopic composition. We expected a bimodal distribution with projection points clustered around two $\delta^{34}S$ values typical of the Keuper and Rhetian. However, the actual pattern illustrated in Figs. B-2 and B-3 is different. The upper diagram in Fig. B-2 shows particularly clearly that the curve is a mixed one, one member being sulphate-rich waters with heavy-isotope sulphur (springs Matejková - pod pňom, Rakytov - vyvieračka) and the other sulphate-low waters with negative $\delta^{34}S$ values. Sulphates in the first group came from Lower - Middle Triassic marine evaporites, but the source of sulphur in the other member is unclear - the sulphur could have been derived from sulphides (but low contents and total hydrochemical character of water) or it can be of biogenic origin. Sulphates in thermal waters at Turčianske Teplice - springs Nižné Krátko, Pod Parohami and Štubne (Fig. B-3) - are also probably formed by mixing (J. Michalko, 1989, 1990). Sulphur in these springs presumably at least partly comes from Keuper sediments - we assume that the three springs represent another mixing line of Keuper sulphates and sulphate-low waters with negative $\delta^{34}S$ values. All the above-mentioned springs, whose groundwaters circulate in carbonate masses without obvious sulphur occurrences, fall into a single point. Both sulphate contents and isotopic composition of their sulphate sulphur (SO_4 content is approx. 20 mg/l, $\delta^{34}S$ = approx. 5 - 7 ‰) do not exceed background values. The origin of this sulphur is difficult to explain. It could have come from minerals (pyrite) disseminated in rock, but J. Hanáček (1990) and D. Martinský (personal communication) object that such rock types contain very little sulphur. Another possible source of sulphur is precipitation. K. Vrana et al. (1989) note that the average sulphate content in winter precipitation at Donovaly is 4.19 mg/l. The isotopic composition of sulphur in precipitation ranges from values typical of modern marine sulphates to negative values due to human activities (industry). An analysis of snow collected on the roof of the Dionýz Štúr Institute of Geology building (J. Michalko, unpublished datum) yielded results similar to those from the above springs. Further *dissolution of sulphates from the traditional source rocks in the West Carpathian Mesozoic (Permian, Lower Triassic shales, Carpathian Keuper shales) subsequently rises the soluble sulphate content reflecting the isotopic composition typical of the respective source rocks modified by mixing with the "background" isotopic composition which in accordance with the mixing rule also changes δ^{34} values.*

The main objective of the project was to preliminarily identify the most probable circulation areas of the individual water sources rather than to compile a hydrochemical characteristics of the territory concerned and therefore the project's hydrogeochemical section did not discuss the hydrogeochemical conditions of the territory nor the potential rock environment of groundwater circulation of each springs. The principal hydrogeochemical characteristics of the individual rock environments are as follows:

Mesozoic limestone-dolomite circulations:

1) *Mg/Ca ratio - it indicates the percentage of limestones and dolomites in the rock environment (S. Gazda - E. Kullman, 1964; S. Rapant in E. Kullman et al., 1985).*
2) *T.D.S. - in the investigated waters it mostly ranges from 300 to 400 mg/l, increases with time the water spent in the rock environment and also rises in the row limestones - dolomites - marly limestones, marls.*
3) *SO_4 content - in waters unaffected by Lower or Upper Triassic rocks, the content is below or closely around 20 mg/l provided that their chemistry was not changed by secondary contamination.*
4) *Na+K/Mg+Ca ratio - in West Carpathians carbonatogenic groundwaters the ratio is less than 0.01 (S. Rapant in E. Kullman et al., 1985). Higher ratios suggest the effect of crystalline units, neovolcanics, sandstone-quartzite-claystone-shale formations etc. The Na+K/Mg+Ca ratio in groundwaters from Jurassic marly limestones and marls largely varies from 0.01 to 0.03.*

Sulphatogenic, carbonate-sulphatogenic waters

1) *SO_4 contents in groundwaters circulating through the Werfenian are roughly 2 - 3 times higher than in groundwaters from Keuper formations. SO_4-ion contents in the Keuper groundwaters largely attain 100 - 300 mg/l, while Werfenian ones often exceed 1000 mg/l.*
2) *T.D.S. - in Keuper groundwaters mostly amounts to 500 - 700 mg/l, while in Werfenian ones it largely exceeds 1000 mg/l.*

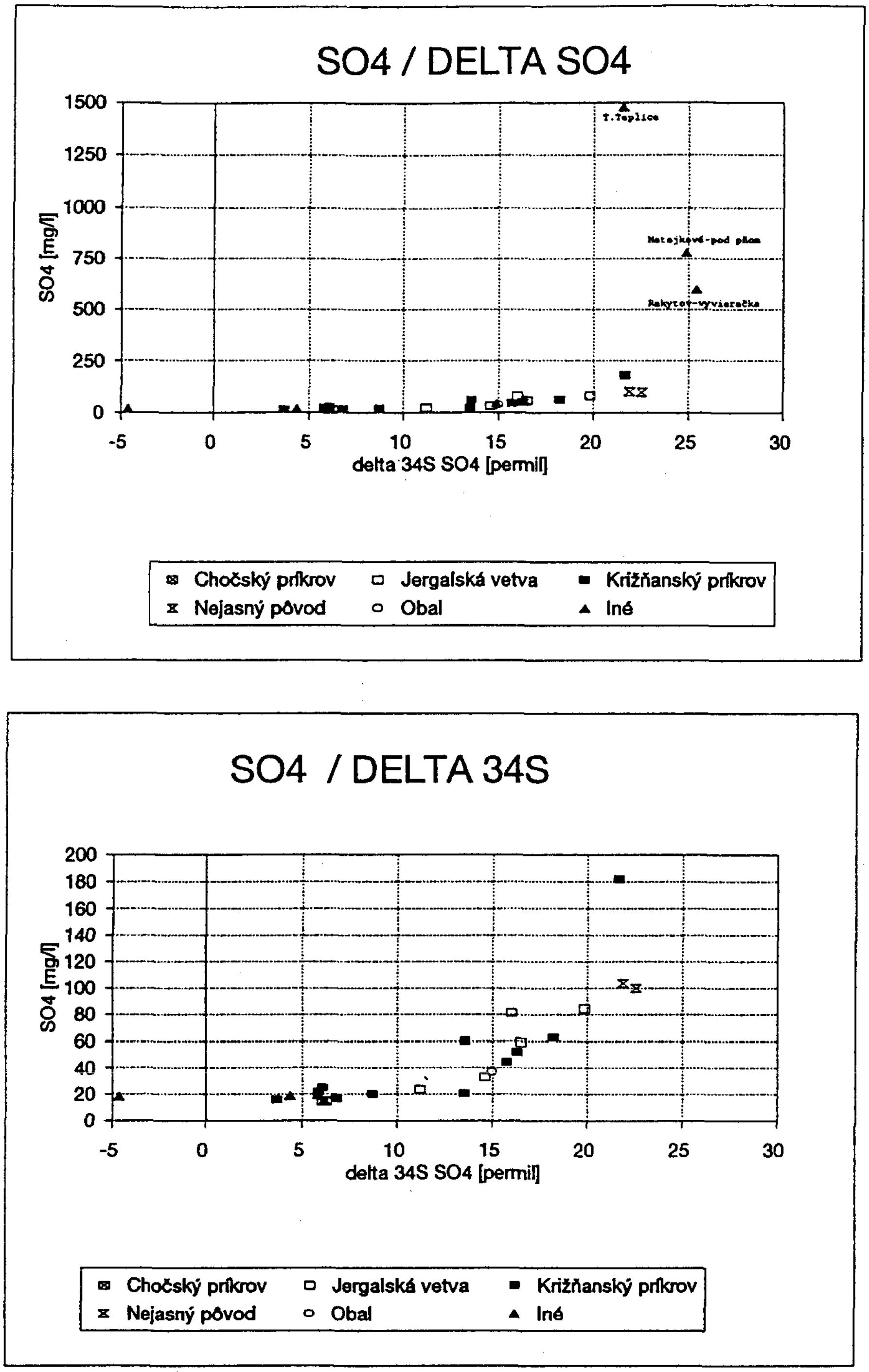

Fig. B-2 : Relationship between the amount of dissolved sulphates in the spring waters and their isotopic composition (general, in 2 scales for SO_4 content).

Explanation of the Slovak expressions :

Chočský príkrov = Choč nappe

Jegalská vetva = the spring in the vicinty of Jergaly (unclear genesis)

Krížňanský príkrov = Krížna nappe

Nejasný pôvod = unclear genesis

Obal = Envelope unit

Iné = others

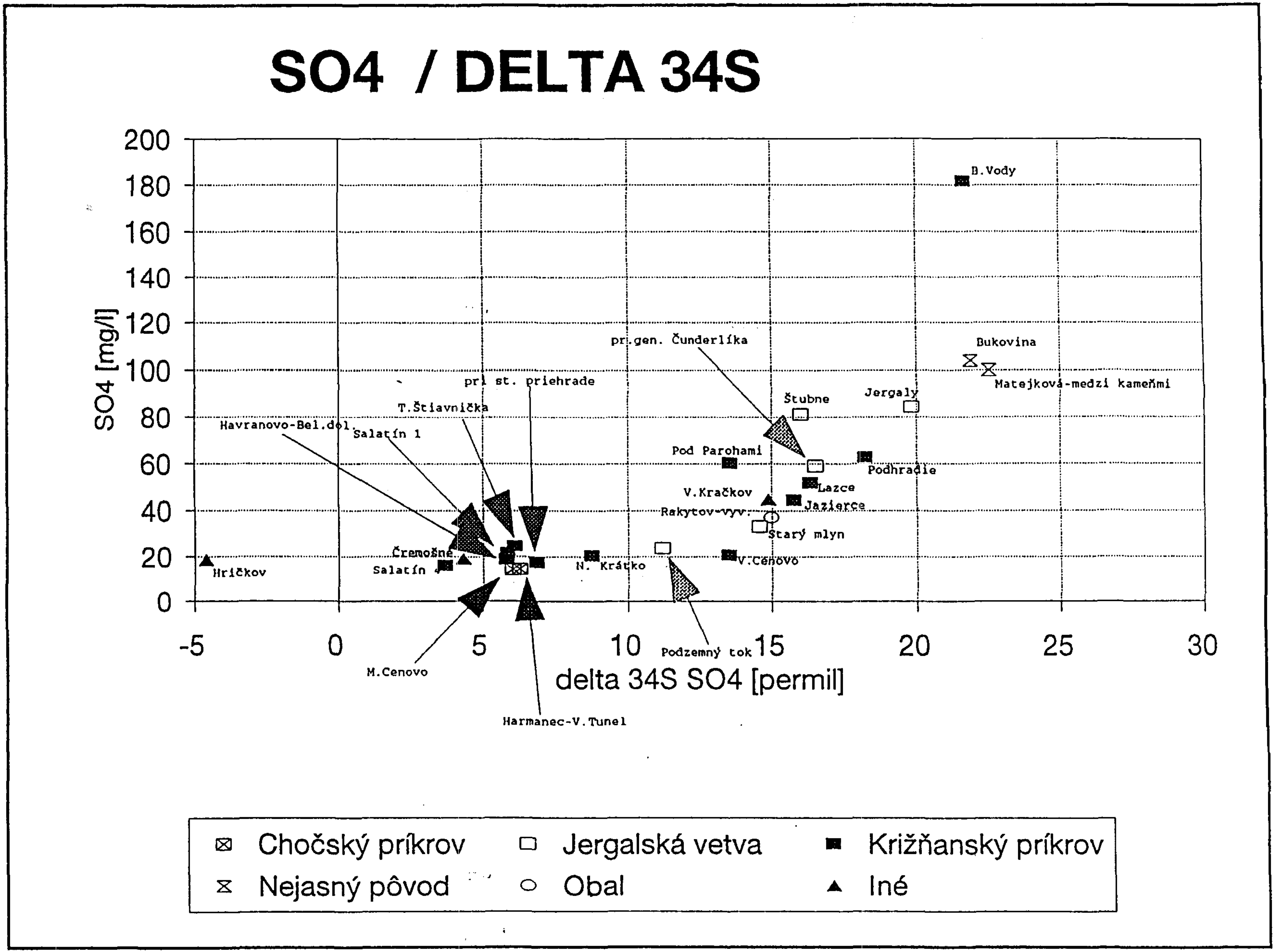

Fig. B-3 : Relationship between the amount of dissolved sulphates in the spring waters and their isotopic composition (detailed, with spring names).

3) *Water type after S. Gazda - groundwaters from the Keuper are usually A2-S2(SO_4) transient, while those from the Werfenian are $S_2(SO_4)$ basic, clear.*

4) *Mg/Ca ratio - is considerably low as a result of gypsum dissolution.*

Silicatogenic waters of the crystalline unit and neovolcanics

1) *Low T.D.S., below 100 mg/l.*

2) *Groundwaters from the neovolcanics are characterized by increased silica contents - frequently as much as 50 mg/l.*

3) *Na+K/Mg+Ca ration above 0.1.*

The genesis of groundwaters in the investigated territory cannot be resolved by individual separate disciplines and techniques of applied research. However, it was cleared up through the combination of all three essential disciplines - hydrogeology, hydrogeochemistry and isotope geology which allowed us to determine the characteristics of respective groundwater sources and their circulation.

The infiltration area of the spring Hradská near the village of Podhradie in the northeastern section of the mountain range was assigned into the envelope unit limestones and dolomites in the vicinity of Mt. Prieložnica. The water source Jazierce at Ružomberok - Biely potok was also assigned into the envelope unit in the area of elevation points Maďarová and Pulčíkovo, although the spring itself is situated amidst Krížna nappe dolomites. Analogous assessment criteria suggest that groundwaters issued forth in the spring Bukovina, another major water source for the town of Ružomberok, could also come from the same area. It seems that these groundwaters probably communicate with surface waters of an important water source for Martin - spring Lazce - not only in the upper section of the Belianska dolina valley as was previously assumed but also in the Necpalská dolina valley from a brook flowing in the immediate vicinity of the spring. This circulation is likely to be affected by pumping groundwaters from a well situated near the water source. The communication with surface waters has been proved in some minor springs as well (Havranovo, Pri starej priehrade, Hričkov). Moreover, Werfenian sulphur was identified in the spring Lazce possibly indicating the presence of Lower Triassic Werfenian shales in the Krížna nappe sequence of strata in this area or the envelope unit in the immediate vicinity of the groundwater circulation route in the Hrosková - Osično structure (P.Malík - J.Michalko - S.Rapant 1993).

The assessment of hydrogeochemical properties of groundwaters discharged by five springs allowed us to identify two possible genetic groundwater types in the source area of the

Jergaly branch of the Pohronie water pipe. Each of the types is associated with a different tectonic unit - springs Starý mlyn and Podzemný tok are probably recharged by groundwaters from a Choč nappe outlier in Veľký Šturec pass between Dolný Jelenec and Vyšné Revúce. The infiltration areas of groundwaters discharged by the three highest sources of the Pohronie waterpipe (Jergaly, Štubne and Generál Čunderlík) are presumably ii surface carbonate exposures of the envelope unit (Bukovec syncline) and Krížna nappe between Motyčky, Hanesy and Donovaly as well as on the southern slopes of Mt. Motyčková hoľa and Mt. Zvolen (gradual seepage from surface streams on an area of 12.59 km^2 *into carbonate substratum) and finally in a 6.8* km^2 *area north of the Váh/Hron water divide extending approximately as far as the southern edge of carbonate inliers in Žarnovka and Veľká Bzdová valleys and roughly lower edge of the higher inlier of the Krížna nappe Triassic carbonates in Hričkov valley. It implies groundwater circulation below the geomorphologic water divide (P.Malík - J.Michalko - S.Rapant 1993).*

With only one exception - an inlier of Triassic limestones and dolomites of the envelope unit in the upper and of Belianska dolina valley where gauging in the driest season of 1992 indicated a loss of 14.28 l/s - in all other inliers we have noted that the volumes of flows increase downstream. Hydraulic passivity, i.e. no communication with the adjacent areas, has been noted in several cases. It has also turned out that this drainage function reflects stream flows and, particularly in the upper sections of valleys, the amount of water recharged from the adjacent areas falls nearly to zero during dry periods.

Major drainage has been noted in the Turecká area. Seepage in the upper tract of the Turecká valley amounted to 50.92 l/s in 1991, 15.92 l/s in 1992 and 65.68 l/s in 1993. Seepages in the lower valley tracts were smaller - only 25.34 and 38.84 l/s respectively in 1992 and 1993. 3-year gauging in the upper section of the Necpalská dolina valley, called Hornoborišovská, revealed concealed seepages 30.39, 21.43 and 30.49 l/s and in Bystrica valley near Harmanec 12.35 and 11.75 l/s. No major seepage was noted in the other inliers.

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RECONSTRUCTION WORKS IN THE HARMANEC SUMMIT TUNNEL

Introduction

The Harmanec tunnel on the railway line from Banská Bystrica to Diviaky was completed in 1938. The tunnel had to be dewatered and since the mid-1960s its waters were diverted to the Pohronie water-supply network. The tunnel thus became a major source of potable water.

As the railway line was to be electrified, the rails in the tunnel were lowered and at the same time measures to improve water quality were taken.

1. Hydrogeologic setting of Harmanec summit tunnel

The area around Harmanec tunnel has been assigned into the so-called Harmanec syncline hydrogeologic structure composed of limestones and dolomites. It occupies 27.9 km^2 and its average altitude is 963 m (E.Kullman, 1990).

The structure consists of Middle to Upper Triassic formations of the Šturec nappe, i.e. dark-gray Guttenstein limestones 10 - 200 m thick (Anissian) overlain by light thick-bedded to massive dolomites (Ladinian) whose maximum thickness attains 500 - 600 m in the axis of the syncline. In the eastern section of the area concerned, above a thrust line there occur brecciated dolomites which were assigned by earlier geologists (D.Andrusov, 1936; Q.Záruba-Pfefferman - D.Andrusov, 1937) to the Krížna nappe (see section of the summit tunnel - Appendix C-2).

The tunnel lies 540 - 690 m above sea level. It runs E-W across a synclinal structure composed of permeable carbonates - limestones and dolomites except in the interval 30.5 - 31.6 km where it intersected marly limestones (Neocomian) which we characterize as an impermeable substratum. According to Záruba and Andrusov (1939), dolomites account for 47 % of the tunnel length, Neocomian marly limestones for 34 % and Guttenstein Limestones for 19 %. The tunnel diverted major amounts of groundwaters, and consequently nearby surface streams and springs went dry. Archive records note that huge water incursions occurred during the driving of the tunnel. The biggest of them took place on Jan. 17, 1938 in km 29.992 when after blasting the tunnel was flooded with 300 - 400 l/s of water. Its colour was brick-red in the beginning and later turned dirty yellow. At the same time, maximum discharge from the tunnel on the Harmanec side was recorded - around 800 l/s. The maximum discharge on the Čremošné side - about 85 l/s - was noted on Oct. 2, 1937. After the tunnel driving was completed in August 1938, the discharge from the tunnel on the Harmanec side fell to 400 l/s and on the Čremošné side to about 40 l/s. The authors assumed that in 1939 the average discharge would be less than 400 l/s. In 1981 - 1991, the average monthly discharges varied from 203 to 453 l/s. At present the tunnel is recharged mostly in the interval composed of dolomites (Appendix 1). Our gauging in the tunnel's dewatering channel was aimed to find out the amount and distribution of inflows into the tunnel.

