

Isotopic Composition of Waters in the Demänovská dolina Valley and Its Underground Hydrologic System During Winter and Spring of 2010/2011

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Abstract: In the Demänovská dolina Cave system (Slovakia) and its vicinity, 32 sampling places for regular observation (in 2-months interval) of $\delta^{18}\text{O}$ and $\delta^2\text{H}$ in water were established. This monitoring included precipitation waters, waters in the surface streams, waters of the underground hydrological system as well as the dripping seepage waters of the cave system. Altitudinal extent of the area was from 800 m a.s.l. (lowermost cave entrance) to 2024 m a.s.l. (Chopok Mt. on the top of the crystalline range). Initial results show some similarities but also differences within the analyzed water types. For precipitation, a high variability of isotopic composition was confirmed, from quite depleted up to more enriched waters ($\delta^{18}\text{O}$ from -16.8‰ up to -5.7‰; $\delta^2\text{H}$ from -121.6‰ to -32.7‰). During the recharge process and groundwater/surface water formation, precipitation water is homogenized, what is reflected in much more stable isotope content. The most depleted ($\delta^{18}\text{O} \approx -11.7\text{‰}$ to -10.8‰ ; $\delta^2\text{H} \approx -78.9\text{‰}$ to -73.4‰) were the waters of surface streams, running from the northern slopes of the Nízke Tatry Mts., formed by crystalline rocks, alochtonous to the underground hydrological system. Smaller autochtonous surface water streams (formed in the side valleys of the main karstic canyon) are slightly enriched (heavier, as $\delta^{18}\text{O} \approx -11.4\text{‰}$ to -10.6‰ ; $\delta^2\text{H} \approx -78.3\text{‰}$ to -71.5‰), what reflects lower altitudes of their watersheds. Interesting is the distribution of the isotope content of the underground streams in the cave system. The most depleted are the underground streams directly (visibly) communicating with surface waters ($\delta^{18}\text{O} \approx -11.33 \pm 0.13\text{‰}$; $\delta^2\text{H} \approx -76.88 \pm 1.68\text{‰}$). Extent of the relationship of underground streams to the autochtonous seepage waters (slow circulation through the fissures) is manifested by respective portion of isotopically enriched waters—as the underground streams show different isotope composition. The combination of the alochtonous water components (from surface streams reaching the karstic area from the adjacent crystalline via swallow holes) and autochtonous water components (recharged directly in karstified limestones) is visible especially on the subsurface stream of Demänovka. The most isotopically enriched (heaviest) of all water types are dripping seepage waters ($\delta^{18}\text{O} \approx -10.4\text{‰}$ to -9.4‰ ; $\delta^2\text{H} \approx -71.6\text{‰}$ to -65.0‰).

Keywords: Demänovská dolina Valley, Karst system, Hydrological system, Isotopes $\delta^{18}\text{O}$ & $\delta^2\text{H}$

DEMÄNOVSKÝ CAVE SYSTEM, SLOVAKIA

Demänovský Cave System is up to now the longest speleologically interconnected karst system

in Slovakia. Its position is within the northern slopes of the Nízke Tatry Mts. (northern part of Central Slovakia), just beneath the highest peaks of this range (directly 5.8 km north from Chopok with 2,024.0 m a.s.l., and 8.5 km NW from the Ďumbier Mt. of 2,043.4 m a.s.l.). Two show caves are

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opened in the system, with position of their entrances of N48.998135°/E19.585230° (Demänovská jaskyňa Slobody/Cave of Liberty) and N49.016383°/E19.580893° (Demänovská ľadová jaskyňa / Demänovská Ice Cave).

The length of the system is 35.358 km, the system was formed by the Demänovka River under the eastern slopes (right side) of the Demänovská dolina Valley in the Middle Triassic dark-grey Guttenstein limestones of the Fatricum tectonic unit (Križna nappe; Biely et al. 1997). It represents a large and complicated complex of cave passages, domes and abysses developed in 9 evolution levels with an active allochthonous stream. Altogether 10 speleologically interconnected caves form the system as known today—the most important are: Demänovská jaskyňa Slobody/Cave of Liberty (8.336 m) and Demänovská ľadová jaskyňa/Demänovská Ice Cave (2.445 m), which are open to the public. The other ones are Demänovská jaskyňa mieru/Cave of Peace (16.174 m), Vyvieranie Cave (1.437 m), Demänovská medvedia jaskyňa/Bear Cave (1.447 m), Pustá

Cave (4.663 m) and another five smaller caves (Údolná Cave, Cave Pod útesom, Pavúčia Cave, Jaskyňa trosiek Cave and Cave No.15). Other interesting caves, present within the Demänovská dolina valley like Štefanová Cave (10.047 m), Okno Cave (2.570 m), and Suchá Cave (780 m) are genetically related. We can expect speleological connection of these caves with the system in the future, but also further discoveries.