2. Results of gauging

We carried out gauging in a way that did not disturb the reconstruction works. During the reconstruction, the water source was not used and had to be replaced by other ones. Data provided by the company Banské stavby (Mining Constructions) indicate that the first inflow is roughly in km 30.525.

The results of our measurements unaffected by the reconstruction works are given in Tab. C-1. Appendix C-2 shows all gauging sites.

Table C-1 : *Results of gauging during tunnel reconstruction*

Kilometerage [km]	*Date*	*Discharge [l/s]*
30.067	*29.3.1993*	*40.67*
29.905	*29.3.1993*	*94.55*
29.755	*5.4.1993*	*123.05*
29.628	*5.4.1993*	*153.08*
29.497	*14.4.1993*	*185.39*
29.244	*19.4.1993*	*201.33*
27.782	*17.5.1993*	*264.82*
28.624	*4.5.1993*	2 *36.15*

To better illustrate the inflows between gauging sites, we calculated inflows per 100 m of tunnel length (Tab. C-2).

Table C-2 : *Inflows in the tunnel*

Interval *[km]*			*Length* *[m]*	*Inflow into the interval* *[l/s]*	*Specific inflow* *[l/s/100 m]*
30.525	-	*30.067*	*458*	*40.67*	*8.88*
	-	*29.905*	*162*	*53.88*	*33.26*
	-	*29.755*	*150*	*28.50*	*19.00*
	-	*29.628*	*127*	*30.03*	*23.65*
	-	*29.497*	*131*	*32.31*	*24.66*
	-	*29.244*	*253*	*15.94*	*6.30*
	-	*28.624*	*620*	*34.82*	*5.62*
	-	*27.872*	*752*	*29.67*	*3.95*

The measured maximum inflows well correspond to the maxima recorded during tunnel driving.

3. Qualitative properties

This most significant source of the Harmanec branch of the Pohronie water-supply network is recharged by meteoric water which underwent karst-fissure circulation in carbonates. The water is of clear Ca-Mg-HCO_3 type and its Mg/Ca ratio 0.77 - 0.82 suggests interaction with dolomites. T.D.S. is around 350 mg/l, with Ca-SO_4 content being low. A wide range of Cl^- values and fairly high Na^+ contents (around 6 mg/l) are noteworthy. We do not assume that the chlorides are of fecal origin, the overall pattern of water chemistry here suggests that infiltrated precipitation is a more likely source of Na-Cl. However, the most probable initial source is winter salting of roads and dumps of road salt.

Water quality in the source Tunnel was monitored before and during the reconstruction as well as before supplies to the distribution network were resumed. The samples were collected and analysed (complete physicochemical, biologic andmicrobiologic analyses) by employees of the company Stredoslovenské kanalizácie a vodárne (Central Slovakian Water Management Company - StVaK) headquartered in Banská Bystrica. The laboratories of Geologický prieskum (Geological Survey) at Spišská Nová Ves analysed the contents of Na, K, Se, Ag, Pb, Ni, Cd, V, Be and Ba.

After the works had been completed, another complete chemical analysis was made to check the previous ones. It was analysed by the staff of the Groundwaters Department of the Faculty of Natural Sciences at the Comenius University in cooperation with the Analytic Department and the Institute of Geology at the same faculty and the Medical Engineering Department of the Building Faculty at the Slovak Technical University.

The last samples for physicochemical, biologic and microbiologic analyses before the water source stopped to operate were collected by StVaKn personnel on March 16, 1993. The results of the analyses are given in Tabs. C-3 and C-4.

During the reconstruction, samples were collected and analysed from individual inflows into the tunnel, dewatering channel and one sample also from a spring near the tunnel portal on the Čremošné side. The sampling sites are marked by small letters on a section (Appendix C-2) and the results of the analyses are given in Tab. C-5. A total of 19 samples were collected and analysed (shorter chemical analyses) by the employees of the groundwaters Department and Medical Engineering Department.

The water quality from the source Tunnel before its operation resumed is characterized by analyses of samples collected on May 31, 1993.

Table C-3 : Physicochemical analyses of water

Dátum		16.3.93	10.5.93	17.5.93	24.5.93	31.5.93	31.5.93 (K)
water temperature	°C	-	-	-	-	-	8,0
air temperature	°C	-	-	-	-	-	18,5
colour (PT)	$mg.l^{-1}$	5	5	5	5	5	-
obscurity	ZF	1	1	1	1	5	-
smell	0	0	0	0	0	0	-
conductivity	*$m.S.m^{-1}$*	36,0	38,0	40,0	39,0	31,5	37,0
pH		7,2	7,2	7,2	7,2	7,2	7,2
KNK-4,5	$mmol.l^{-1}$	3,9	3,85	3,85	3,9	3,85	3,83
ZNK-8,3	$mmol.l^{-1}$	0,12	0,12	0,12	0,15	0,12	0,13
free CO_2	$mg.l^{-1}$	5,3	5,3	5,3	6,6	5,3	5,7
CO_2 Heyer aggr.	$mg.l^{-1}$	0,0	0,0	0,0	0,0	0,0	0,0
O_2	$mg.l^{-1}$	11,4	10,3	10,2	10,5	10,8	-
ChSK-Mn	$mg.l^{-1}$	0,8	1,3	1,3	1,3	0,8	0,56;TOC 1,9
Na	$mg.l^{-1}$	5,9	6,0	-	5,8	5,7	4,5
K	$mg.l^{-1}$	0,1	0,5	-	0,4	0,2	0,7
Ca^{2+}	$mg.l^{-1}$	42,1	46,1	46,1	48,1	46,1	49,0
Mg^{2+}	$mg.l^{-1}$	23,0	25,5	25,5	26,7	25,5	25,1
Fe	$mg.l^{-1}$	0,0	0,0	0,03	0,02	0,02	< 0,05
Mn	$mg.l^{-1}$	0,0	0,0	0,0	0,0	0,0	< 0,05
Al	$mg.l^{-1}$	0,0	0,0	0,0	0,0	0,0	-
NH_4^+	$mg.l^{-1}$	0,1	0,05	0,05	0,0	st.	0,13
NO_2^-	$mg.l^{-1}$	0,0	0,0	0,0	0,0	0,0	0,05
NO_3	$mg.l^{-1}$	9,8	8,3	6,3	6,8	8,3	9,48
HPO_4^{2-}	$mg.l^{-1}$	0,04	0,06	0,03	0,03	0,04	0,08
SO_4^{2-}	$mg.l^{-1}$	21,0	22,0	22,0	24,0	18,0	20,0
Cl^-	$mg.l^{-1}$	12,8	11,3	12,1	12,1	13,1	9,8
F^-	$mg.l^{-1}$	0,0	0,0	0,0	0,0	0,0	0,02
evaporation resid.	$mg.l^{-1}$	312,0	312,0	316,0	280,0	300,0	-
SiO_2	$mg.l^{-1}$	5,1	4,0	5,3	4,9	3,3	-
Huminous matter	$mg.l^{-1}$	-	-	-	-	-	2,2
Phenols	$mg.l^{-1}$	0,0	0,0	0,0	0,0	0,0	-
Petroleum der.	$mg.l^{-1}$	-	0,012	0,005	0,005	0,002	< 0,001
Absorbancy		0,012	0,01	0,012	0,012	0,008	-
Mercury	$mg.l^{-1}$	3.10^{-5}	1.10^{-4}	7.10^{-5}	6.10^{-5}	6.10^{-5}	-
Copper	$mg.l^{-1}$	0,009	0,007	0,007	0,01	0,009	-
Zinc	$mg.l^{-1}$	0,06	0,05	0,04	0,05	0,005	-
Chromium	$mg.l^{-1}$	0,0	0,0	0,0	0,0	0,0	-

Note: 31.5.93 (K) = Check analysis

Table C-4 : Microbiologic and biologic analysis of water

Date	*16.3.93*	*10.5.93*	*17.5.93*	*24.5.93*	*31.5.93*
Coliform bacteria in 100 ml	*0*	*7*	*1*	*0*	*45*
Mesophilous bacteria in 1 ml	*0*	*4*	*8*	*2*	*3*
Psychrophilous bacteria in 1 ml	*5*	*58*	*28*	*13*	*7*
Enterococci in 100 ml	*0*	*5*	*0*	*0*	*1*
Fermentation test (neg., pos.)	*neg.*	*poz.*	*poz.*	*neg.*	*poz.*
Pathogenic microorganisms	-	-	-	-	-
Bioseston	*1*	*1*	*2*	*1*	*1*
Saprobity index	-	-	-	-	-
Total number of microorganisms	*10*	*0*	*8*	*0*	*0*
in 1 ml	-	-	-	-	-
Saprobity (Purity class)	*1-2*	*1-2*	*1-2*	*1-2*	*1-2*
Amorphous matter in %					

The results obtained so far confirm that the reconstruction works have not worsen the water quality. Temporary microbiologic changes in the water quality were caused by construction activities in the tunnel.

Table C-5 : Results of short chemical analyses

Sample label	*Date of sampling*	*pH*	*conductivity [µS/cm]*	*CHSK -Mn [mg/l]*	Ca^{2+} *[mg/l]*	Mg^{2+} *[mg/l]*	HCO_3^- *[mg/l]*	Cl^- *[mg/l]*	SO_4^- *[mg/l]*	NO_3^- *[mg/l]*
Čremošné - spring in front of the tunnel	*31.5.1993*	*7.3*	*368*	*0.56*	*49*	*24*	*230*	*10*	*20*	*11.0*
p	*11.5.1993*	*7.4*	*393*	-	*53*	*29*	*247*	*3*	*35*	*6.9*
a	*22.3.1993*	*8.5*	*410*	*1.4*	-	-	-	*4*	-	*8.5*
b	*22.3.1993*	*7.7*	*395*	*0.7*	*47*	*25*	*234*	*6*	*28*	*7.5*
i	*22.3.1993*	*7.7*	*501*	*0.6*	*51*	*27*	*258*	*29*	*16*	*8.0*
c	*11.5.1993*	*7.7*	*363*	-	*49*	*27*	*242*	*3*	*21*	*8.3*
d	*14.4.1993*	*8.3*	*479*	*0.9*	*49*	*27*	*237*	*22*	*21*	*10.7*
e	*14.4.1993*	*8.0*	*399*	*0.8*	*51*	*24*	*231*	*3*	*18*	*9.3*
f	*19.4.1993*	*7.9*	*400*	*0.8*	*50*	*27*	*243*	*11*	*22*	*10.3*
g	*19.4.1993*	*8.2*	*460*	*0.6*	*51*	*27*	*246*	*29*	*17*	*9.7*
h	*26.4.1993*	*8.1*	*360*	*0.6*	*47*	*24*	*231*	*8*	*15*	*7.5*
i	*22.3.1993*	*7.7*	*501*	*0.6*	*51*	*27*	*258*	*29*	*16*	*8.0*
j	*11.5.1993*	*7.3*	*440*	-	*51*	*27*	*253*	*27*	*17*	*7.8*
r - recess III. (km 28.874)	*7.6.1993*	*7.2*	*439*	*0.69*	*50*	*27*	*250*	*25*	*7*	*8.4*
k	*4.5.1993*	*8.1*	*365*	*0.2*	*47*	*25*	*231*	*10*	*16*	*8.3*
l	*11.5.1993*	*7.5*	*369*	*0.4*	*47*	*24*	*230*	*10*	*19*	*8.0*
m	*17.5.1993*	*7.3*	*372*	*0.3*	*48*	*25*	*233*	*11*	*18*	*8.4*
n	*11.5.1993*	*7.9*	*362*	*0.6*	*47*	*15*	*239*	*11*	*18*	*8.0*
Harmanec - channel in front of the tunnel	*31.5.1993*	*7.3*	*368*	*0.56*	*49*	*24*	*230*	*10*	*20*	*11.0*
Harmanec - channe in front of the tunnel	*7.6.1993*	*7.3*	*369*	*0.53*	*47*	*25*	*230*	*11*	*13*	*8.4*

Analysed by Groundwaters Department, Faculty of Natural Sciences, Bratislava.

Note: pH measured in laboratory.

4. Assessment of Reconstruction Works

During the reconstruction of rails, water channel on the Harmanec side of the tunnel was refurbished as well. The rails, gravel bed and original reinforced-concrete slab 15-20 cm thick were removed, and the height of the dewatering channel was lowered so that the new 15 cm-thick concrete slab is on the same level as the concrete base. The space obtained in this way was used to make an insulation layer. The layer should keep polluted water from the dewatering channel and ultimately from the water distribution system. The original project was modified in the interval 30.326 - 31.071 km where the dewatering channel is made of monolithic concrete. Here the original channel was not demolished but a polyethylene tube 200 mm in diameter was placed in it. Smaller pipes 63 mm across entered into this main tube and all this was covered with concrete. The reconstruction started near the highest point of the tunnel 12 m towards Čremošné where the dewatering channel was closed by a 150-mm-thick concrete wall covered by a PENETRON film on the outer side.

Water flowed into the main dewatering channel through minor channels (8 x 8 and 16 x 16 cm). 63 mm polyethylene pipes were placed in the 8 x 8 cm channels, while the 16 x 16 cm channels were covered by slabs. After new cover slabs were put on top of the main and 16 ~~m~~cm channels, and pipes were inserted into the 8 ~~m~~cm channels, the whole concrete base was smoothed by the addition of further concrete. 1565 right-hand and 1559 left-hand channels were built between the portal and the tunnel summit. Of this number, 1004 channels are larger (16 ~~m~~cm) and 2120 smaller.

The smoothed base was covered with a layer of concrete capillary insulation PENETRON. Chemical reaction between PENETRON and concrete will make the latter waterproof but not airtight and therefore the concrete can dry up. Above is 4-mm-thick geotextile TATRATEXT on which in turn rests 1 mm insulation foil EKOPLAST which will repulse petroleum derivatives. All this is topped by another geotextile layer.

The insulation is protected from mechanical damage by a 150 x 150 mm mesh bars of 5.5 mm wire. In the middle of the protective concrete layer is a ceramic channel to divert water seeping through the gravel bed. The channel is topped by a 60-mm-thick cover of reinforced concrete.

The layer of water-construction concrete is in longitudinal direction divided by dilatation joints into 9-m-long sections. The dilatation joints are filled with medium-elastic polyuretan putty RC-270 manufactured by the firm BURKE.

A new gravel bed was placed and new rails will be mounted on the new concrete base.

Despite its smaller depth, the dewatering channel is sufficient to divert all water flowing into the tunnel.

The reconstruction works did not apply only to the tunnel but also to the connection between the dewatering channel in the tunnel and water distribution object.

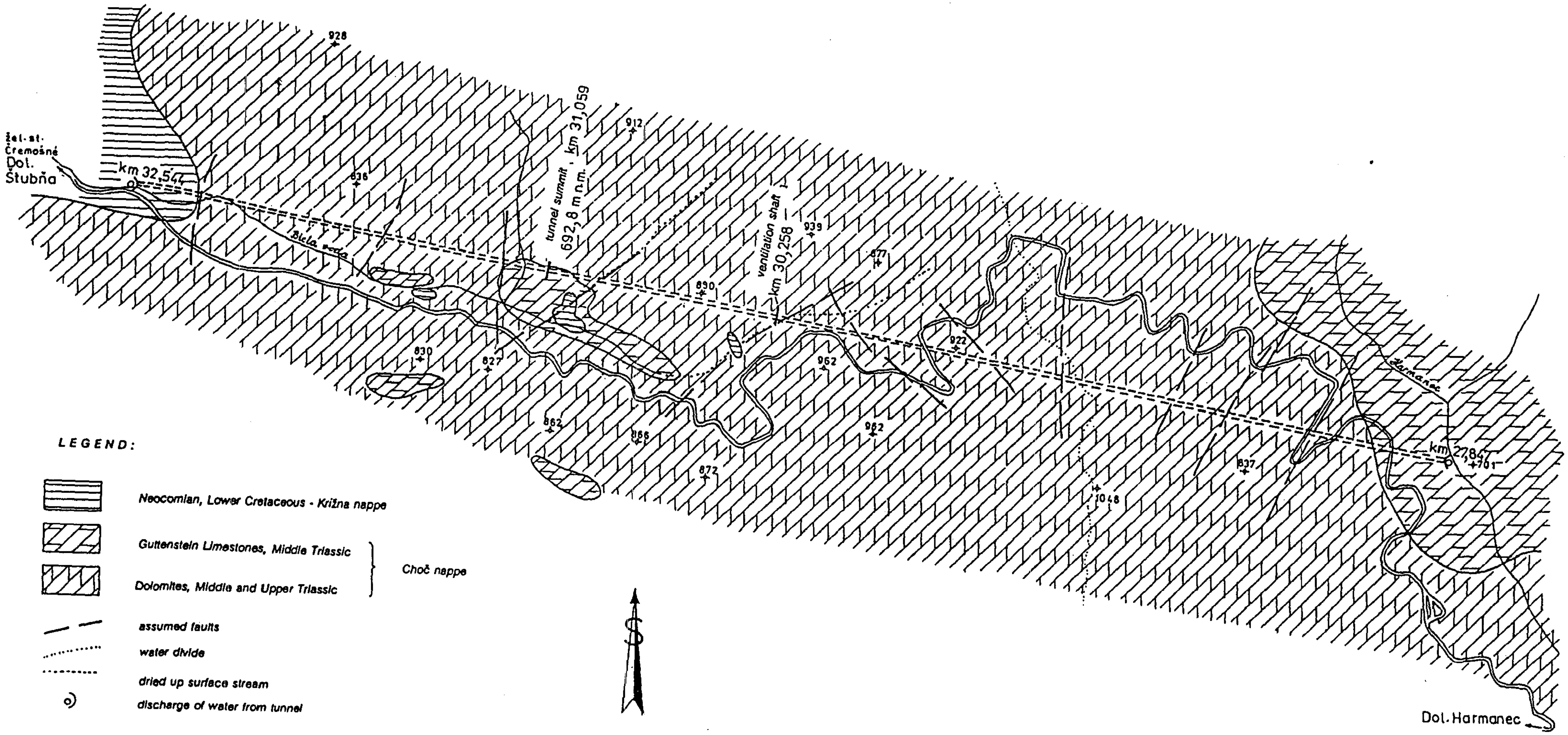
In front of the tunnel portal at the mouth of the dewatering channel, an exit pool was built from which leads a 600-mm tube with a regulation flap in an inspection room and a tube to a bypass channel. When the flap is closed, the water level in the exit pool will rise and water will be diverted into the earlier bypass channel (to make repairs between the inspection room and water distribution object).

The water flows further through an inspection shaft, calm-down channel gauging object to the water distribution object. From here some water will flow on into a distribution system and the rest through a Poncellet dam to a brook.

In the former distribution chamber are 6 vertical PVC tubes 100 mm in diameter in which gauging instruments will be installed. A limnigraph was installed here to record the amount of water discharged from the tunnel.