Demänovská jaskyňa Slobody/Cave of Liberty

Demänovská jaskyňa Slobody/Cave of Liberty is considered to be the most beautiful cave in the system, as it represents morphologically the most variegated part of the Demänovský Cave System, developed in six levels by the ancient ponor inflows of Demänovka River and its side hanging ponor tributaries. The length is reported to be 8.336m with elevation distance of 120 m.



Fig.1 Position of the Demänovský Cave System (Nízke Tatry Mts., Slovakia, Europe)

The underground part of the Demänovka water-course flows through the lowest floor of the Cave of Liberty. Demänovka River springs in the non-karstic granitic territory of the main ridge of

the Nízke Tatry Mts., and on its northward flow it partly sinks into underground in the area of Lúčky. The underground part of the river reappears again on the ground surface in the form of a massive

karst stemming point, called Vyvieranie/Springing, through the Vyvieranie Cave northerly from the Cave of Liberty.

Air temperature here ranges from 6.1 to 7.0 °C, relative humidity is between 94 and 99%. Apart from running water, several lakes are found within the system—with the most interesting Veľké jazero “Těsnohlídko”/Great Lake of “Těsnohlídko” is 52 m long, 5 to 12 m wide and more than 7 m deep.

Demänovská jaskyňa Slobody/Cave of Liberty is unique with quantity and variety of stalactite formations of all types. Apart from white stalactites, we can find here also yellow, pink, red and even purple stalactites, and sometimes grey, dark-green up to black coloration. In addition to the Veľké jazero “Těsnohlídko”, several little sinter lakes with various stalactite and stalagmite formations are found at the bottom (lakes of Zlaté/Golden, Korálové/Atoll, Leknové/Water Lily, Perlové/Pearl's, Hroznové/Grape's). Cave pearls in the form of pea balls in the Veľký dóm/Big Dome, frost stalactites, Stony Sun in Klenotnica/Treasury

House and water lily lakes with rococo style dolls in the Ružový dóm/Pink Dome are considered as the cave's rarity. All stalactite and stalagmite formations are still growing, with high gloss in comparison to other caves of the system.

Discovered by A. Král and A. Mišura in the dry period of 1921 through the swallow hole, lead the Demänovská jaskyňa Slobody/Cave of Liberty was opened for the public in 1927, after pathways and electric lights were completed. Later, current entrance was dug in 1930. It is situated in the western slope of the Točište hill at the altitude of 870 m a.s.l. (50 m above the bottom of the valley). Attractive for domestic and foreign visitors, with 100,000-180,000 visits annually, it is the most visited cave in Slovakia and deserves relevant degree of its protection. However, the surrounding area, known as popular ski resort of Jasná, is developing quickly thus creating a constant environmental threat (not only) to the whole underground karst system.

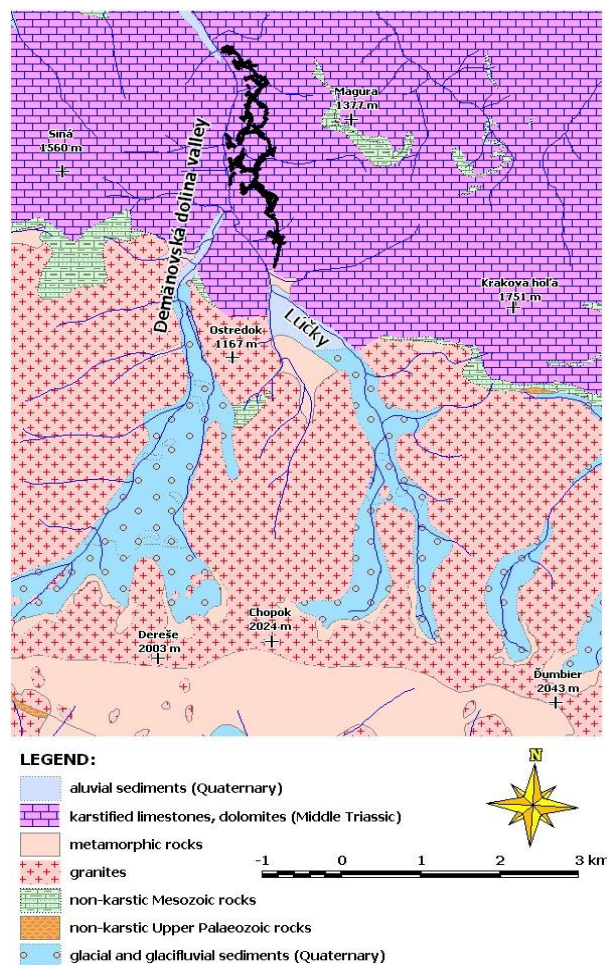


Fig2. Geological settings of the Demänovský Cave System (in black) surroundings (after Biely et al., 1992)

Activity background

To extend existing knowledge on hydrogeological and hydrological settings of the Demänovský Cave System, which seem to play key role for its protection, that should serve as technical arguments for management measures aimed at maintaining favorable status of the site in professional positions of the Slovak Cave's Administration in planning and building procedures associated with this site, a large project of hydrogeological prospection started here in 2009 (Haviarová et al., 2011).