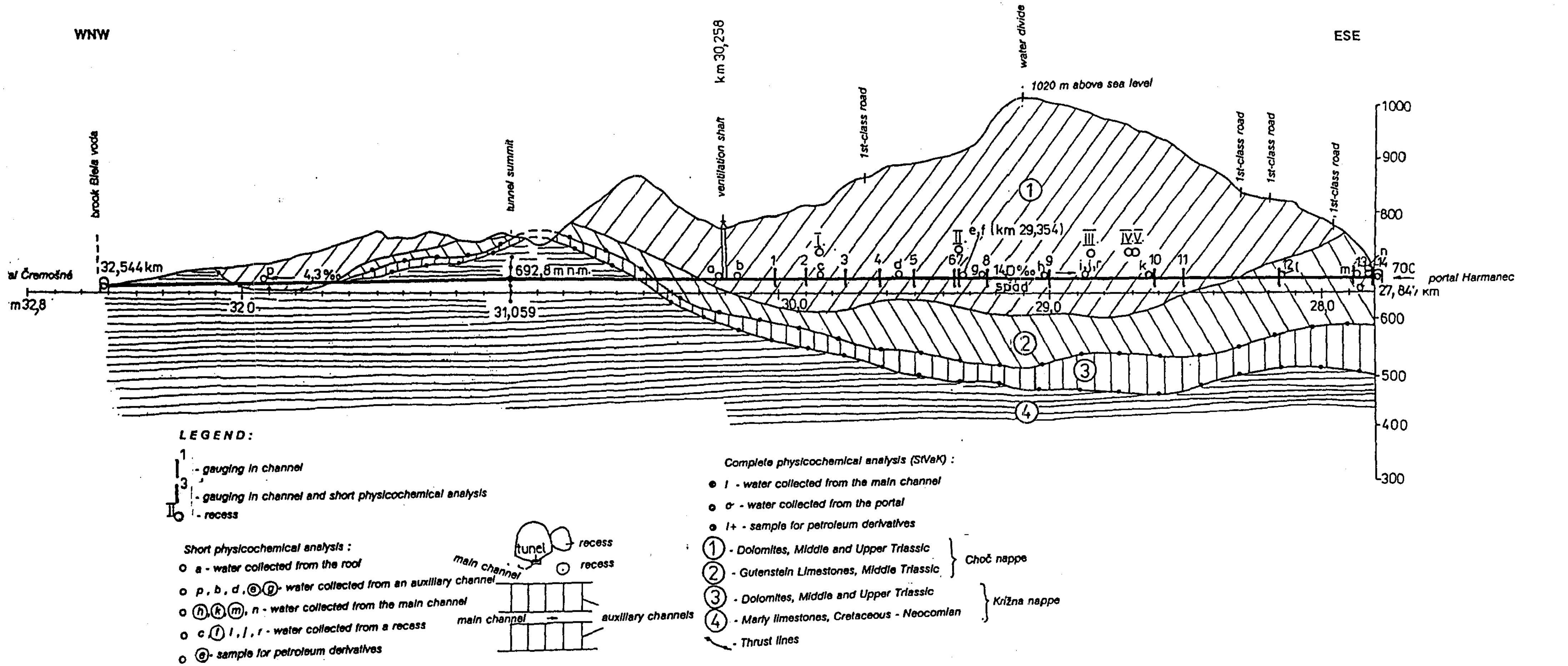
In the bypass channel near the Poncellet dam, the Slovak Hydrometeorologic Institute installed a limnigraph to record the amount of surplus water.

The reconstruction works as well as their technical design should improve the quality of distributed water. Once the proposed measurement and control apparatuses are installed, this water source will be better equipped than any other source in Slovakia.



Appendix C-1 :

Schematized geologic setting of summit tunnel Harmanec-Čremošné



Appendix C-2 : Schematized section of summit tunnel Harmanec-Čremošné

Length scale 1 : 20 000 (1 cm = 200 m)

Height exaggerated 1 : 10 000 (1 cm = 100 m)

Geology from D.Andrusov - Q.Pfefferman-Záruba 1936

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Department of Groundwaters

WATER QUALITY OF PODZEMNÝ TOK AND JERGALY SPRINGS

a) "PODZEMNÝ TOK" spring

The water source Podzemný tok (Underground flow) situated 571 m above sea level is the lowest-lying source in the valley of the Starohorský potok brook. Its groundwaters are of basic clear Ca-Mg-HCO_3 type. From a genetic poiunt of view, the water here is comparable with that from the spring Jergaly but its circulation is shallower as is suggested by its T.D.S. (370 mg/l) and water temperature (7 - 8 °C). Anions are dominated by HCO_3 ions (230 - 260 mg/l) while most abundant cations include Ca^{2+} (55 - 65 mg/l) and Mg^{2+} (20 - 25 mg/l) ions. The content of SO_4^{2-} ions (20 - 30 mg/l) is much lower than in the spring Jergaly. The water quality is affected by a surface stream. The water source Podzemný tok has been monitored since 1981. The water's physical and chemical properties meet potable-water standards except for temperature which is usually lower than permitted - only 5.5 - 8.6 °C. Microbiologic and biologic analyses show that the water is not potable because of the constant presence of coliform bacteria (as many as 94 % of analysed samples) and frequent occurrences of pathogenic microorganisms and enterococci (56 % of samples). The amounts of psychrophilous bacteria never exceed permitted limits and mesophilous ones do so only exceptionally. Specific electric conductivity and HCO_3^- contents (Figs. D-1 and D-2) indicate that the primary composition of the water is fairly stable and seasonal differences are small - e.g. only 10 - 20 mg/l in the case of HCO_3^-. In contrast, secondarily affected components (Cl^-, NO_3^-) display a slightly increasing trend (Figs. D-3, D-4 and D-5) but their contents are still insignificant and cannot threaten the source's water quality.

Organic pollution, however, can pose a major threat as the average ChSK Mn values are fairly high and variable (0.6 - 2.2 mg/l). Its slightly decreasing contents should be viewed cautiously as the set of analysed samples is little representative and the overall evolution in time is obscured by some anomalies.

The microbiologic composition which was very alarming in 1981 - 1982, with an extreme analysis indicating 800 KTJ of coliform bacteria, gradually improved after 1985. But still this source of potable water always contains coliform bacteria. Because of the bacterial contamination and increased contents of organic matter it is necessary to monitor the influence of the nearby surface stream on the source's water quality.

b) spring "JERGALY"

Water source Jergaly situated 708 m above sea level is a typical fissure-karst spring in Mesozoic carbonates. Water of this source is of clear Ca-Mg-HCO_3 type. The Ca-Mg-HCO_3 component came from Jurassic limestones and dolomites of the crystalline unit envelope series but mainly from Triassic limestones and dolomites of the Krížna nappe. The Ca-SO_4 component probably came from Carpathian Keuper gymsum. Water temperature 10 - 11 °C suggests deeper circulation of the groundwaters. Anions in these waters are dominated by HCO_3^- ions (280 - 350 mg/l) and cations by Ca^{2+} (85 - 95 mg/l) and Mg^{2+} (30 - 40 mg/l) ions. SO_4^{2-} ion content (75 - 95 mg/l) is higher than in other springs in the valley including spring Podzemný tok. T.D.S. averaging 510 mg/l is controlled by the character of fairly fast circulation in a fissure-karst environment and a lower CO_2 content on circulation routes. pCO_2 values (2.4×10^{-3} MPa) suggest that the CO_2 is of exogenic origin.

The source's water quality has been continously monitored since 1982. Physical properties and chemical composition of the water here meet standards for potable water, but permanent presence of coliform bacteria (in 50 % of samples), frequent pathogenic microorganisms and enterococci make it unsuitable from a bacteriologic-biologic point of view. Amounts of psychrophilous bacteria do not exceed permitted limits and nor do mesophylous bacteria except for one case.

ChSK Mn is always below permitted limits but is highly variable (0.4 - 2.4 mg/l) - during large spring discharges it is sometimes twice the annual average. Water samples collected in November 1991 had increased contents of petroleum derivatives (0.038 mg/l), huminous matter (1.27 mg/l) as well as some phenols indicating that the source is contaminated. The source of the contamination most probably is a busy road from Banská Bystrica to Donovaly and further on to Ružomberok. The source is seriously threatened by traffic accidents with spills of pollutants.

In the long term, the water chemistry is stable, with regular seasonal oscillations which are most conspicuous in a primary component - HCO_3^- ions. The differences between minimum concentrations (in March and June) and winter maxima (roughly from October to February) attain as much as 40 mg/l HCO_3^- . These cyclical changes similar to analogous changes in surface waters suggest karst circulation in continuous channelways without a major accumulation reservoir. Sulphates, which are both of primary and secondary origin, display no cyclical changes but in the long term their contents increased by 5 -9 mg/l over the ten years they were monitored (Fig. D-10). This fact may attest to the contamination of the catchment area, particularly in heating periods.

HCO_3^-, Cl^- and NO_3^- contents are virtually stable (Figs. D-6, D-8, D-9). In contrast, as mentioned above, ChSK Mn values are much higher during spring snow thawing. In 1982 - 1983 the values decreased considerably while in the following years the water quality was fairly stable with low ChSK Mn values and since 1990 it slightly deteriorates. Over the whole monitored period, the ChSK Mn values slightly fell.

The organic contamination was accompanied by increased bacterial contamination in 1982 - 1983 even with an extremely high number of coliform bacteria. From 1984 onwards these bacteria are still present but only in small amounts.

The water quality here is considerably affecteded by seasonal fluctuations, especially huge summer flows. It is noteworthy that the flow culmination antedates the worsening of qualitative properties, i.e. contamination, by some 7 - 8 days. During the flow culmination the water's electric conductivity and ChSK Mn contents are extremely low, even lower than their average values. However, about seven days after the maximum flow these characteristics begin to increase and electric conductivity becomes stable after about two months. The changes in ChSK Mn contents and bacteriologic indices are of shorter duration.

As regards protection of this water source against contamination, its structure is very vulnerable despite its deep circulation. If the recharging water was secondarily contaminated, all contaminants would probably reach the spring.

Fig. D-1

PODZEMNÝ TOK

trend surface analysis (255.107 + 0.414*X) - HCO_3

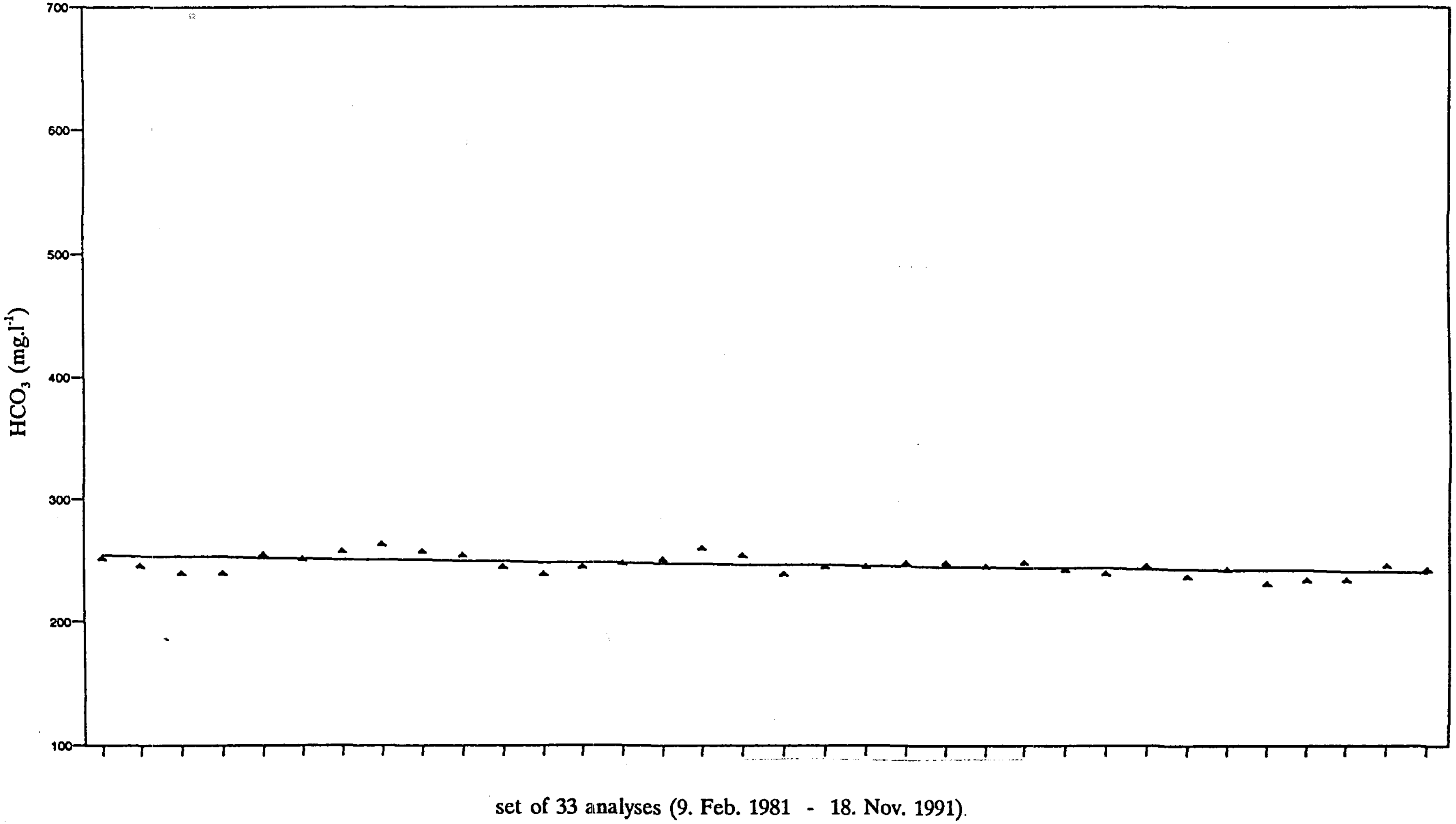


Fig. D-2

PODZEMNÝ TOK

trend surface analysis (412.879 + 0.711*X) - conductivity

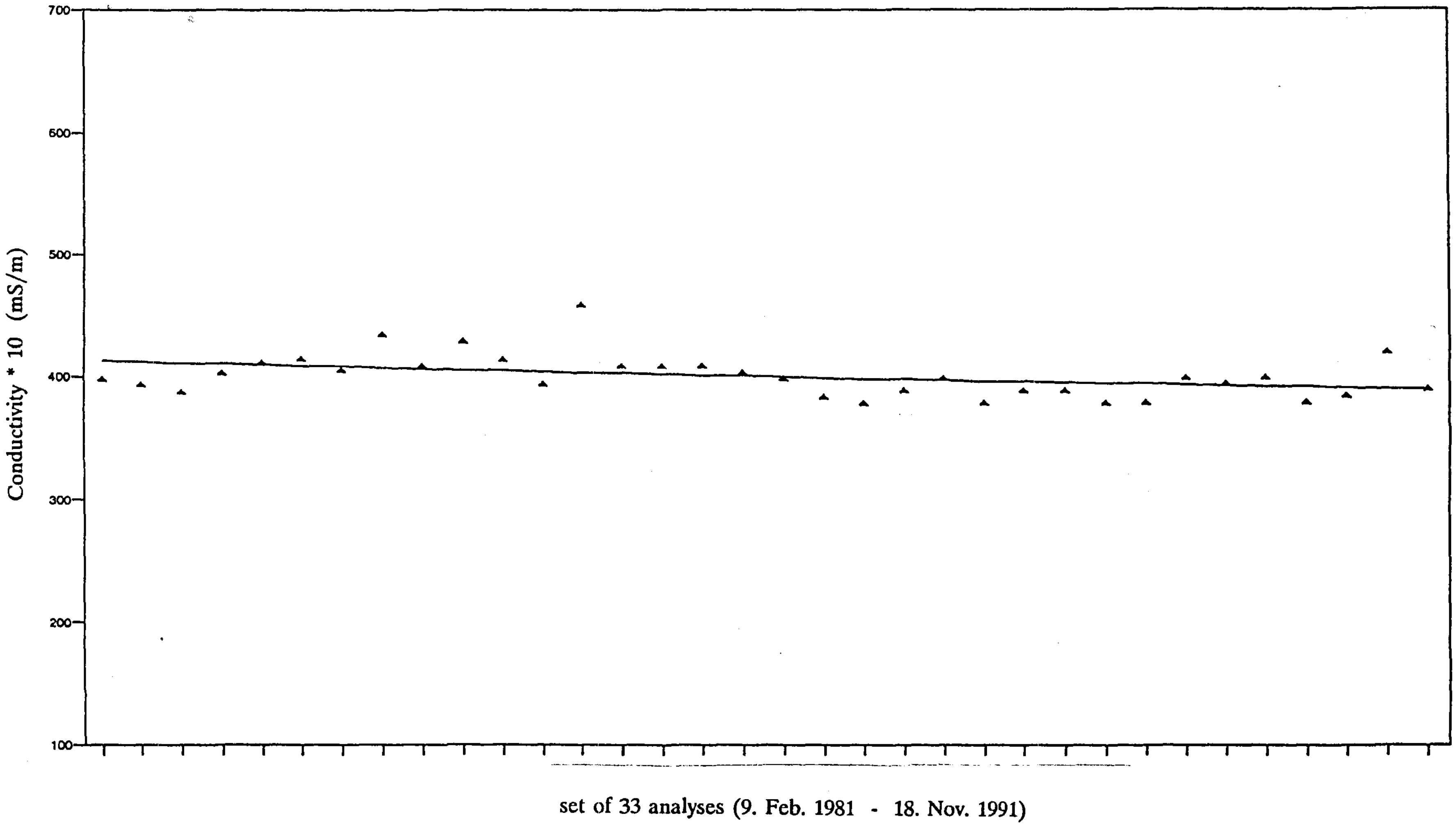


Fig. D-3

PODZEMNÝ TOK

trend surface analysis (2.413 + 0.0545*X) - Cl

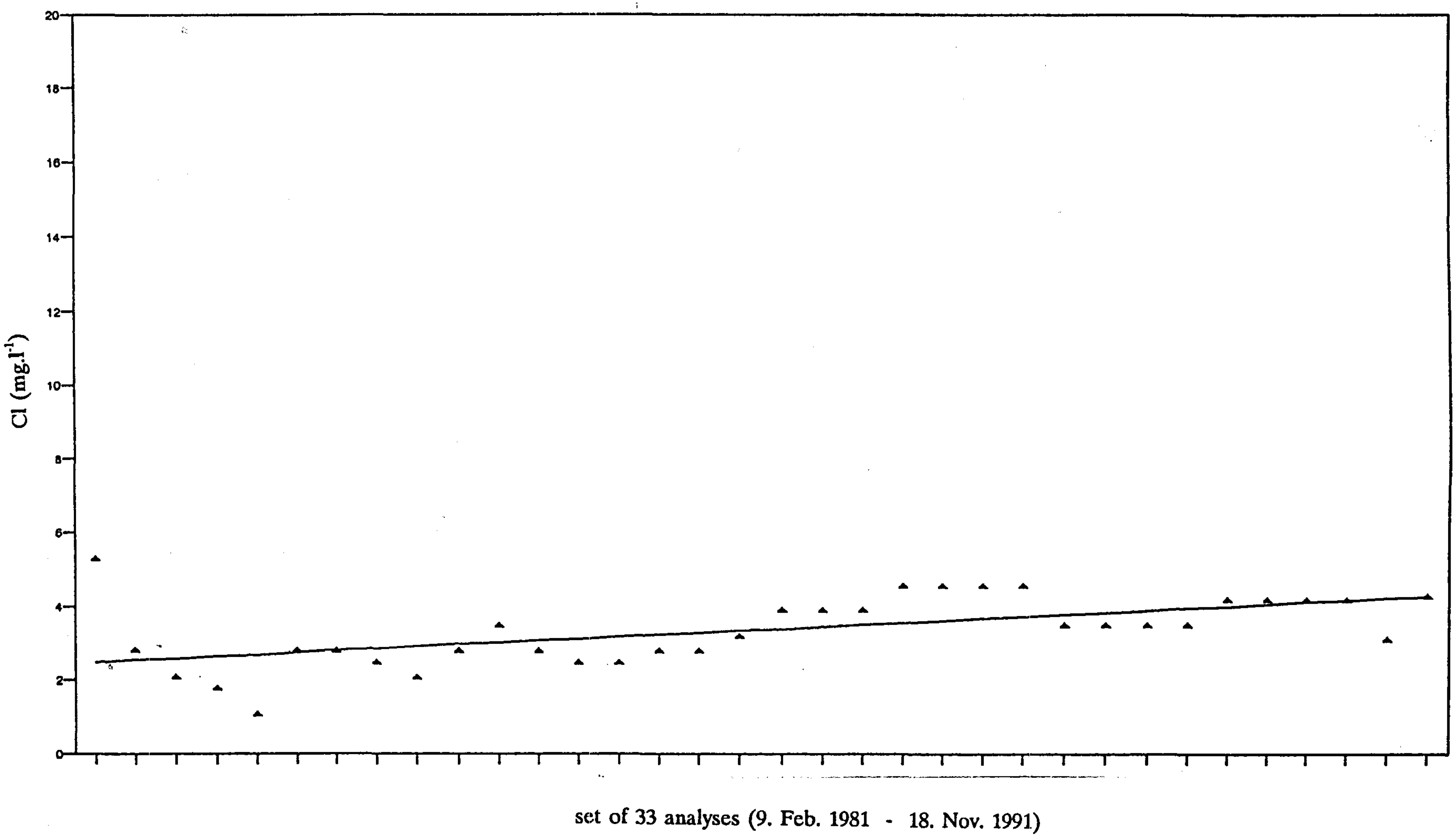


Fig. D-4

PODZEMNÝ TOK

trend surface analysis (4.501 + 0.0619*X) - NO_3

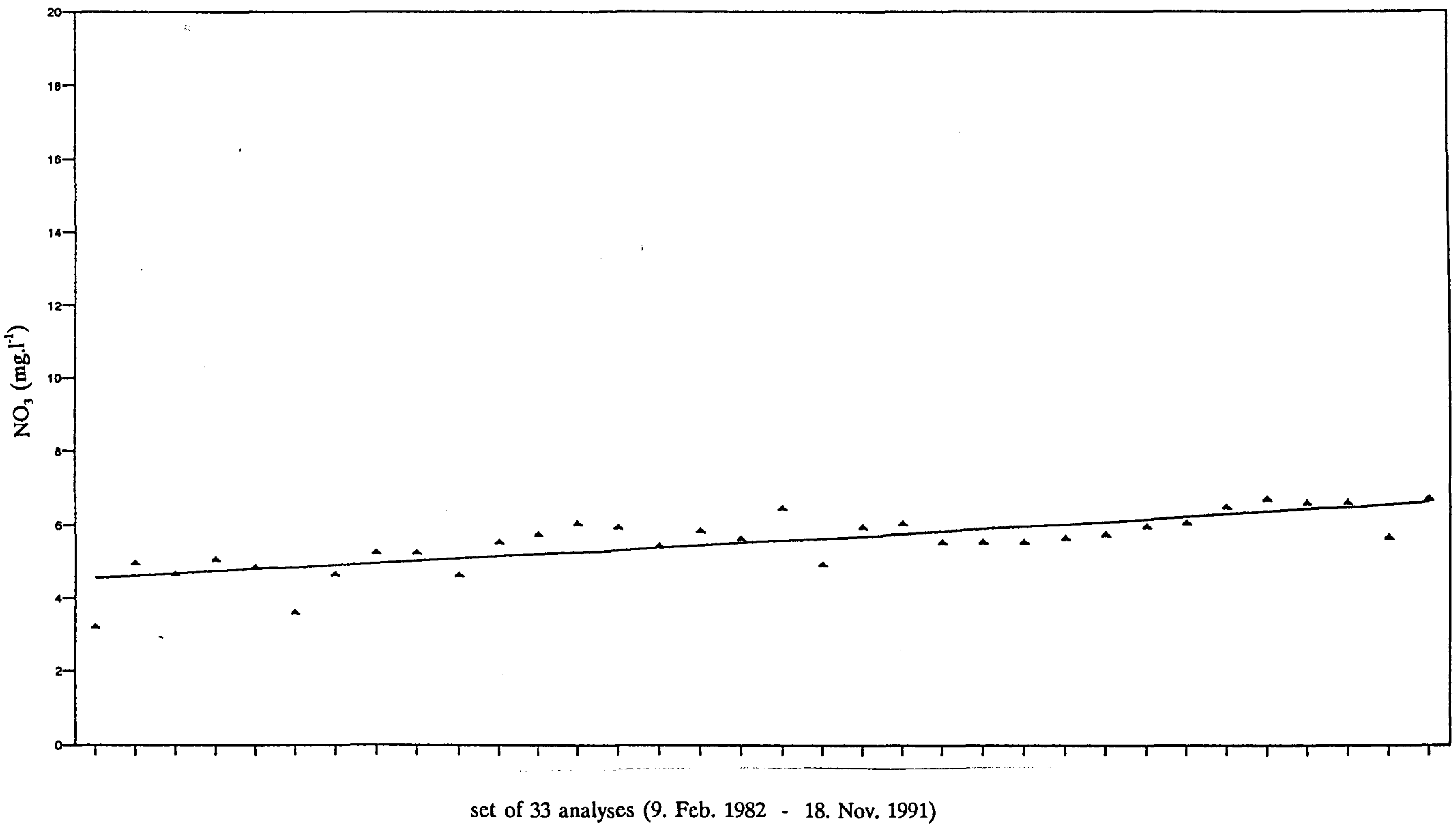


Fig. D-5

PODZEMNÝ TOK

trend surface analysis (25.591 + 0.0116*X) - SO_4

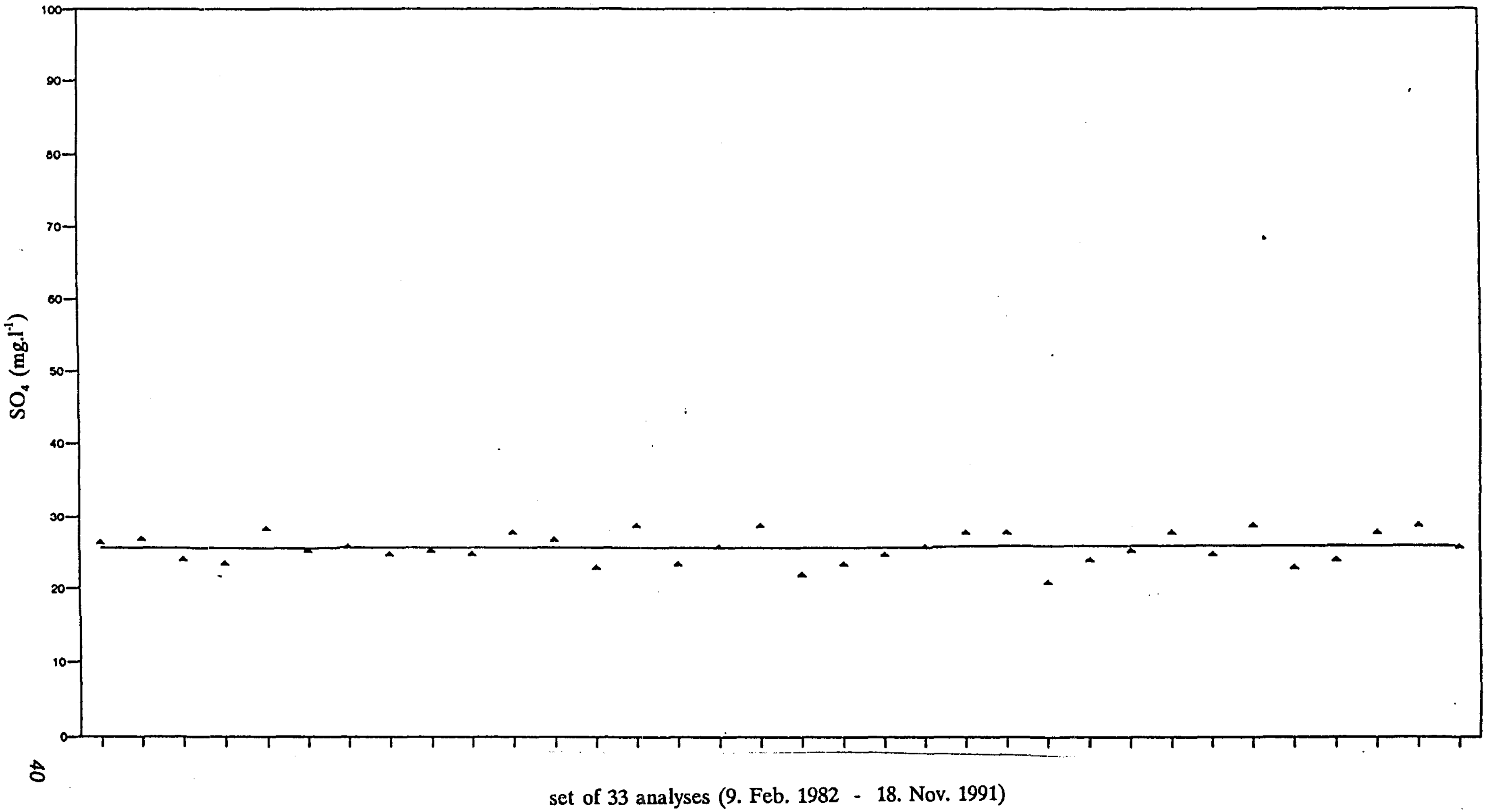


Fig. D-6

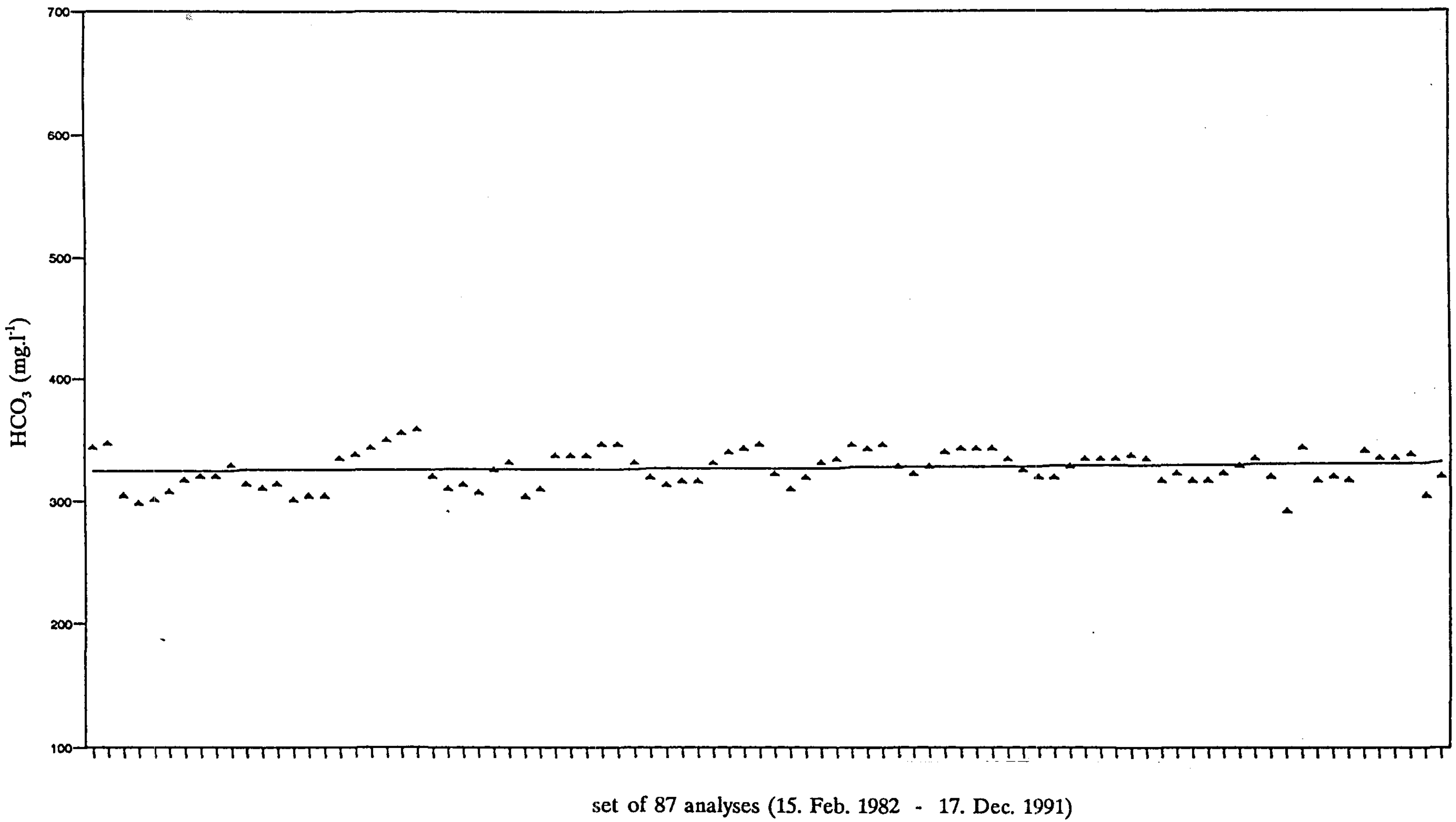

JERGALY
trend surface analysis (324.051 + 0.078*X) - HCO$_3$
700
600
500
400
300
200
100
HCO$_3$ (mg.l^{-1})
set of 87 analyses (15. Feb. 1982 - 17. Dec. 1991)