Several specific hydrogeological activities were planned and realized within the framework of this project. They include geophysical measurements-magnetometry and geoelectric methods in symmetrical modifications of resistance profiling and vertical electrical soundings in the area of Lúčky (a contact zone between crystalline rocks and karstified Mesozoic carbonates) from where the development of the Demänovský Cave System begins. Hydrogeological settings of this part of the Demänovská dolina valley have not been thoroughly investigated yet. Therefore, in this part also drilling of 3 boreholes and following hydrodynamic tests was performed and subsequent groundwater level gauging was set here. Discharge gauging started since the beginning of November 2009 on 5 profiles of the Demänovka River (Fig. 3) or its tributaries on the ground surface, and long-term monitoring of discharges in its underground part was set up in the same time. Continuous discharge measurements on these gauging objects were supplemented by denser network of current meter measurements in seven different climatic periods. These were performed mainly in these parts of water courses, where the existence of active river sinks was proven. To identify directions of groundwater flow, hidden karstic flow connection and possible interaction between low mineralized surface water and groundwater with 3-4 times higher TDS content, 12 tracer tests using a biological tracer were realized in the whole Demänovský Cave System.

Finally, a monitoring network of so-called environmental isotopes ($\delta^{18}\text{O}$; $\delta^2\text{H}$ and tritium) counting 32 sampling places for regular observation (in 2-months interval) of in water was established. This type of analysis-in contrast to the relatively large number of classical analyzes, providing the basic physicochemical parameters of water-in Demänovská dolina valley has not been realized.

Isotope sampling

Taking into account existing knowledge of hydrogeological settings of the area, different sources of water for sampling were selected on the surface and in the underground. Sampling of precipitation water was performed on three different altitudinal levels (#30 Chopok-2,020 m, #31 Luková-1,650 m, #32 Jasná-1,150 m a.s.l.; Fig.3).

Major surface stream in the area, Demänovka River was sampled at several locations: #1- Demänovka above the area of Lúčky; #2 - Demänovka above the main swallow hole; #3 - Demänovka above the Zadná voda tributary; #4 - Zadná voda above the swallow holes (Kožiarok); #5 - Radový potok stream; #6 - Demänovka above the spring of Vyvieračka; #25 -Priečny potok stream above the swallow holes (see Fig.4). In addition to these, smaller autochthonous surface water streams (formed in the side valleys of the main karstic canyon of the Demänovská dolina valley) were also sampled: #8 - Machnatá dolina valley tributary; #9 - Pustá dolina valley tributary; #10 - Vyvieranie dolina valley tributary; #18 -Okno dolina valley tributary.

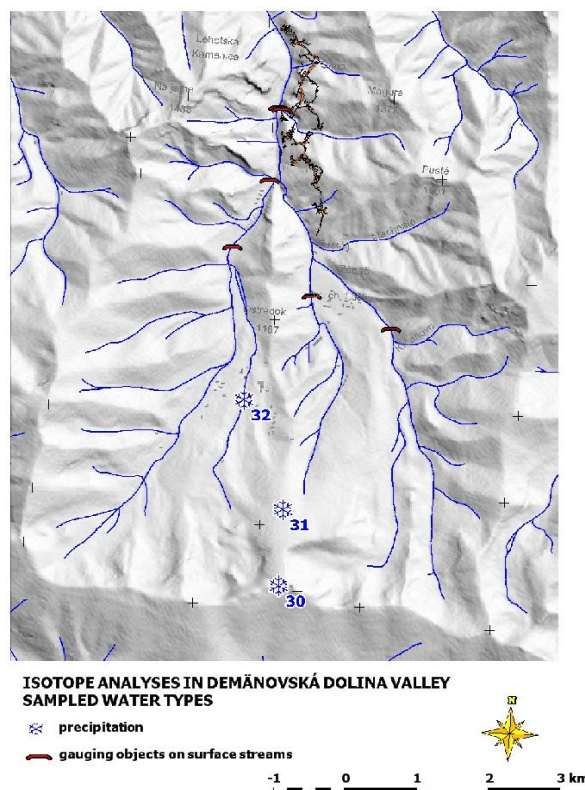


Fig3. Position of river gauging objects on the ground surface and precipitation sampling points in the Demänovská dolina Valley–Demänovský Cave System surroundings

Two different types of groundwater sources were sampled: #7- major spring of Vyvieranie (massive karst water stemming point) and #13- smaller spring under the dolina Okno valley as natural groundwater outlets, while sampling points #28 - Vrt 1 (borehole No.1) and #29 - Vrt 3 (borehole No.2) in the area of Lúčky represented groundwater found in aforementioned boreholes.

As autochthonous seepage waters, presumably with the slowest circulation through the fissures, sampling points #11-chrlič (spout) No.1 in the Janáčkov dome; #12 - chrlič (spout) No.2 in the Mramorové riečisko (“Marble watercourse”); #26 - Demänovská jaskyňa Mieru/Cave of Peace-jama; and #27-Demänovská jaskyňa Mieru/Cave of Peace-seepages were sampled. In addition to these, sampling point #23 - Veľké jazero “Těsnohlídka”/Great Lake of “Těsnohlídka” was devoted to accumulated water within the cave, not visibly connected to any water flow in the system.

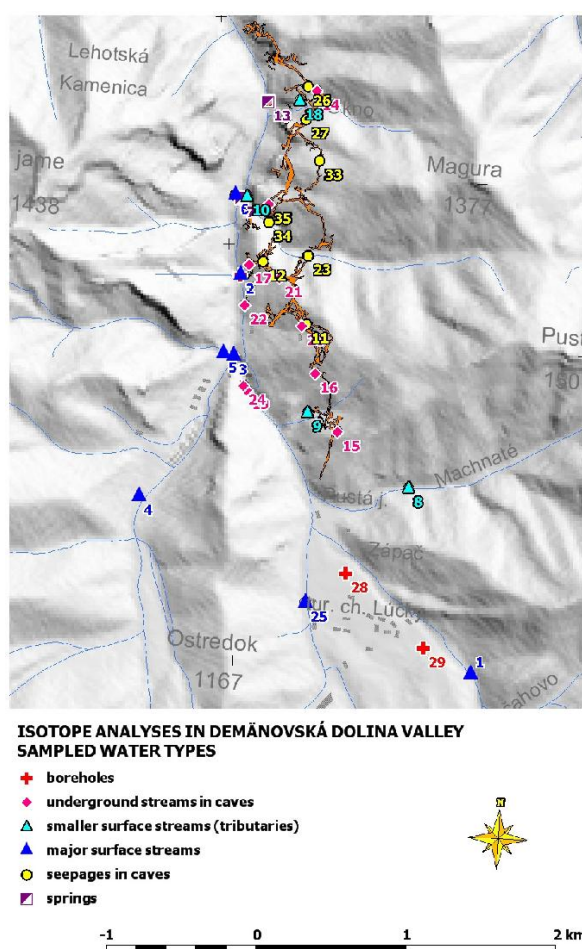


Fig4. Position surface water and groundwater sampling points (for $\delta^{18}\text{O}$ and $\delta^2\text{H}$ analyses) in the Demänovská dolina Valley – Demänovský Cave System surroundings (detail)

Karstic underground streams, directly communicating with surface waters were sampled in several caves, sometimes also speleologically not connected to the main Demänovský Cave System. In the Demänovská jaskyňa Slobody/Cave of Liberty sampling points #16 - Pekelný dóm (“Dome of Hell”); #21 - Podzemné prepádanie (“Underground slumping”) and #17 - Mramorové riečisko (“Marble watercourse”)- underground stream between the 6th and 7th siphon were placed on the underground branch of the Demänovka River, and point #20 was the its left-side tributary from Medvedia jaskyňa Cave (“Demänovská Bear Cave”). Sampling point #15 - Achátový dóm (“Dome of Agates”) in the Pustá jaskyňa Cave was established on the uppermost part of the know underground stream, while sampling point #14- underground stream in the rear part of the Demänovská jaskyňa Mieru/Cave of Peace was placed on its lowermost part. Proven connection to the Údolná jaskyňa Cave was sampled as point #22. Two sampling points were set in the Štefanová Cave: #19 - Štefanová “old parts” and #24 - Štefanová - outflow siphon, with not yet existing speleologically proven connection to the main Demänovský Cave System.

In total, 32 sampling sites were established (see Figs.3 and Fig.4), from which we now can describe results from three campaigns of samplings. Regular sampling in 2-months interval in seven campaigns was planned for the whole project duration. From the first three campaigns, reported here, sampling within campaign 1 took place during December 4-5, 2010, campaign 2 during February 2-4, 2011 and campaign 3 during April 4-6, 2011.