Fig. D-7

JERGALY

trend surface analysis (599.54 + 0.0457*X) - conductivity

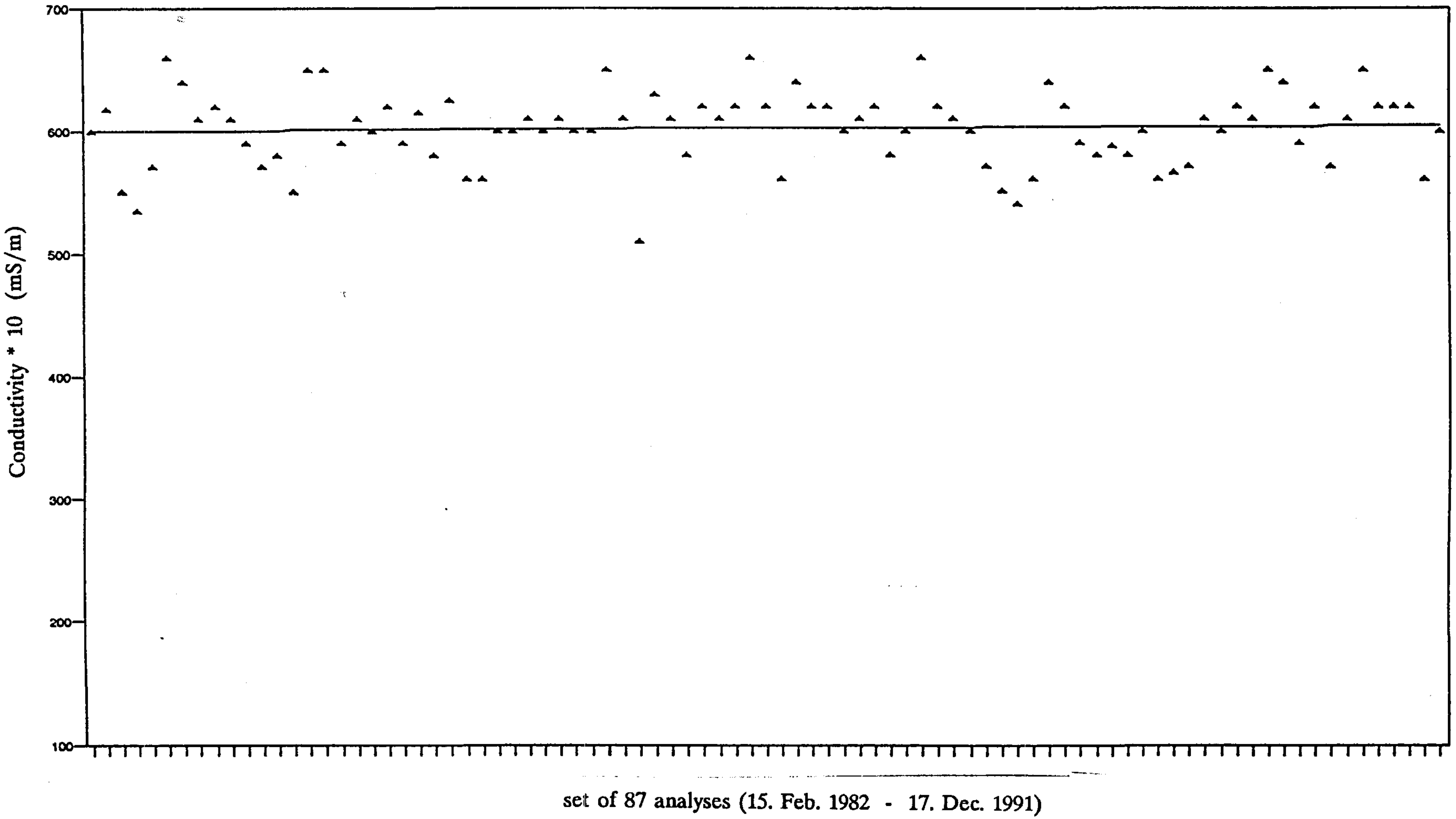


Fig. D-8

JERGALY

trend surface analysis (3.476 + 0.00022*X) - Cl

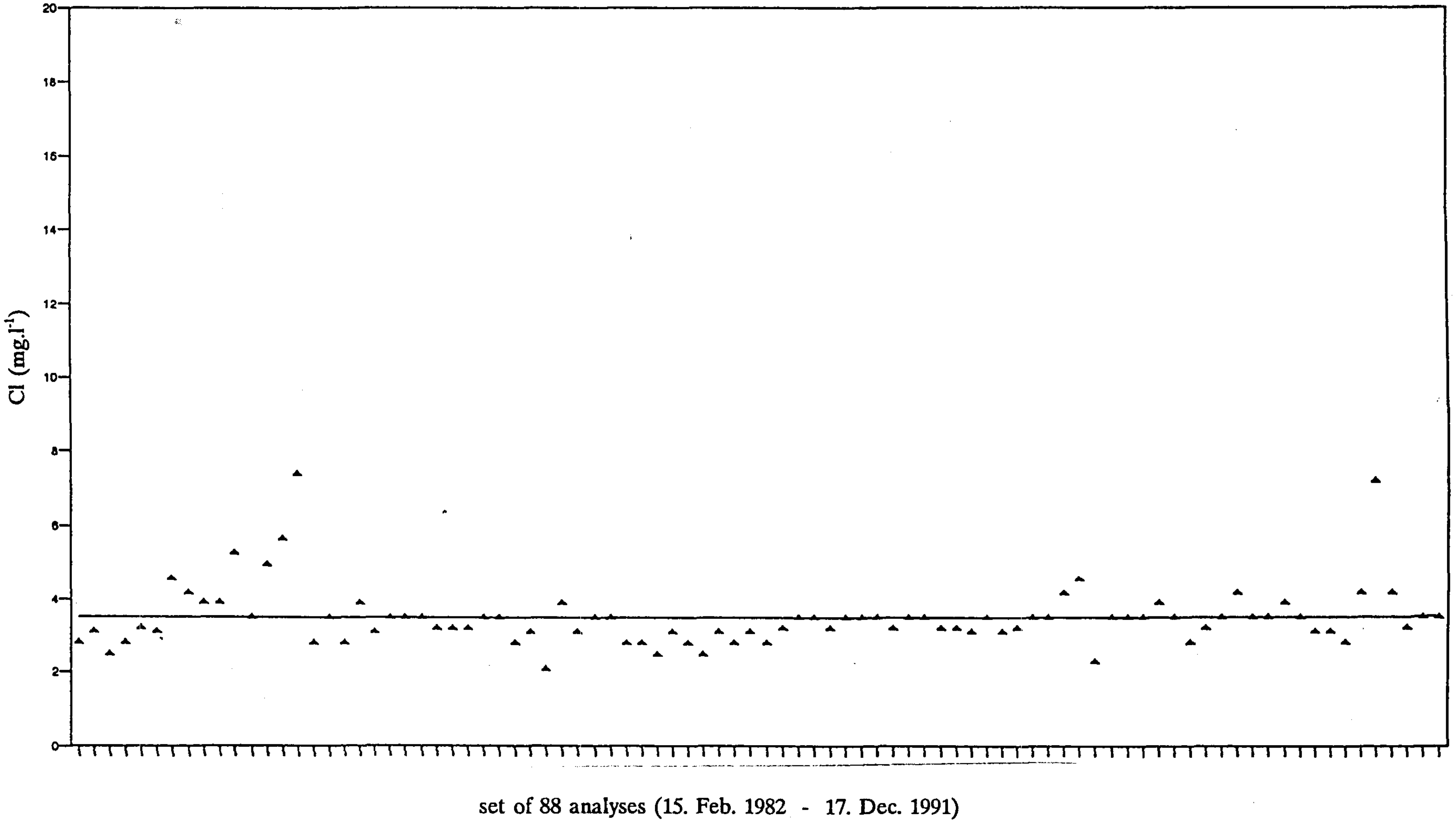


Fig. D-9

JERGALY

trend surface analysis (3.894 + 0.0011*X) - NO_3

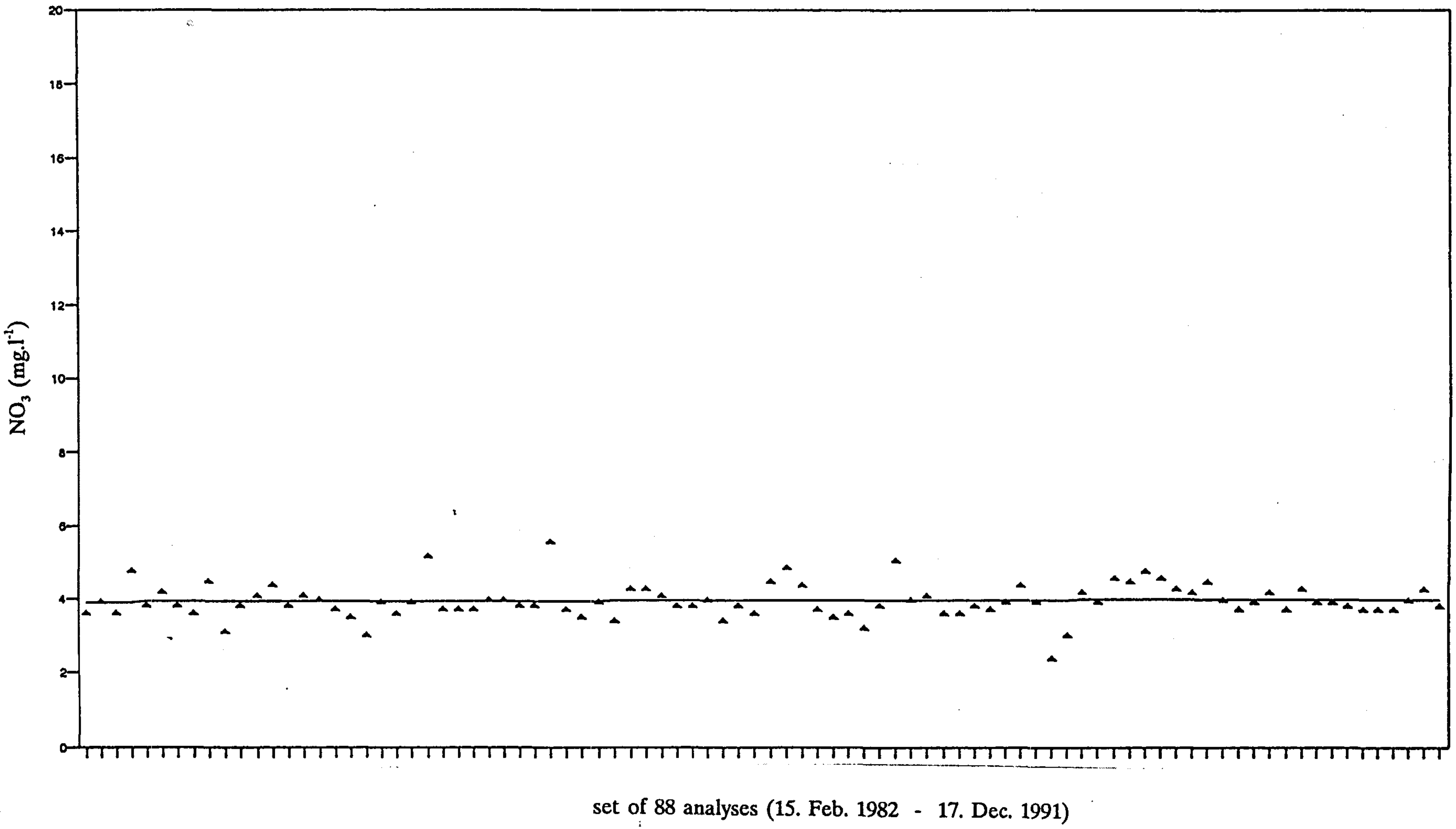
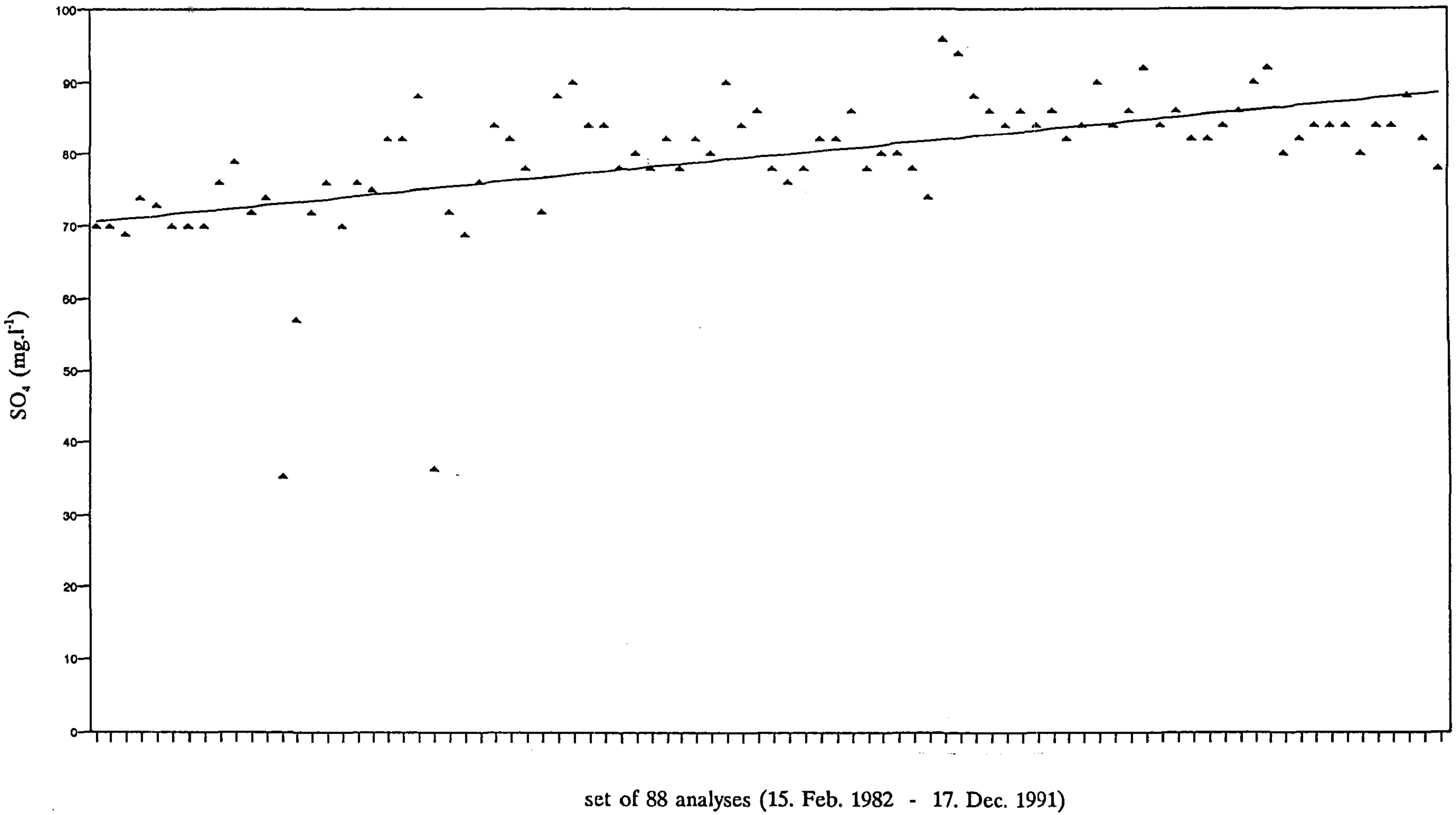


Fig. D-10

JERGALY

trend surface analysis (70.474 + 0.2047*X) - SO_4



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Catchment Area of Major Groundwater Sources in the Donovaly Area

Five springs of the Jergaly branch of the Pohronie water-supply system in the Donovaly - Dolný Jelenec area make up a major groundwater source, its average total discharge being about 502 l/s. Hydrogeochemical properties of their groundwaters allowed us to determine two source areas of these springs: 1. carbonatic rocks of the Choč nappe - springs Podzemný tok and Starý mlyn and 2. Krížna nappe and/or the envelope unit - springs Generál Čunderlík, Štubňa and Jergaly. The catchment area of the former presumably is a dolomite and limestone outlier in the vicinity of the Veľký Šturec pass. The springs are situated in the lowest section of the outlier which is large enough (15.326 km^2, average altitude 915.4 m) to provide sufficient recharge potential for such springs as Starý mlyn with an average discharge 33.7 l/s and Podzemný tok which yields 86.6 l/s.

The other springs (Jergaly - avergage discharge 278.5 l/s, Štubne 39.2 l/s and Generál Čunderlík 64.4 l/s), however, have only one obvious catchment area in their vicinity - Krížna nappe limestones and dolomites exposed on an area 2.726 km^2 between Donovaly, Hanesy and Štubne, their average altitude being 889.9 km^2. Likewise, this unit is discharged only by the above-mentioned springs. Nevertheless, gauging indicated that carbonate rocks of this unit are recharged from the immediate vicinity - brooks on the southern slopes of Mt. Motyčková hoľa and Mt. Zvolen gradually disappear in their alluvia and seep into the carbonate substratum higher upstream than is suggested by the geological map. Some of the brooks dry up completely during dry periods - this applies to all righthand tributaries south of Donovaly as far as the Mackova dolina valley. The most persistant is the brook in Mackova dolina, probably as a result of a geologic complication in the substratum, but still in the driest periods it gradually disappears in the area of Starohorský potok brook. The recharge potential of the Donovaly-Hanesy-Štubne hydrogeologic structure composed of Krížna nappe Triassic carbonates derived from its area and 1992 precipitation is 45.78 l/s (16.79 l/s/km^2). The recharge potential calculated according to empirical equations (1) and (2) based on ten-year-long monitoring (Kullman, 1990) for representative closed karst-fissure structures in the Veľký Choč outlier and Harmanec syncline situated close to the investigated area is as follows:

$$\mathbf{Q_z} = 0.4743248\ \mathbf{Z} + 11.644437 \qquad (1)$$

for Veľký Choč outlier and

$$Q_z = 0.65911\,Z - 206.29721 \qquad (2)$$

for Harmanec syncline, where

Z *- total annual precipitation (mm)*

Q_z *- effective precipitation or specific discharge (mm).*

South of the Donovaly-Hanesy-Štubne structure lies another carbonate body - Bukovec syncline in the Donovaly envelope series. Geologic situation suggests that these two hydrogeologic structures are not hydraulically connected with one another (M.Rakús in E.Kullman, 1971) but hydrogeochemical, balance and isotopic evidence indicates the opposite. The Bukovec syncline covers an area of 10.248 km^2, its average altitude is 936.5 m and its recharge as well as discharge capacity based on the area of carbonates exposed on the surface is as much as 184.41 l/s (assumed i.e. potential specific discharge is 17.99 l/s/km^2). In addition, the structure receives an average of 27.76 l/s (inferred from average spring discharges in 1992) from a sinkhole in the valley "pod Bulami" (south of settlement Buly) about 300 m above the settlement Môce. Given the combined recharge potential of both hydrogeologic units, their total average annual recharge is 230.19 l/s. The connection between the Môce sinkhole and springs of the Pohronie water-distribution system has not yet been confirmed. Discharge from the syncline through the valleys Jelenská and Bukovecká is roughly 32.68 l/s. If we subtract this discharge and ignore recharge from Môce sinkhole, the remaining total recharge potential of the Donovaly-Hanesy-Štubne structure and Bukovec syncline amounts to 197.51 l/s compared with the actual discharge of 382.1 l/s. The discharge thus exceeds recharge by 184.59 l/s whose recharge area must lie somewhere outside these structures.

In the very beginning of our speculations we have to realize that springs Jergaly (712 m above sea level), Štubne (690 m) and Generál Čunderlík (650 m) are situated close to the erosion level of the very deep valley of Starohorský potok whose bottom lies much lower than those of all nearby valleys. Thanks to their geomorphologic position, the springs may be recharged from a fairly wide area. Sulphur isotopic composition from springs Jergaly and Generál Čunderlík suggests that their waters percolated through Werfenian members, most probably in envelope sequences. The isotopic composition of oxygen in these springs is stable, the average $\delta\ ^{18}O$ content in the Jergaly spring being -11.05 ‰. A clear minimum was noted in September (see Fig. E-3). If the minimum was caused by light waters from thawing snow in spring, the duration of groundwater circulation would be about 5 months. This is not sure, however, and so the age

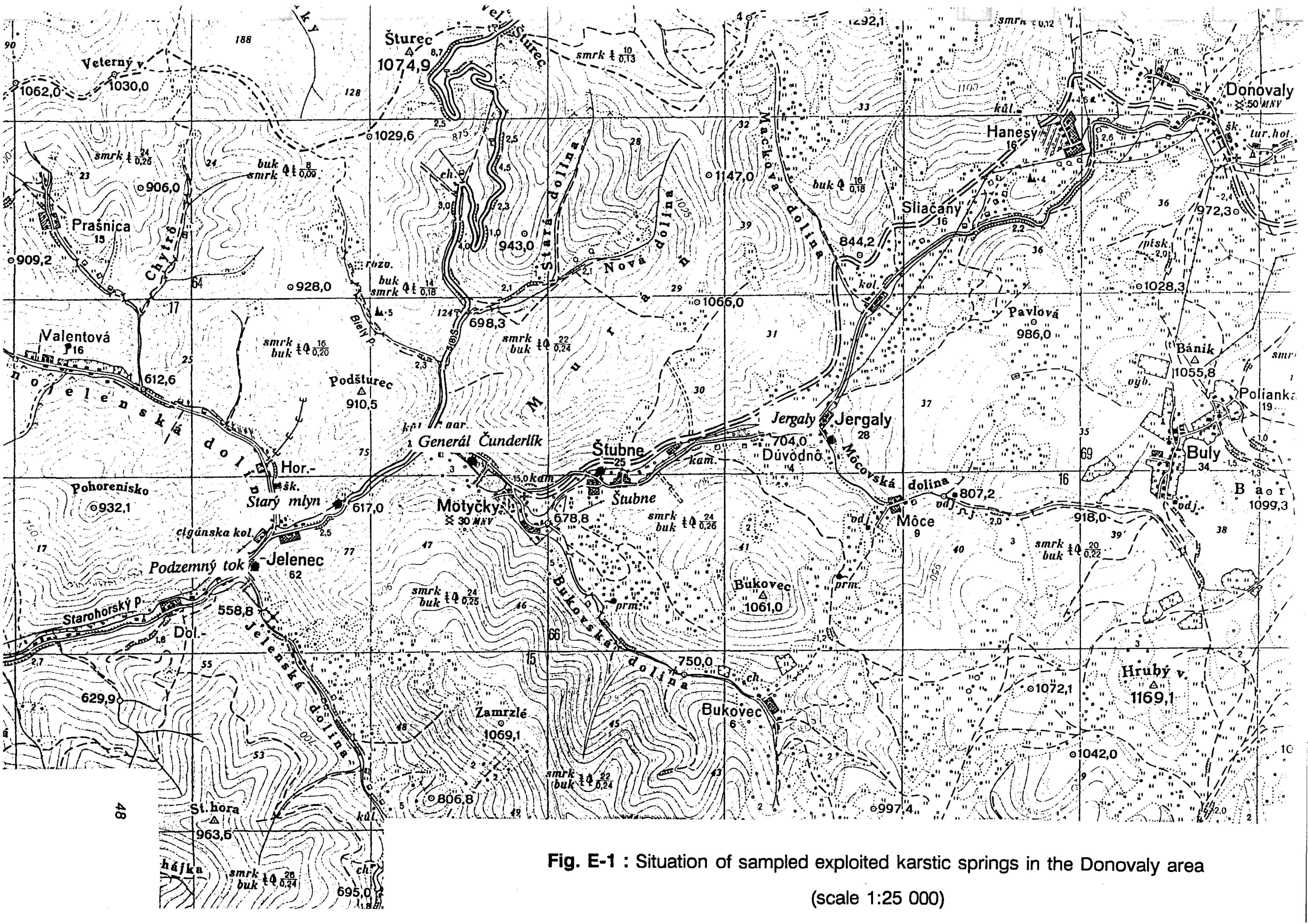


Fig. E-1 : Situation of sampled exploited karstic springs in the Donovaly area

(scale 1:25 000)

of the waters cannot be determined accurately. Sulphate sulphur from these groundwaters displays values typical of Lower Triassic marine sulphates (Werfenian shales) mixed with 20 mg/l of background mineralization with approx. 6 ‰ content of $\delta^{34}S$ (Fig. E-2). Total $\delta^{34}S$ content in spring Jergaly is 19.84 ‰. In contrast, the composition of sulphur from spring Štubne lies on the mixing curve of Keuper sulphates ($\delta^{34}S$ is 16.02 ‰, but SO_4-ion content is approximately 80 mg/l) - probably as a result of Keuper layers exposed on the foothills of Mt. Bukovec 1061.0 m high. In this case the spring would be recharged mostly from the north. Its oxygen isotopic compositions, temperatures, conductivities and discharges over time are very similar to those of the preceding spring (Fig. E-4). The minimum is not so conspicuous and, like in the previous spring, is accompanied by a coeval conductivity maximum. The average oxygen isotopic composition, $\delta^{18}O = -11.00$ ‰, is lighter than in spring Jergaly but heavier than in spring Generál Čunderlík.

Spring Generál Čunderlík has an analogous isotopic composition, changes over time in all its monitored properties ($\delta^{18}O$, specific electric conductivity, water temperature, discharge) are very similar to the two foregoing springs - Jergaly and Štubne, the average $\delta^{18}O$ content 10.83 ‰ (Fig. E-5) characterizing the altitude of precipitation is somewhat lower. Sulphur isotopic composition $\delta^{34}S = 16.52$ ‰ lies on the same mixing curve as in the case of Jergaly (Fig. E-2). Isotopic analyses of sulphate sulphur from springs Starý mlyn and Podzemný tok suggest that their waters must have dissolved a little bit of Werfenian gypsum as is indicated by their position on the mixing curve compiled by us. Spring Starý mlyn has nearly all its characteristics (changes in $\delta^{18}O$, discharge, temperature and specific electric conductivity; Fig.E-6) similar to the above-described springs, but its average $\delta^{18}O$ content -10.70 ‰ is lower than in any other spring of the Jergaly branch and its sulphate sulphur content is almost the lightest from all ($\delta^{34}S = 14.58$ ‰; Fig. E-2). Spring Podzemný tok, the last in the Jergaly branch, has the average $\delta^{18}O$ content (-10.80 ‰) very similar to the other springs but its range is much wider -10.49 to -11.22 ‰ (Fig. E-7). Its characteristics resemble those of the other springs but the curves characterizing changes in the monitored properties over time seem to be retarded as if two superposed sets were put together (mixing ?). The isotopic composition of sulphatic sulphur from the spring $\delta^{34}S = 11.2$ ‰ falls among values typical of the Permian (Zechsteinian), provided that pure Permian sulphates were dissolved, or it could result from the mixing of Werfenian and "background" sulphur of unknown origin as in the case of the foregoing springs except for Štubne (Fig. E-2). Recharge from the crystalline unit or Lower Triassic quartzites is, because of the hydrochemical characteristics of Jergaly branch springs, less probable than from Tithonian-Neocomian marly limestones. In contrast, sulphates in waters particularly from the three highest springs in the

Jergaly branch most probably came from Werfenian beds in the envelope unit. Therefore we assume the following structural setting: carbonatic rocks of the Krížna nappe are underlain by envelope limestones and dolomites at a substantial depth which in turn rest on Werfenian sulphate-bearing shales of Lower Triassic age. The stratigraphically higher members of the envelope sequence are probably faulted and consequently at least in some places poorly permeable Jurassic and Cretaceous envelope members do not separate the envelope carbonates from the overlying Triassic carbonatic rocks of the Krížna nappe. The envelope limestones and dolomites thus presumably make up a single hydrogeologic unit with limestones and dolomites of the Krížna nappe. We also assume recharge along faults and fractures from the overlying Tithonian-Neocomian beds or by seepage from surface streams in more elevated areas composed of Tithonian-Neocomian rocks as well. Surface streams on an area of 12.59 km^2 flow down the slopes composed of Tithonian-Neocomian rocks towards Jergaly and gradually disappear in Triassic carbonates. Geologic evidence indicates that the overlying nearly horizontal Tithonian-Neocomian beds of the Krížna nappe along with the permeable Triassic substratum stretch further north beyond the Váh / Hron water divide (leading through Mt. Zvolen 1402.3 m and Motyčkova hoľa 1292.1 m high) on an area of 6.8 km^2 roughly as far as the lower edge of Krížna nappe Triassic carbonate inliers in Žarnovka and Veľká Bzdová valleys and approximately the lower edge of the higher Krížna nappe Triassic carbonate inlier in the Hričkov valley. Therefore we assume that groundwaters circulate below the geomorphologic water divide. Formerly we expected that the amounts missing from the recharge potential of the Krížna nappe Triassic carbonate inliers in Žarnovka and Veľká Bzdová valleys (which have virtually no visible dicharge) percolate beneath Mt. Zvolen (1402.3 m) and Malý Zvolen (137222.1 m) to another Krížna nappe carbonate inlier in Hričkov valley (Liptovské Revúce) where the lowest-altitude carbonates lie 702 m above sea level. Nevertheless, gauging on all three structures did not confirm this assumption - the Hričkov unit turned out to be balanced (measured discharge in 1992 was 4.59 l/s and discharge adjusted to spring discharge was 5.92 l/s) with a specific discharge 16.64 l/s, but the other two units displayed deficits in comparison with their recharge potential -18.00 l/s (carbonate inlier in Veľká Bzdová valley) and -16.44 l/s (carbonate inlier in Žarnovka valley). This fact alone does not explain the surplus in the Donovaly-Hanesy-Štubne structure and Bukovec syncline below Donovaly, but provides clues for a possible solution. The lower margins of these units situated north of the water divide lie at an elevation of 860 m (carbonate inlier in Žarnovka valley) and 720 m (carbonate inlier in Veľká Bzdová valley), and the lower one of the two inliers in Hričkov valley ends at an altitude of 720 m. Surface streams in valley Barboriná - near the road from Donovaly to Korytnica -

obviously have less water than other streams of similar drainage area in the neighbourhood (I.Valušiak, pers. comm.). A rough hydrologic balance therefore indicates that the three highest sources of the Pohronie water-supply system (Jergaly, Štubne and Generál Čunderlík) are recharged from exposed carbonates of the envelope unit (Bukovec syncline) and Krížna nappe (Donovaly-Hanesy-Štubne unit), from the southern slopes of Mt. Motyčková and Zvolen (gradual disappearance of surface streams on an area of 12.59 km^2) and finally from a 6.8 km^2-large territory north of the Váh/Hron water divide extending roughly as far as the lower edges of carbonate inliers in Žarnovka and Veľká Bzdová valleys and the lower edge of the higher Krížna nappe Triassic carbonate inlier in Hričkov valley.

If the effective recharge amounts to only a half of the recharge potential inferred by E.Kullman's (1990) equations for local total precipitation, i.e. 9 l/s/km^2 instead of 18 l/s/km^2, possible recharge in the latter two territories is about 175 l/s. This amount corresponds to the 184.59 l/s surplus above the recharge capacity of carbonates exposed in this area which were looked for in the beginning of this chapter. The existence of such a recharge area in the north is also suggested by oxygen isotopic compositions in springs Jergaly, Štubne and Generál Čunderlík - these isotopes indicate that waters from spring Jergaly are recharged about 150 m higher than is the average altitude of the Bukovec syncline and 200 m higher than is the altitude of the Donovaly-Hanesy-Štubne unit. The roughly estimated average altitude of spring Jergaly and Mt. Zvolen is 1057 m, which corresponds fairly well to the assumed average isotopic composition of precipitation according to the regression equation expressing the change in $^{18}O/^{16}O$ isotopic ratio with altitude (calculated assumed altitude 1095 m).

The above evidence confirms E.Kullman's (1972) assumption that Jergaly spring groundwaters are recharged along dislocations dissecting Tithonian-Neocomian marly limestones which rest on permeable carbonates in this area. Further evidence presented by E.Kullman to suggest that carbonatic rocks underlying younger members of the Krížna nappe are dewatered is as folows:

1. quantitative - given the local climatic conditions, recharge potential 16.3 l/s/km^2 and the area of carbonates exposed on the surface 7.37 km^2, the discharge from the area concerned should be about 120 l/s whereas the three above-mentioned springs discharge a total of 420.0 - 560.0 l/s.

2. temperature - although the average yearly temperature in the vicinity of the spring varies from 4.5 to 5.0 °C, water from spring Jergaly always has a constant temperature of 11.5°C suggesting groundwater circulation at a depth of 150 - 200 m.

3. retardation - discharge by spring Jergaly increased 7 to 14 days after rain, which is a retardation typical of deeper circulation.

Further recharge to this structure through a connection between the carbonate inliers at the bottom of some valleys, e.g. in the Ploské - Staré Hory area (E.Kullman - M.Kršák, 1972), has not been confirmed by these investigations nor by gauging in Triassic carbonate inliers in valleys Suchá, Zelená and Lopušiná (Liptovské Revúce).

Two gaugings near spring Generál Čunderlík, between the outflow from spring Jergaly and the line graveyard - water tank in the settlement Motyčky revealed that a surface stream here loses 6.69 and 18.20 l/s. As water from spring Generál Čunderlík is turbid after heavy rains and snow melting, a connection between this spring and surface streams in Bukovecká dolina valley or Starohorský potok brook was assumed long ago (E.Kullman - M.Kršák, 1979). Our results and gauging in Bukovecká dolina, where only small discharges were noted (14.08, 2.73 and 17.00 l/s in 1991, 1992 and 1993, respectively), indicate that the latter is more probable. The drop in the discharge of the Starohorský potok between Jergaly and Motyčky is given in Tab. E-1.

Table E-1 : Drop in discharge in the upper section of the Starohorský potok brook in the Motyčky area indicated by gauging between profiles No. 314 (below the outflow of spring Jergaly) and 221 (opposite to a cemetery at Motyčky).

Profile No.	1992				1993			
	Date	discharge [l.s^{-1}]			Date	discharge [l.s^{-1}]		
		main stream	tributary	increase / decrease		main stream	tributary	increase / decrease
314	2.10.	21,64			29.7.	116,94		
221	2.10.	14,95		- 6,69	29.7.	98,74		- 18,20
	total : - 6;69 l.s^{-1}				total : - 18,20 l.s^{-1}			

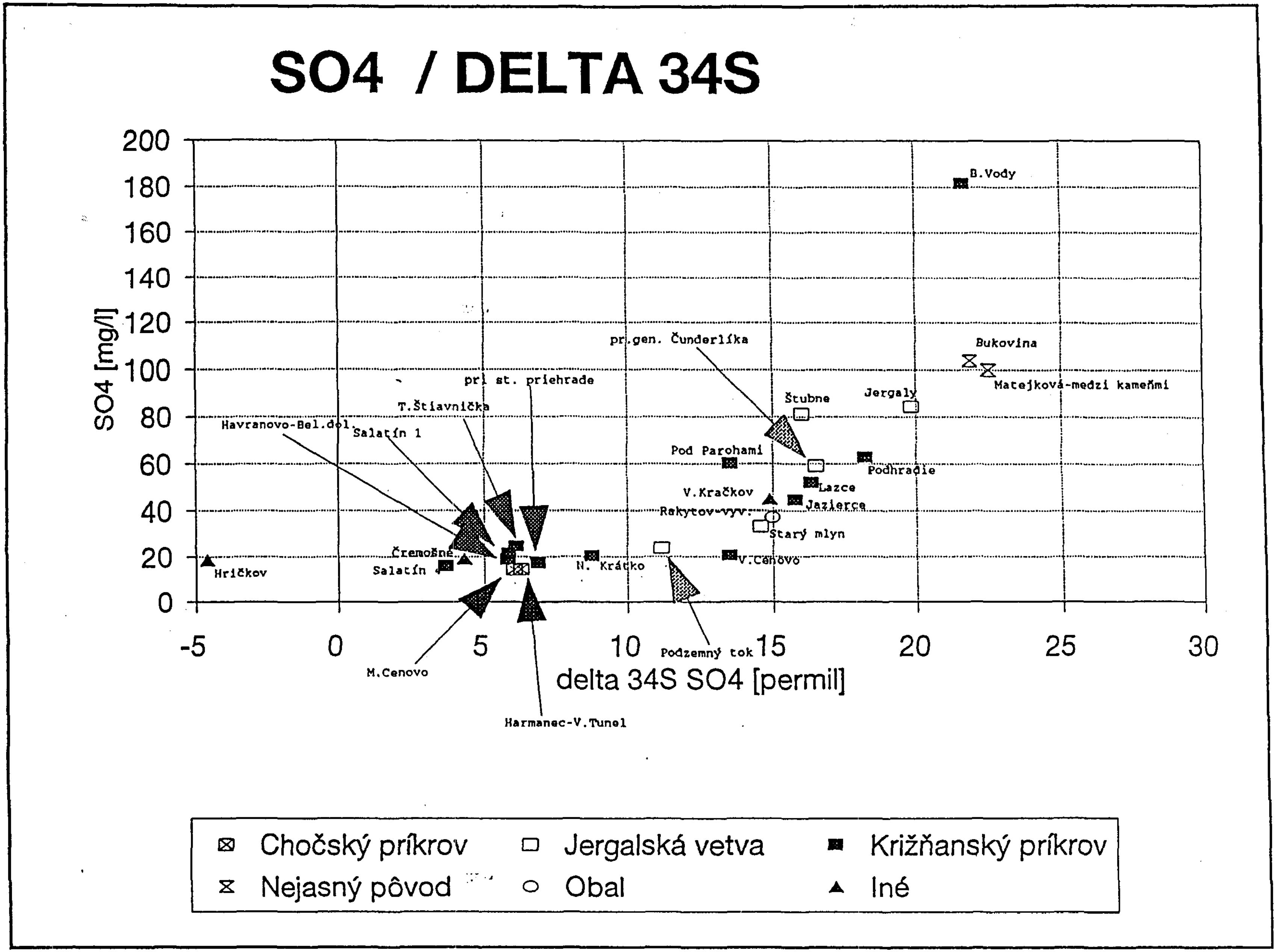
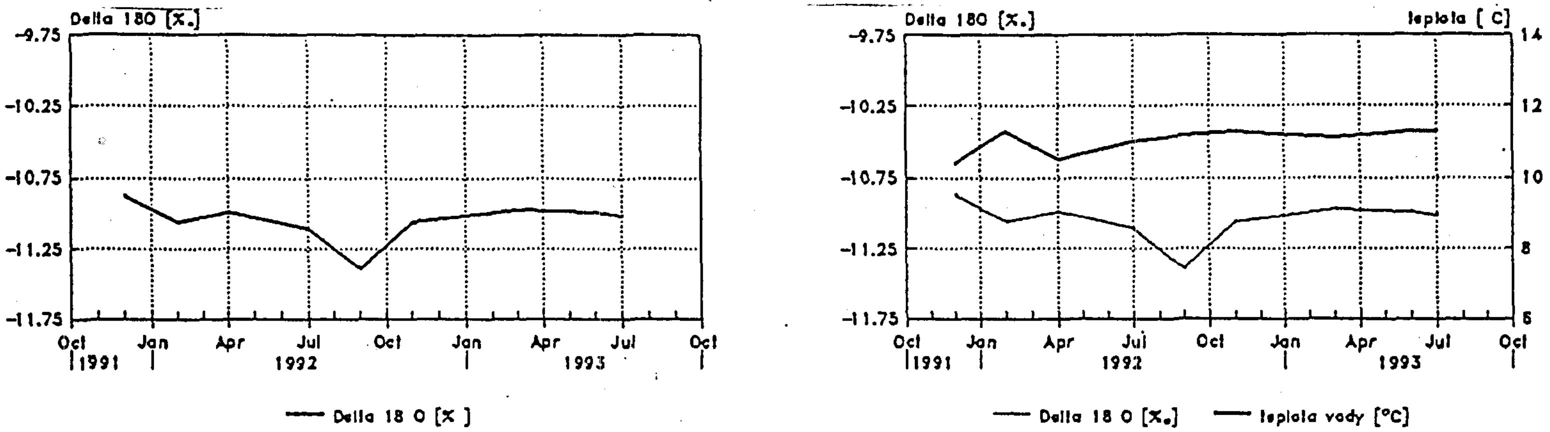


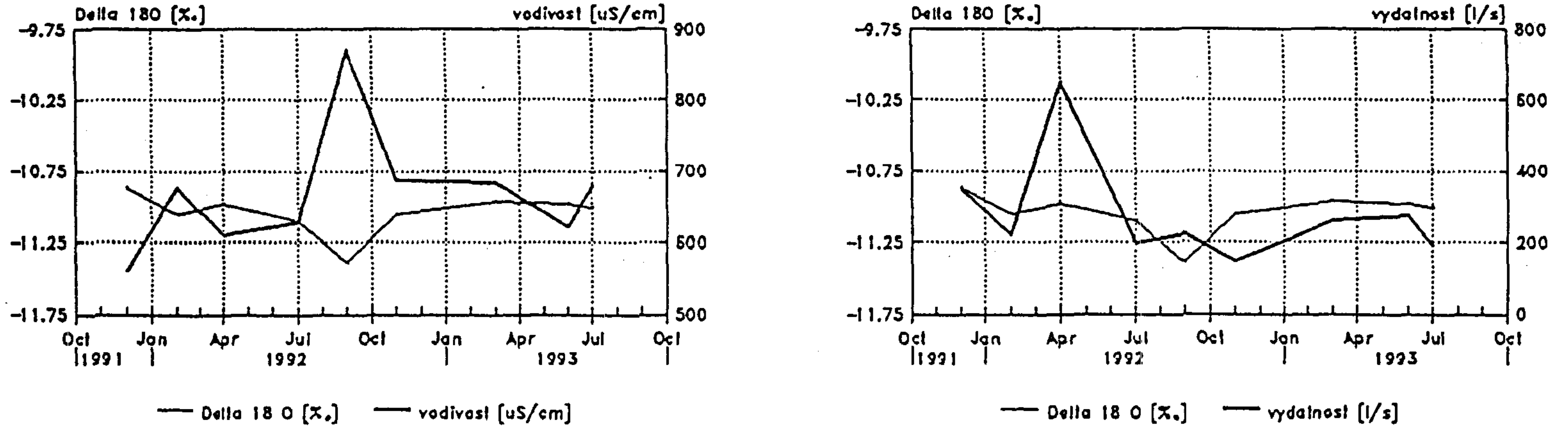
Fig. E-2 : Relationship between the amount of dissolved sulphates in the spring waters and their isotopic composition.