The specific electric conductivity (EC; in $\mu\text{S}/\text{cm}$) and temperature ($^{\circ}\text{C}$) of sampled water were measured in sampled sources, at a depth of 0.1 m using a portable WTW (LF 323 and Cond 315i) and HANNA (HI 98311/2) conductivity meters with respective probes.

Precipitation water was cumulatively collected every month, following the guidelines of the Isotope Hydrology Laboratory, International

Atomic Energy Agency (IAEA 2002). On the respective day of each month, all the amount of the precipitation collected was transferred into a glass bottle, tightly capped and sent directly to the laboratory for analysis of its isotopic composition.

Water samples for the stable isotopes analysis were collected into glass bottles of 100ml capacity, at a depth of 0.1 m bellow water level, if possible. Bottles were fully filled and air bubbles inside eliminated before capping. All collected samples were processed in special laboratories, isotopic composition of oxygen and hydrogen in Laboratories of Isotope Geology of Štátny geologický ústav Dionýza Štúra - Geological Survey of Slovak Republic.

Upon the arrival into the laboratory, 200 μl for $\delta^2\text{H}$ and 500 μl for $\delta^{18}\text{O}$ measurements were pipetted into vials of 12 ml capacity for triplicate stable isotope analysis per sample. For stable isotope analyses, the Gas Bench II device connected to the Continuous Flow Isotope Ratio Mass Spectrometer (CF-IRMS) Delta V Advantage from Thermo Fisher was used. This periphery is the system with the special Valco loop used for repetitive injection of gases and allowed $\delta^2\text{H}$ and $\delta^{18}\text{O}$ measurements based on the equilibration method, where about mill mole amount of equilibration gas (0.5% CO_2 in H_e for oxygen and 2% H_2 in H_e for hydrogen analysis) is brought into isotopic equilibration with a few μl of water sample. The minimal equilibration time for $\delta^{18}\text{O}$ measurements was 20 hours and in the case of $\delta^2\text{H}$ measurements, platinum catalysts were used for acceleration the equilibration time. The conversion of investigated compound into simple gases is the principle of isotope ratio mass spectrometry.

The results of deuterium and oxygen-18 analyses were expressed by standard delta notation in ‰ as the ratio of the deuterium and oxygen-18 abundance in water samples and in the reference gas. Calibration was performed against the internal and LGR standards and the results are reported relative to the Vienna Standard Mean Ocean Water (VSMOW). The precision of the deuterium and oxygen-18 analysis was in the range $\pm 0.8\text{‰}$ and $\pm 0.08\text{‰}$, respectively.

Table1 Waters of Demänovský Cave System – results of oxygen-18 analysis

Sampling point No.	$\delta^{18}\text{O}$ [‰ VSMOW]		
	Campaign 1	Campaign 2	Campaign 3
1	-11.25	-11.23	-11.72
2	-11.21	-11.38	-11.54
3	-11.11	-11.07	-11.54
4	-11.37	-11.31	-11.48
5	-10.98	-11.16	-11.08
6	-11.10	-10.99	-11.40
7	-10.93	-11.16	-11.27
8	—*	—*	-11.45
9	-10.86	-10.80	-10.99
10	-10.82	-10.91	-10.92
11	-9.63	-10.07	-10.06
12	-9.57	-9.39	-9.70
13	-10.57	-10.62	-11.01
14	-10.58	-10.25	-10.61
15	-10.73	-10.77	-11.08
16	-10.78	-11.06	-11.24
17	-10.93	-11.04	-11.28
18	-10.62	—*	-10.56
19	-10.41	-10.50	-10.46
20	-10.47	-10.73	-10.86
21	-10.75	-11.00	-11.15
22	-11.19	-11.34	-11.46
23	-10.07	-10.22	-10.12
24	-10.71	-11.21	-11.25
25	-10.83	-10.85	-11.04
26	-10.41	-10.43	0.00
27	-9.60	-9.76	-9.66
28	-10.64	-10.79	-10.92
29	-10.58	-10.83	-10.83
30	-14.74	-13.06	-12.81
31	-12.91	-13.09	-16.81
32	-16.82	-12.66	-12.91

* not sampled

Table2 Waters of Demänovský Cave System – results of deuterium analysis

Sampling point No.	$\delta^2\text{H}$ [‰ VSMOW]		
	Campaign 1	Campaign 2	Campaign 3
1			
2	-75.4	-76.9	-77.9
3	-74.8	-75.3	-77.2
4	-76.0	-76.8	-77.8
5	-75.4	-75.6	-78.3
6	-75.7	-74.3	-77.7
7	-74.9	-74.3	-76.7
8	—*	—*	-78.0
9	-74.4	-74.6	-74.3
10	-73.2	-74.4	-74.1
11	-67.6	-70.5	-68.1
12	-65.5	-65.3	-65.7
13	-71.7	-72.1	-73.4
14	-71.6	-69.9	-71.9
15	-72.7	-72.7	-75.1
16	-72.8	-74.7	-75.2
17	-74.8	-74.5	-76.6
18	-71.5	—*	-72.2
19	-70.3	-72.5	-71.2
20	-71.2	-73.7	-74.4
21	-73.3	-74.4	-74.9
22	-75.7	-76.1	-78.8
23	-68.1	-69.9	-71.0
24	-73.2	-75.6	-77.1
25	-74.9	-73.4	-75.9
26	-71.6	-71.2	0.0
27	-65.0	-66.3	-66.1
28	-74.4	-73.9	-73.8
29	-72.7	-75.4	-75.5
30	-103.7	-91.3	-92.8
31	-92.1	-92.7	-121.3
32	-121.6	-91.1	-91.2

*not sampled

Results

The results of measurements - isotopic composition of oxygen and hydrogen - are documented in Tables1 and Table2 and plotted on Fig.5 and Fig.6. Data here are presented for the sampling points described in Chapter 2 for three sampling campaigns in the period Dec. 13, 2010-April 6, 2011 (see also Chapter 2 for specification of individual campaigns).

Initial results of $\delta^{18}\text{O}$ and $\delta^2\text{H}$ monitoring in water, including precipitation waters, waters in the surface streams, waters of the underground hydrological system, groundwater as well as the dripping seepage waters of the cave system show some similarities, but also differences within the analyzed water types. Altitudinal extent of the area, ranging from 800 m a.s.l. (lowermost cave entrance) to 2,024 m a.s.l. (Chopok Mt. on the top of the crystalline range) enables us to count with altitudinal effect on $\delta^{18}\text{O}$ and $\delta^2\text{H}$ distribution in waters of different altitudinal genesis and circulation history. As for of Slovakia, Malík et al. (1993) reported some 100 m altitude change with 0.1 ‰ of $\delta^{18}\text{O}$ difference for karst springs in the Veľká Fatra Mts. And Malík & Michalko (2010) -0.15 ‰ of $\delta^{18}\text{O}$ values with each 100 m of altitude in Brezovské Karpaty Mts.

For precipitation, a high variability of isotopic composition was confirmed, from quite depleted up to more enriched waters ($\delta^{18}\text{O}$ from -16.8‰ up to -5.7‰; $\delta^2\text{H}$ from -121.6‰ to -32.7‰). During the recharge process and groundwater/surface water formation, precipitation water is homogenized, what is reflected in much more stable isotope content. This is clearly demonstrated on Fig.5, where all the other samples are plotted with much narrower interval.

The most depleted ($\delta^{18}\text{O} \approx -11.7\text{‰}$ to -10.8‰ ; $\delta^2\text{H} \approx -78.9\text{‰}$ to -73.4‰) were the waters of surface streams, running from the northern slopes of the Nízke Tatry Mts., formed by crystalline rocks, allochthonous to the underground hydrological system-streams of Demänovka, Zadná voda, Priečny potok (sampling points #1 to #6 and #25).