spring Jergaly

isotope composition of oxygen

spring Jergaly

water temperature - isotope composition of oxygen


spring Jergaly

specific conductivity - isotope composition of oxygen

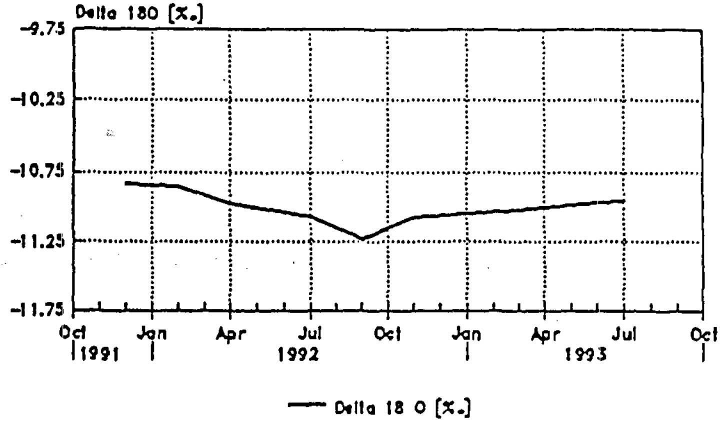
spring Jergaly

discharge - isotope composition of oxygen

Fig. E-3

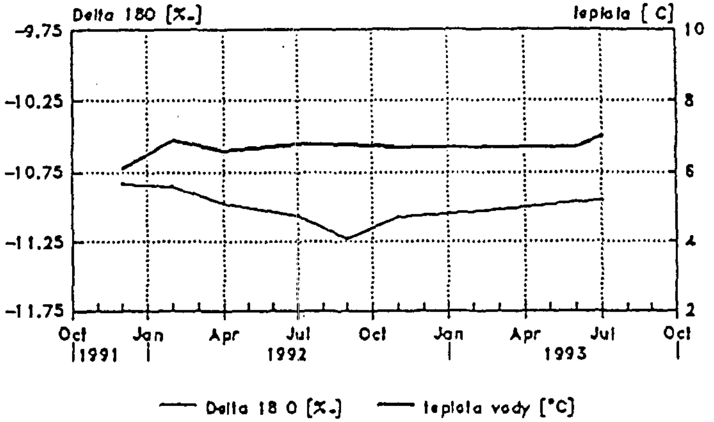
spring Štubne

isotope composition of oxygen



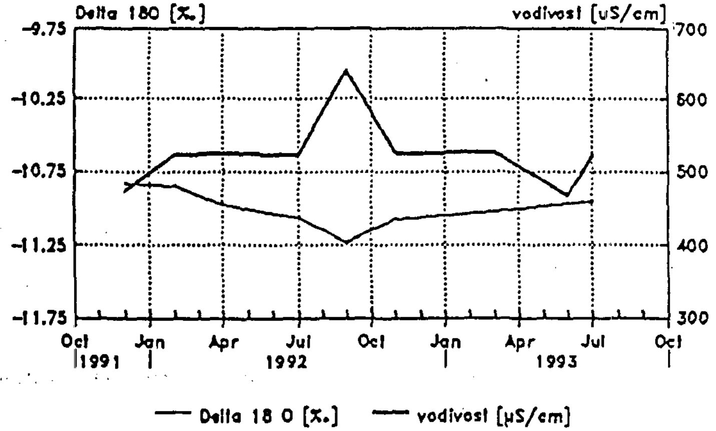
spring Štubne

water temperature - isotope composition of oxygen



spring Štubne

specific conductivity - isotope composition of oxygen



spring Štubne

discharge - isotope composition of oxygen

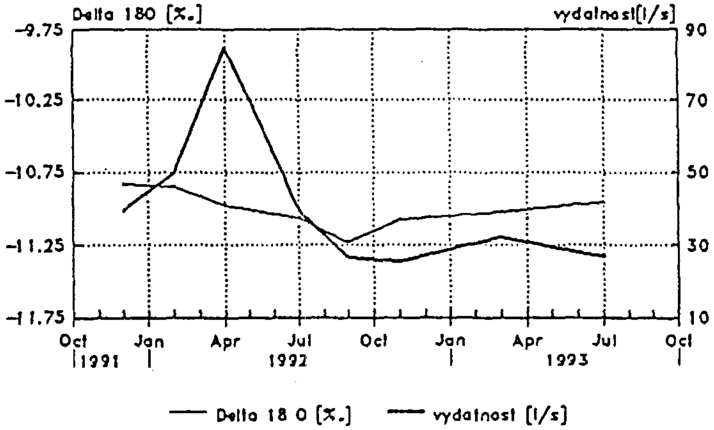


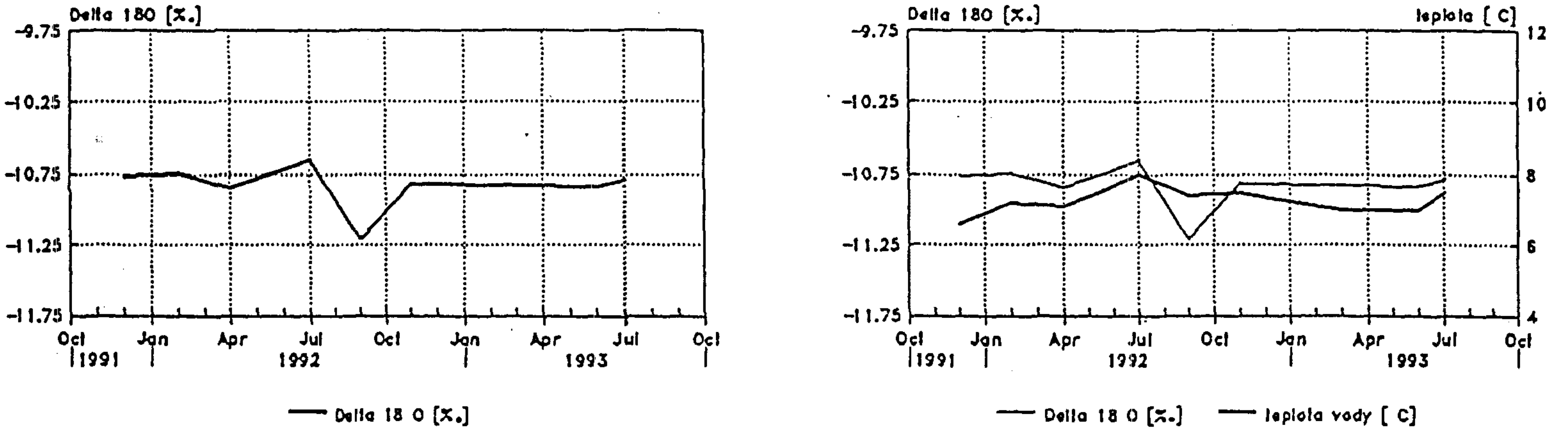
Fig. E-4

spring "Generál Čunderlík"

isotope composition of oxygen

spring "Generál Čunderlík"

water temperature - isotope composition of oxygen



spring "Generál Čunderlík"

specific conductivity - isotope composition of oxygen

spring "Generál Čunderlík"

discharge - isotope composition of oxygen

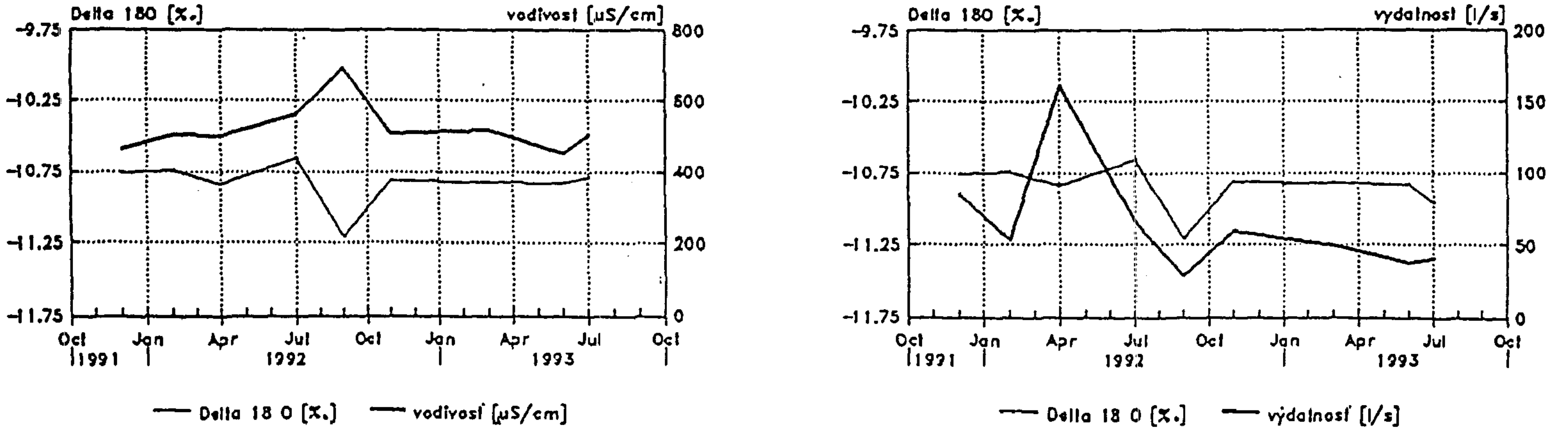


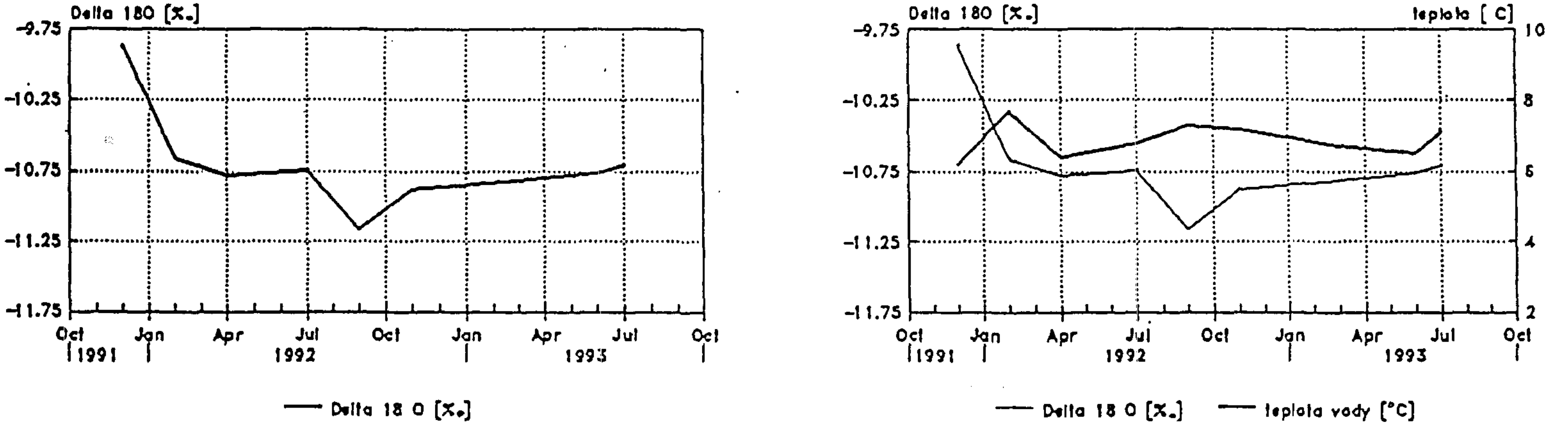
Fig. E-5

spring Starý mlyn

isotope composition of oxygen

spring Starý mlyn

water temperature - isotope composition of oxygen



spring Starý mlyn

specific conductivity - isotope composition of oxygen

spring Starý mlyn

discharge - isotope composition of oxygen

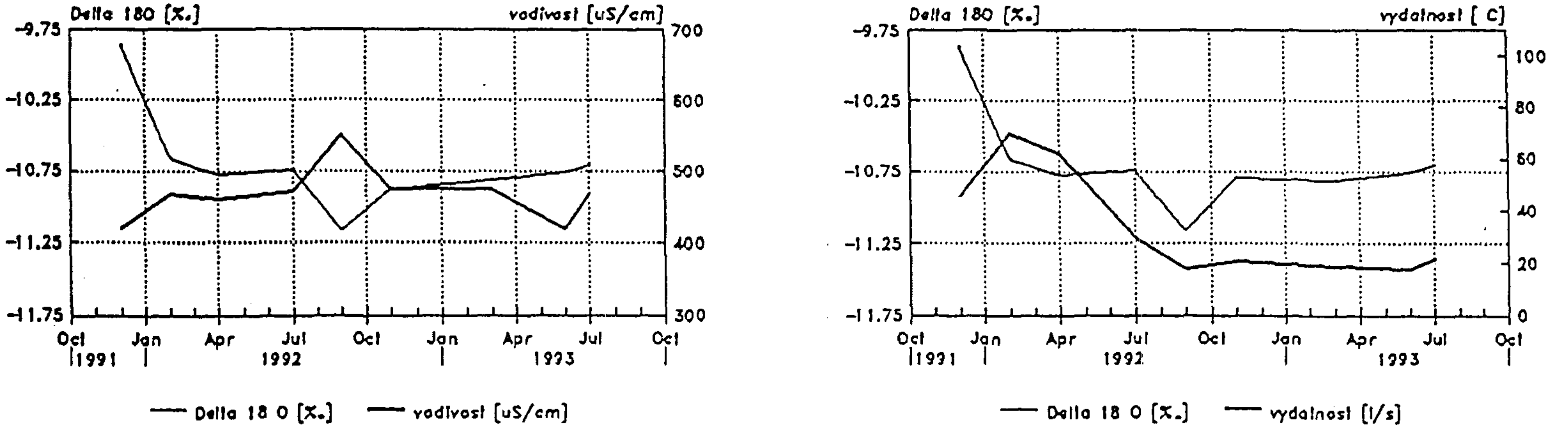
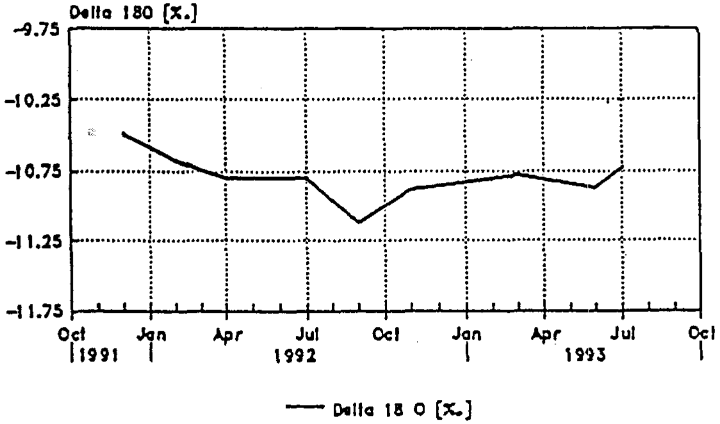


Fig. E-6

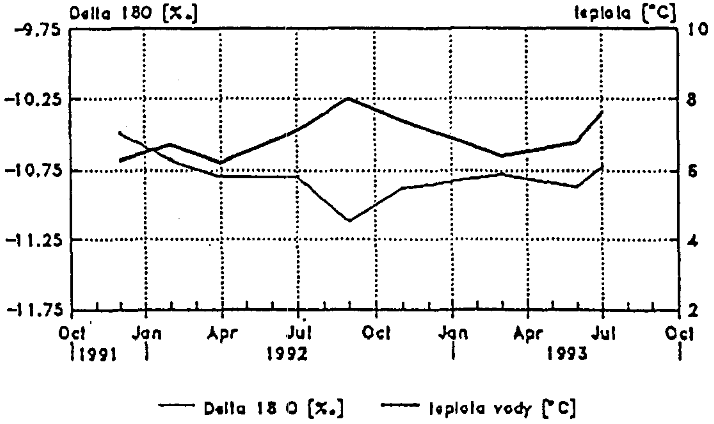
spring Podzemný tok

isotope composition of oxygen



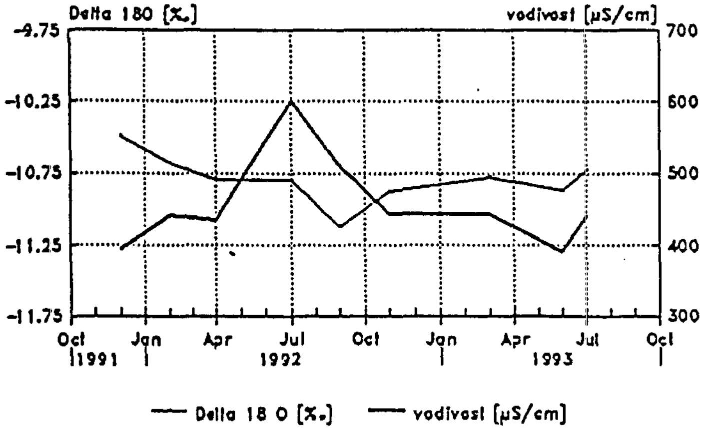
spring Podzemný tok

water temperature - isotope composition of oxygen



spring Podzemný tok

specific conductivity - isotope composition of oxygen



spring Podzemný tok

discharge - isotope composition of oxygen

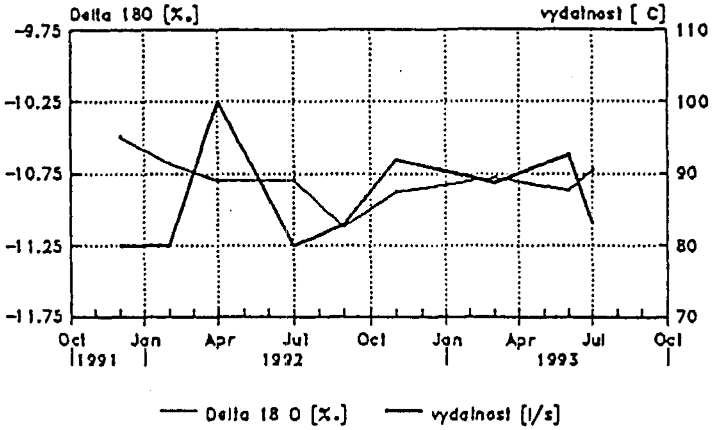


Fig. E-7

Eugen Kullman

Dionýz Štúr Institute of Geology, Bratislava

Optimizing Exploitation of Karst-Fissure Groundwaters from Spring Jergaly in the Veľká Fatra Mts.

The spring Jergaly was comprehensively assessed with the objective to increase the exploitation of groundwaters from both the spring itself and the adjacent sections of its hydrogeologic structure.

The hydrogeologic structure drained by spring Jergaly consists of two tectonic units - a belt of Jurassic limestones of the Mesozoic envelope sequence of the crystalline unit and Mesozoic formations of the Krížna nappe composed of permeable Triassic limestones and dolomites. The main catchment and accumulation areas are composed of the Krížna nappe carbonates while the discharge area lies on the tectonic contact between the nappe and the envelope unit combined with a fractured belt of Jurassic envelope limestones (Fig. F-1). The spring's discharge varies from 123 to 1315 l/s and its water temperature is permanently by 6.5 °C higher than the average annual temperature in the area concerned. The waters rise from a depth of 200 - 250 m and the retardation after effective precipitation is 7 - 14 days.