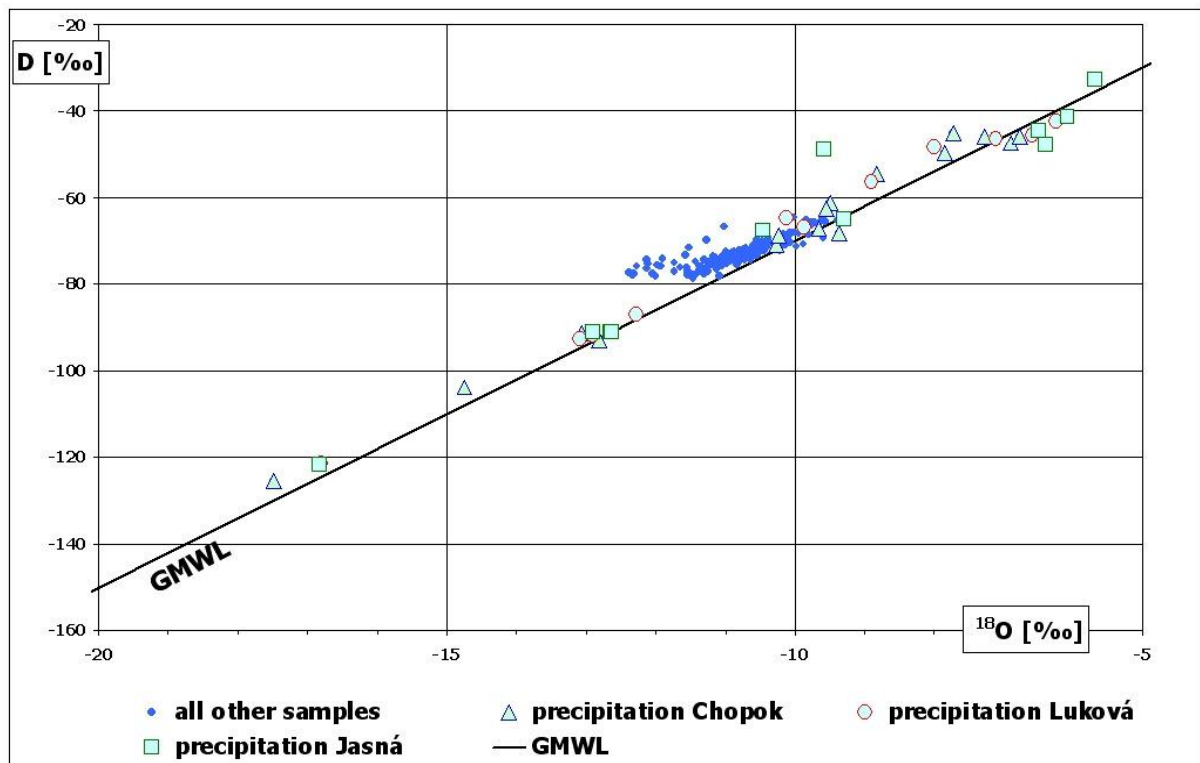


Fig.5 Results of $\delta^{18}\text{O}$ and $\delta^2\text{H}$ monitoring of precipitation waters (stations Chopok, Luková and Jasná) adjacent to the Demänovský Cave System, plotted together with Global Meteoric Water Line (GMWL) together with Global Meteoric Water Line (GMWL)

Smaller autochthonous surface water streams (formed in the side valleys of the main karstic canyon, sampling points #8-Machnatá dolina valley tributary; #9-Pustá dolina valley tributary; #10-Vyvieranie dolina valley tributary; #18-Okno dolina valley tributary) are isotopically slightly enriched (heavier, as $\delta^{18}\text{O} \approx -11.4\text{‰}$ to -10.6‰ ; $\delta^2\text{H} \approx -78.3\text{‰}$ to -71.5‰), what reflects lower altitudes of their watersheds.

Interesting is the distribution of the isotope content of the underground streams in the cave system. The most depleted are the underground streams directly (visibly) communicating with surface waters of Demänovka River and Zadná voda stream ($\delta^{18}\text{O} \approx -11.33 \pm 0.13\text{‰}$; $\delta^2\text{H} \approx -76.88 \pm 1.68\text{‰}$), such as underground stream in the Údolná jaskyňa Cave (#22) and outflow siphon of

the Štefanová cave (#24).

Extent of the relationship of underground streams to the autochthonous seepage waters (slow circulation through the fissures) is manifested by respective portion of isotopically enriched waters-as the underground streams show different isotope composition. As an example serves here sampling point #19 in “old parts” of the Štefanová Cave.

The combination of the allochthonous water components (from surface streams reaching the karstic area from the adjacent crystalline via swallow holes) and autochthonous water components (recharged directly in karstified limestones) is visible especially on the subsurface stream of Demänovka in sampling points #15, #16, #17, #20 and #21.

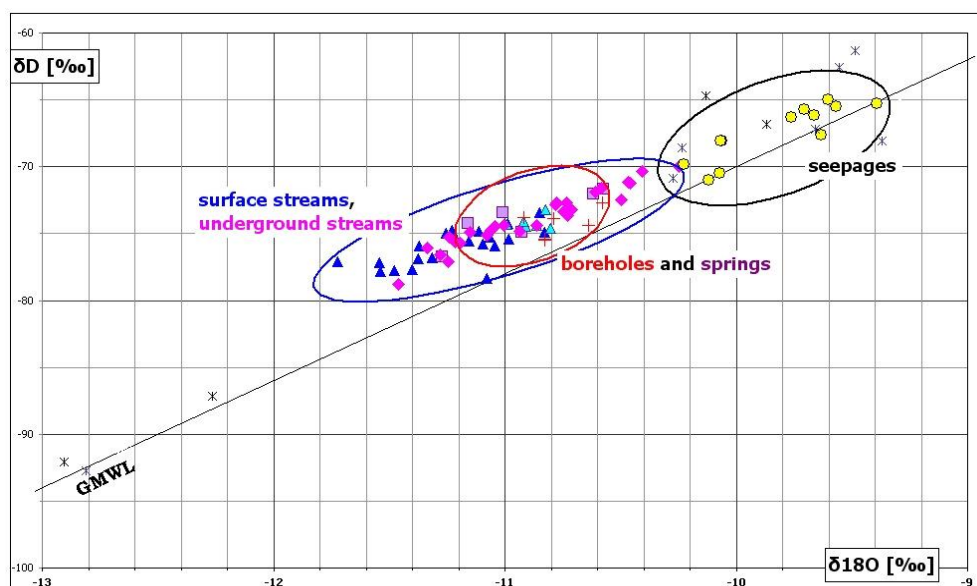


Fig.6 Results of $\delta^{18}\text{O}$ and $\delta^2\text{H}$ monitoring of different waters sources in the Demänovský Cave System, plotted together with Global Meteoric Water Line (GMWL)

Groundwater sources-sampling points #7, #13, #28 and #29 - both in springs and boreholes in the Lúčky area, seem to be more homogeneous in $\delta^{18}\text{O}$ and $\delta^2\text{H}$ composition than surface waters and underground streams in caves (Fig.6; $\delta^{18}\text{O} \approx -11.1\text{‰}$ to -10.7‰ ; $\delta^2\text{H} \approx -74.6\text{‰}$ to -72.4‰). Still, a relatively big difference of about 1.0‰ in $\delta^{18}\text{O}$ values and about 7.0‰ in $\delta^2\text{H}$ values exists between groundwater in found in natural outlets such as #7 - major spring of Vyvieranie and #13-smaller spring under the dolina Okno valley, and also in boreholes - sampling points #28 - Vrt 1 (borehole No. 1) and #29 - Vrt 3 (borehole No. 2). This means that seepages found in the caves show substantially different circulation history than other groundwater sources in the area around.

The most isotopically enriched (heaviest) of all water types are dripping seepage waters ($\delta^{18}\text{O} \approx -10.4\text{‰}$ to -9.4‰ ; $\delta^2\text{H} \approx -71.6\text{‰}$ to -65.0‰ , see Fig.6).

We hope the complete results will allow us a better estimate of yet unknown origin of water in some parts of the cave system (e.g. water in the hole in the Demänovská jaskyňa Mieru/Cave of Peace-sampling point #26, spring under the dolina Okno valley-sampling point #23 etc.).

Acknowledgments

The monitoring of the isotopic composition of water in the Demänovská dolina valley could be

performed within the implementation of the project "Improving the care of the Ramsar site-caves in the Demänovská dolina Valley", proposed by the Slovak Caves Administration to the call of the Operational Program Environment (call number OPZP-PO5-09-1) for the program period of 2007-2013, co-financed by the European Fund of Regional Development and Ministry of Environment of Slovak Republic. All aforementioned institutions are deeply acknowledged.

References

- Biely, A. (ed.), Beňuška, P., Bezák, V., Bujnovský, A., Halouzka, R., Ivanička, J., Kohút, M., Klinec, A., Lukáčik, E., Maglay, J., Miko, O., Pulec, M., Putiš, M. & Vozár, J., 1992: Geologická mapa Nízkych Tatier 1:50 000, GÚDŠ, Bratislava, map sheet
- Biely, A. & Bezák, V. (eds.), Bujnovský, A., Vozárová, A., Klinec, A., Miko, O., Halouzka, R., Vozár, J., Beňuška, P., Hanzel, V., Kubeš, P., Liščák, P., Lukáčik, E., Maglay, J., Molák, B., Pulec, M., Putiš, M. & Slavkay, M., 1997: Vysvetlivky ku geologickej mape Nízkych Tatier 1: 50 000. GÚDŠ, Bratislava, pp. 232
- Haviarová, D., Malík, P., Grolmusová, Z., Veis, P., Michalko, J. 2011: Predbežné výsledky monitorovania izotopového zloženia vôd v Demänovskej doline a jej podzemnom hydrologickom systéme. Aragonit 16/1-2 2011,

- p. 69-70
- IAEA 2002: Water and Environment Newsletter of the Isotope Hydrology Section, International Atomic Energy Agency. Issue No.16, November 2002, p. 5
- Malík, P., Michalko, J. & Rapant, S. 1993: Štruktúrohydrogeologická analýza karbonátov triasu križňanského prikrovu vo Veľkej Fatre. Manuscript-Archive of the Geofond Branch, State Geological Institute of Dionýz Štúr, Bratislava, Arch. No. 79413, pp. 277
- Malík, P. & Michalko, J. 2010: Oxygen Isotopes in Different Recession Subregimes of Karst Springs in the Brezovské Karpaty Mts. (Slovakia). Acta Carsologica 39/2, Postojna 2010, 271–287