To solve the problem, the following procedure was used:

- compiling a representative discharge curve for the spring based on long-term systematic measurements,
- drilling hydrogeologic wells in the area where the spring's karst-fissure waters rise towards the surface and carrying out pumping tests in periods unaffected by precipitation,
- dividing the pumped amounts of water (through the application of discharge curve to the period of the pumping test) into a volume corresponding to natural discharge and a volume representing pumped groundwaters previously accumulated in the structure, the latter being a potential source of water in dry periods,
- assessing the possibility of the permanently increased use of groundwaters based on long-term systematic gauging on the spring and seasonal use of a calculated exploitation volume of groundwaters from the hydrogeologic structure.In the concrete case of the spring Jergaly, the following procedure was employed :

1. Discharge curves of groundwaters based on systematic gauging on the spring were assessed yielding roughly identical results particularly in periods of average and low discharge. The following

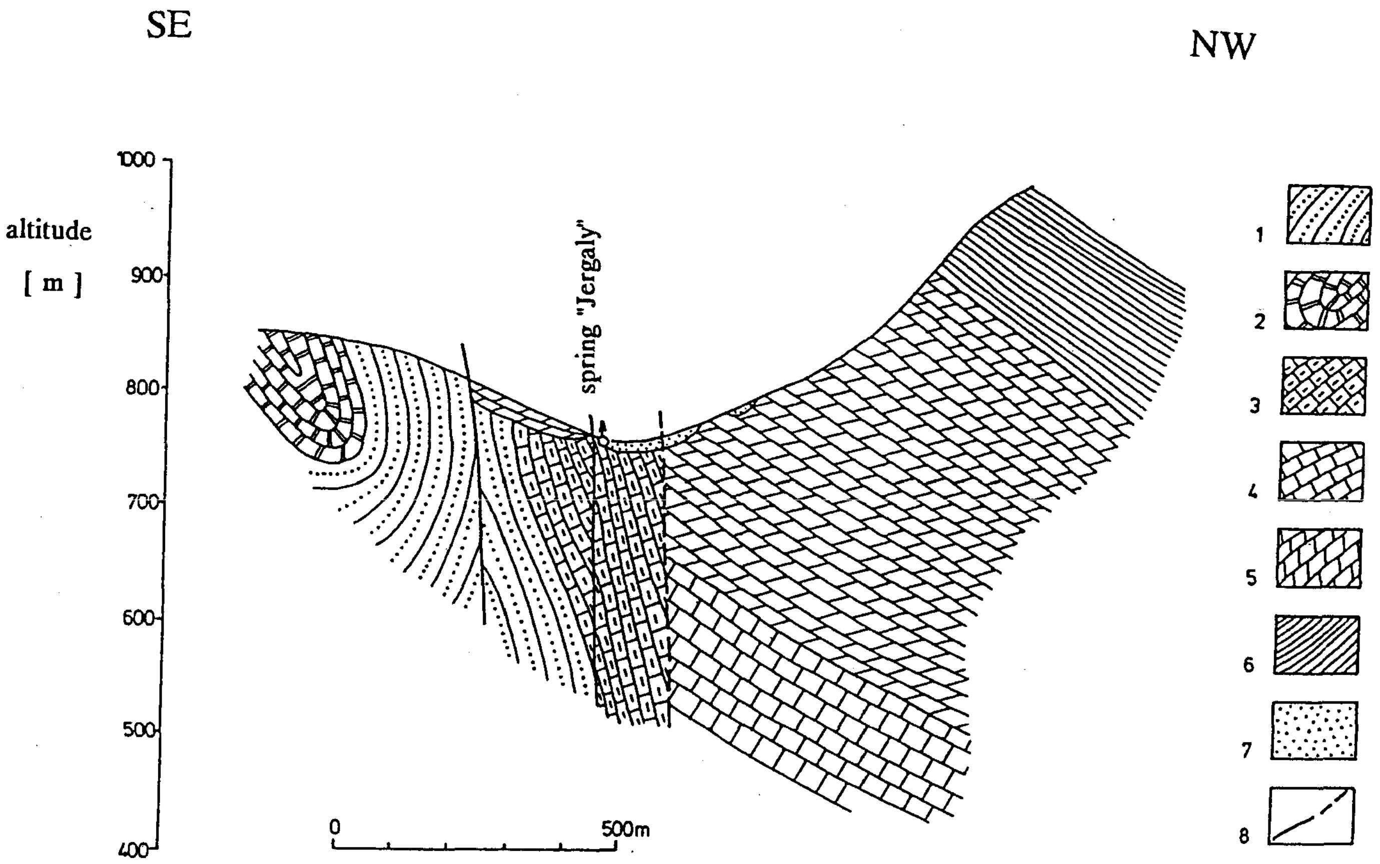


Fig. F-1 : *Hydrogeological section of "Jergaly" spring (Jergaly, Veľká Fatra Mts.). Compiled by E.Kullman - M.Rakús 1972.*

Donovaly envelope unit : 1 - Lower Triassic sandy shales and sandstones, impermeable, 2 - Middle Triassic limestones, high karst-fissure permeability, 3 - Liassic limestones, high karst-fissure permeability, Krížna nappe : 4 - Middle Triassic limestones, high karst-fissure permeability, 5 - Middle Triassic dolomites, high fissure permeability, 6 - variegated claystones (Carpathian Keuper - Upper Triassic), marlstones, marly limestones and and radiolarites, Dogger - Malm, marly Neocomian limestones - low permeable to impermeable, 7 - Quaternary loamy gravel-sands and calcareous tuffs, medium - to high pore permeability dominant, 8 - faults

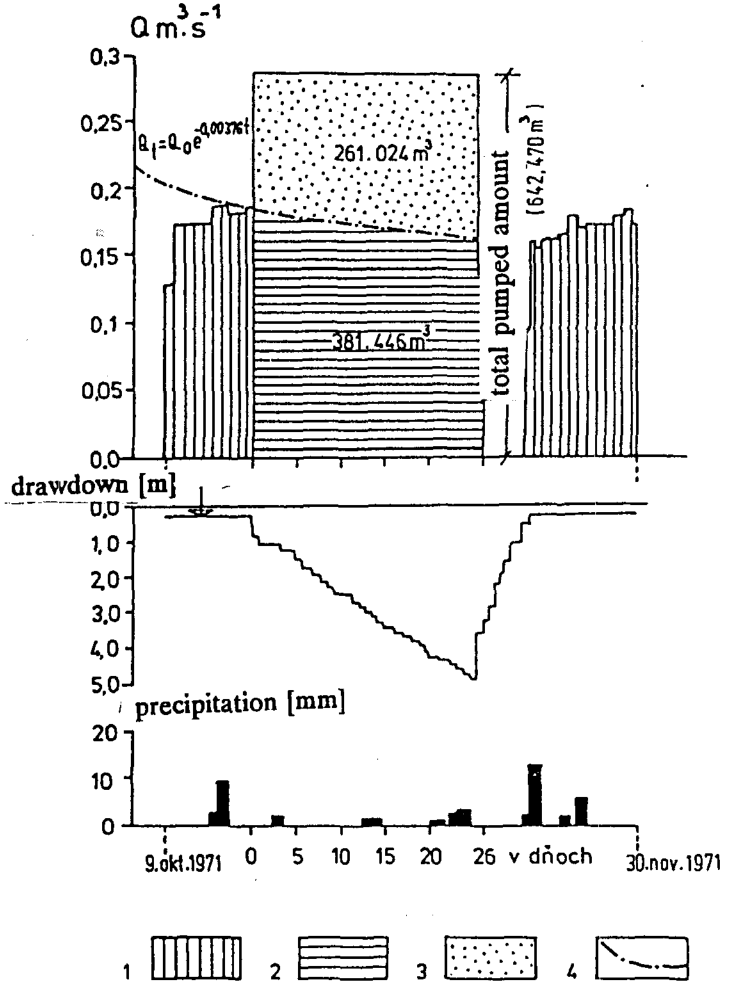


Fig. F-2 : *Schematic determination of exploitable karst-fissure waters for increase of amounts exploited (Jergaly spring - pumping test from 19.10.1971 to 13.11.1971)*

1 - spring yield, 2 - groundwater amount pumped, corresponding to natural spring yield, 3 - amount pumped from accumulated groundwater reserves of hydrogeological structure, 4 - groundwater discharge (depletion) curve

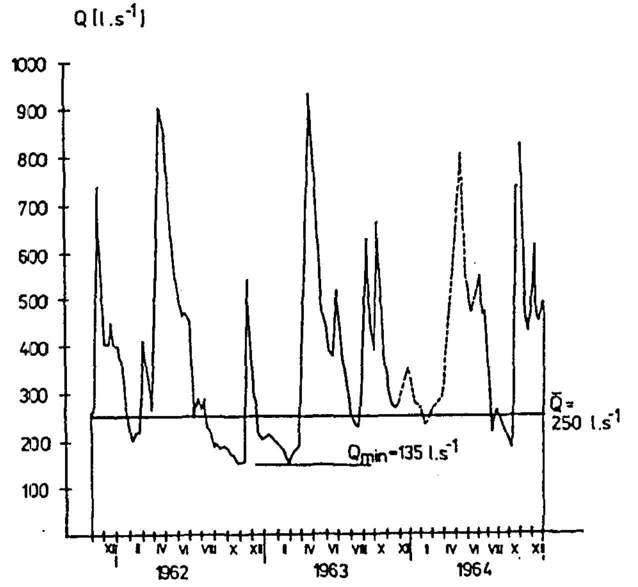


Fig. F-3 : *Graphical illustration of necessity of accumulated groundwater reserves exploitation from hydrogeological structure in 1962 - 1964 to provide permanent exploitation of 250 l/s from "Jergaly" spring area.*

representative discharge curve for the spring was thus obtained:

$$Q_t = 0.315^{-0.091t} + 0.21^{-0.00376t}$$

$$Q_o = 0.525 \text{ m}^3, \quad Q_t = 0.141 \text{ m}^3/\text{s}, \quad t = 105 \text{ days}$$

A total of 642 470 m^3 of groundwaters was pumped out. Of this, the natural groundwater discharge divided with the application of discharge curve accounted for 381 446 m^3. 261 024 m^3 of groundwaters were pumped from the reserves accumulated in the tested hydrogeologic structure (Fig. 2). This volume are recoverable accumulated reserves at a 4.5 m drawdown. The volume was insufficient even to ensure a permanent discharge of 200 l/s and therefore it was decided to increase the recoverable reserves by a much larger drawdown. The recoverable accumulated groundwater reserves were expected to grow linearly during pumping at a constant rate of 286 l/s until the drawdown reached 19 m. This calculation indicated the volume of recoverable accumulated reserves of 1 332 500 m^3.
The second stage was aimed at verifying the above assumption. This stage included drilling three large-diameter hydrogeologic wells (designed to serve later as part of a water-supply object) and the second long-term pumping test in winter 1973-1974. Its objective was to confirm the results from 1971 and to document the volume of the hydrogeologic structure's recoverable reserves at a 19 m drawdown. The spring's discharge before the start of the second pumping test amounted to 157 l/s. In 54 days, the water table was lowered by 19 m, and 1 793 742 m^3 of groundwaters were pumped from the structure. Of this, the natural discharge calculated by the application of discharge curve accounted for 659 489 m^3 and the volume of recoverable accumulated reserves for the remaining 1,134 253 m^3. The documented recoverable volume of accumulated groundwaters was by 15 % lower than that inferred by theoretic speculations based on the first pumping test. To be sufficiently safe, the groundwater reserves were reduced to 911 800 m^3.

A comparison between the accumulated reserves and long-term gauging on the spring in 1962 - 1974 (Tab. F-1, Fig.F-3) has showed that the exploitation of 911 800 m^3 of accumulated groundwaters from the hydrogeologic structure, which will be recharged in periods of high spring discharges, allows to increase the capacity of the water source at least to 250 l/s, i.e. by 60 - 70 % in periods of low discharges. The only major exception during the 12-year-long investigations (aside from an insignificant deficit of 0.004 m^3/s from Aug. 10, 1962 to April 2, 1963) is the period from June 1973 to February 1974 when the accumulated reserves (911 797 m^3) could only partly ensure the necessary amount of groundwaters (1 683 619 m^3) and permanent water supplies would have to be reduced to 215 l/s. Knowledge obtained so far suggests that such an infavourable period takes place only once in 10 - 15 or even more years.

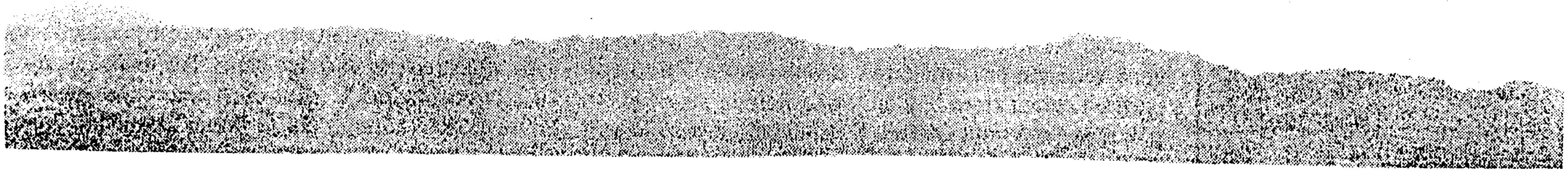
Tab. F-1 : *Periods of "Jergaly" spring yield below 250 l/s, its possible recharge to 250 l/s from accumulated groundwater reserves of hydrogeological structure (hydrological years 1962 - 1974).*

Periods when spring discharge was below 250 l/s	*Total deficit in m^3.*	*Volume of recoverable accumulated groundwater reserves in m^3.*	*Surplus or deficit in exploitation of accumulated reserves in m^3.*
25. 1.1962 - 28. 2.1962	*78 476*	*911 797*	*+ 833 321*
10. 8.1962 - 2. 4.1963	*969 297*	*911 797*	*- 57 500*
1. 8.1963 - 27. 8.1963	*32 348*	*911 797*	*+ 879 449*
17. 8.1964 - 10.10.1964	*102 326*	*911 797*	*+ 809 471*
1. 9.1971 - 12. 3.1972	*374 804*	*911 797*	*+ 536 998*
20.10.1972 - 23. 4.1973	*311 037*	*911 797*	*+ 500 760*
7. 6.1973 - 7. 2.1974	*1 653 619*	*911 797*	*- 741 822*

The source can best be exploited by a combination of three techniques - natural discharge when the spring discharge exceeds 250 l/s, pumping through a hose to a 5 m drawdown at discharge below 250 l/s and finally, in critical periods, pumping by submersible pumps to a 19 m drawdown.

This water source has been exploited in the above-described way since 1982. The source operates very effectively, despite the extremely dry climate in the past decade and consequently ever decreasing discharges of karst-fissure springs from 1984/85 to 1993 (by 20 - 40 % in 1993) in comparison with long-term averages until 1984. The average annual volumes of groundwaters recovered from the spring betwen 1982 and 1990 varied from 230 to 240 l/s. The major general decrease in discharges of karst-fissure groundwaters did not appear until 1991 - 1993 when the average annual recovered amounts of groundwaters fell to 203 - 230 l/s.

SLOVAKIA - LAND OF 1000 BEARS



** According to the last census of bears (up to the Dec. 31, 1992), 954 of these gentle animals inhabit Slovak woods*

References :

Andrusov D., 1936: Popis sond a výsledky sondovacích prací. Hlavní dráha B. Bystrice - Diviaky. Manuscript. Archív Geofondu Bratislava.

Gazda, S. 1971 : Modifikácia Palmerovho klasifikačného systému. Hydrogeologická ročenka 1970-1971. ÚGI Brno.

Gazda, S. - Hanzel, V. 1980 : Influence of natural factors on chemical properties of groundwaters in the West Carpathian Mesozoic. Západné Karpaty, séria hydrogeol. a inž. geológie 3. GÚDŠ Bratislava.

Hanáček, J. 1990 : Prognózne zdroje vápencov a dolomitov Slovenska. Manuskript - Archív Geologického ústavu Dionýza Štúra Bratislava

Hanzel, V. - Vrana, K. - Kullman, E. - Dovina, V. - Škvarka, L. 1989 : Groundwater resources in Slovakia (Czechoslovakia). Západné Karpaty, séria hydrogeol. a inž. geológie 8. GÚDŠ Bratislava.

Kubíny D., 1990: Geologicko-tektonická pozícia harmaneckého krasu. Slovenský kras XXVIII, ss. 47-56.

Kullman, E. 1964 : Krasové vody Slovenska a ich hydrogeologický význam. Geologické práce, Správy 32. GÚDŠ Bratislava.

Kullman, E. 1984 : Investigation of the Representation Joint - Karst Hydrogeological Structures. Czechoslovak Contribution to the IHP UNESCO 1981-1984. Czechoslovak Committe for Hydrology. Bratislava.

Kullman E. - Rakús M., 1982: Správa o možnostiach optimálneho zachytenia podzemných krasových vôd drénovaných vrcholovým harmaneckým tunelom. Manuscript. GÚDŠ Bratislava, 28 strán.

Kullman, E. - Kullmanová, A. - Rapant, S. 1985 : Zhodnotenie hydrogeologických pomerov mezozoika Slovenského raja s ocenením prognóznych prírodných zdrojov a prognóznych využiteľných množstiev podzemných vôd. Manuskript - Archív Geologického ústavu Dionýza Štúra, Bratislava

Kullman, E. 1989: Hydrological balances in fissure-karstic hydrogeological structures. Západné Karpaty, séria hydrogeológia a inžinierska geológia, 8, p. 25 - 66, GÚDŠ Bratislava

Kullman, E. 1990 : Krasovo-puklinové vody. Karst - Fissure Waters. GÚDŠ Bratislava.

Kullman, E. - Malík, P. - Vrana, K. 1994 : Podzemné vody karbonátov mezozoika Čachtických Karpát. Západné Karpaty,sér. Hydrogeológia a inžinierska geológia, 12, 63 - 117, Dionýz Štúr Institute of Geology, Bratislava

Malík, P. - Michalko, J. - Rapant,S. 1993 : Štruktúrno-hydrogeologická analýza karbonátov triasu krížňanského príkrovu vo Veľkej Fatre. Manuskript - Archive of Dionýz Štúr Institute of Geology, Bratislava

Mazúr, E. - Jakal, J. 1969 : Typologické členenie krasových oblastí na Slovensku. Slovenský kras, Ročník VII. Zborník Múzea Slovenského krasu.

Melicherčík P., 1992: B. Bystrica - PSV Tunel, Ochrana zberača pitnej vody, časť A, zákazka č. 15.0-131 Banské stavby š.p. Prievidza, Závod projekcie a technológie.

Melicherčík P., 1993: Technická správa. Ochrana zberača pitnej vody. Projekt skutočného vyhotovenia, zákazka č. 15.0-185, Banské stavby š.p. Prievidza, stredisko projekcie a technológie.

Nešvara J., 1992: PSV - zdroj tunel - hydrogeologický průzkum - záv. správa. Zabezpečení podkladů pro studii Hydroprojektu Ostrava pro získaní vody pro pohronský skupinový vodovod. Manuscript. Ostrava.
Pearson, F.J.Jr. - Balderer, W. - Loosli, H.H. - Lehmann, B.E. - Matter, A. - Peters, Tj. - Schmassmann, H. and Gautschi, A. 1991 : Applied Isotope Hydrogeology A Case Study in Northern Switzerland, Elsevier, p.439

Rank, D. et al. 1990 : Isotopenhydrogeologie in Österreich: Stand 1990. Mitteil. öster. geol. Ges. 83 (1990) 109-124.

Šalagová, V. - Šalaga, I. 1988 : Proving of Possible Optimal Utilizattion of Groundwaters in Some Mountain Ranges of the West Carpathians Mts. Proceedings of seminar "Optimalizácia využitia puklinovo - krasových vôd". GÚDŠ Bratislava.

Vrana, K. - Bodiš, D. - Lopašovský, K. - Rapant, S. 1989 : Regionálno-hydrogeochemické zhodnotenie kvality snehovej pokrývky na území Slovenska. Západné Karpaty, séria hydrogeológia a inžinierska geológia 8, Geologický ústav Dionýza Štúra Bratislava, s. 87-128

Yurtsever, Y. - Gat, J.R. 1981 : Stable isotopes in athmospheric waters. Stable isotopes in hydrology, IAEA Wien

Záruba - Pfefferman Q - Andrusov D., 1937: Geologické poměry území projektované dráhy Banská Bystrica - Diviaky. Zprávy železničných inženýrů československých, roč. XIV, čísla 9 a 11.

Záruba-Pfefferman Q - Andrusov D., 1939: Srovnání geologických profilů Harmaneckým tunelem na dráze Banská Bystrica-Diviaky. Technický obzor, roč. XLVII, číslo 11, ss. 161-164.