# SOIL EFFECT ON KARST PROCESSES

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## PROCEEDINGS

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# Stable isotope study on karst water in the Béke Doline, Aggtelek Karst, Hungary

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## Abstract

Details of the karstic infiltration processes are revealed by stable isotope study of water samples taken continuously from the karst-corrosion monitoring system installed in the catchment area of the Béke Cave in the Aggtelek Karst, Hungary. Different systems of infiltration paths developed in the loose-structure sediment-filling of the dissolution doline above the Béke Cave is inferred from the $\delta^{18}O$ data: vertical, horizontal and on-slope infiltration. The infiltrating water of winter-spring precipitation mixes with the infiltrating water of other seasons in varying ratio resulting in mixing corrosion. In the cave at the level of karstic water table at least two components of the infiltrating water can be distinguished based on the $\delta^{18}O$ data: fast infiltrations through the wider fissures are superimposed on a slow basic-infiltration through the narrow fissures and capillaries.

## Introduction

The stable oxygen isotopes are very good natural tracers for tracing the path of the infiltrating water and for resolving the mixing processes. The element oxygen has three natural stable isotopes with different abundancies:

$^{16}O$: 99.762%
$^{17}O$: 0.038%
$^{18}O$: 0.200%

Because the abundance of the $^{17}O$ isotope is very low, and technically it is difficult to measure, the $^{18}O/^{16}O$ ratio is measured and used for hydrological applications. The isotope composition is expressed in a special way, by the delta notation as follows:

$$\delta^{18}O = \frac{(^{18}O/^{16}O)_{sample} - (^{18}O/^{16}O)_{standard}}{(^{18}O/^{16}O)_{standard}} * 1000 \text{ [‰]}$$

Since the international standard for water is the VSMOW (Vienna Standard Mean Ocean Water) and the ocean water is the richest water in $^{18}O$ on the Earth surface (not regarding few lakes), the above $\delta^{18}O$ value is usually negative.

## *Characteristic oxygen isotope composition of waters in Hungary*

There is an indirect relation between the monthly mean air temperature (near the Earth surface) and the stable isotope composition (δD, δ18O) of the precipitation (see e.g. Clark & Fritz, pp. 64-65). Increasing temperature comes together with increasing δD and δ18O values, with other words: wintertime the δD and δ18O values are more negative than summertime. In the Carpathian Basin J. Deák (Deák 1995) studied this relationship on precipitation samples collected at Abádszalók (Great Hungarian Plain, Hungary) between the years 1977-1988. A part of his results is shown on the Figure 1 (δ18O-T relationship). This relationship a little bit varies by different areas, but that on Figure one can be regarded as characteristic for the territory of Hungary. Figure 2 shows the characteristic variation of δ18O value of precipitation at Budapest for the period of 1997-2000. J. Deák (Deák 1995) determined the multi-annual mean δ18O value of the precipitation in Hungary and he got -9.1 [‰]VSMOW. The mean δ18O value of the recently infiltrated water is -9.3‰ ± 0.4‰ (Deák et al. 1996). Latter value is a little bit more negative than the previous one, because the summer precipitation (characterized with less negative δ18O values) does not infiltrate at many places.

Many of the deeper groundwater in the Carpathian Basin was infiltrated during the last glaciation (Ice Age), which ended about 10 000 years ago. The δ18O value of these groundwaters varies between -11‰ and -14‰ (Deák et al 1996 and author's data).

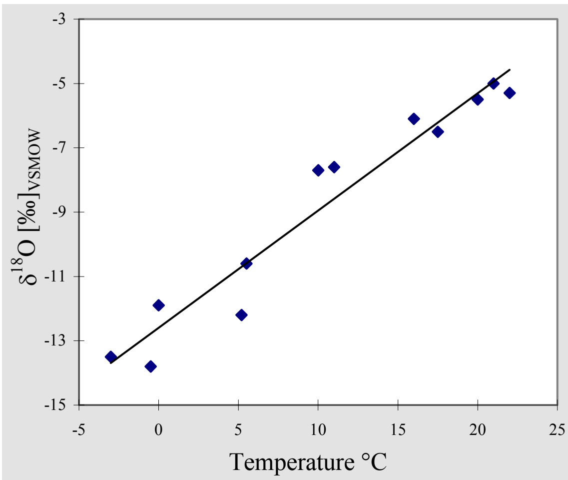


*Fig. 1 The linear relationship between the average monthly air temperature and the average monthly $\delta^{18}O$ value of the precipitation collected at the Abádszalók Meteorological Station (Hungary) between the years 1977 and 1988 (Deák 1995).*

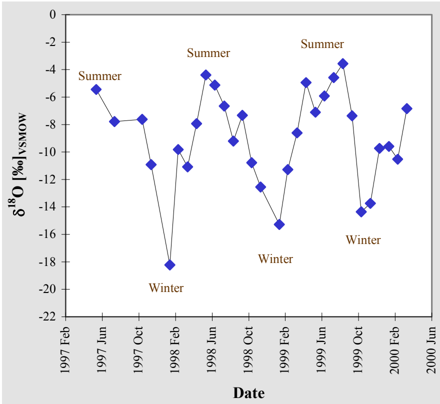


***Fig. 2*** *The $\delta^{18}O$ value of the precipitation collected by Süveges, M. (Water Resources Research Centre, Plc.).*

## *Samples and analytics*

Samples were continuously collected by the karst-corrosion monitoring system (Fig. 3) from the following points:

- AK-1: at 0.5 m depth in the centre of the sediment-filling of the corrosion doline;
- AK-2: at 2.5 m depth in the centre of the sediment-filling of the corrosion doline;
- AK-3: at 6 m depth in the centre of the sediment-filling of the corrosion doline;
- AK-4: at 9 m depth in the centre of the sediment-filling of the corrosion doline;
- AK-5: at 0.5 m depth on the in the rim of the sediment-filling of the corrosion doline;
- AK-6: a karren-like rock;
- AK-10: precipitation collector;
- AK-11, -12, -13, -14: drip water collecting points in the Béke Cave.

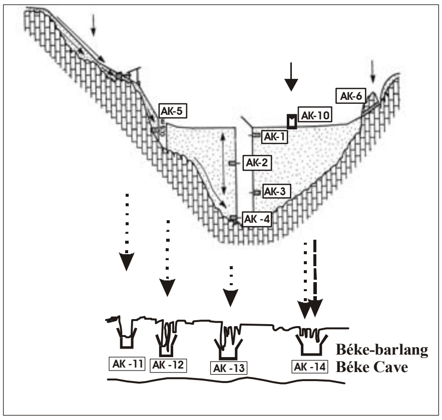


***Fig. 3*** *Sketch map of the sample collecting points of the karst corrosion monitoring system of the Béke Doline and Béke Cave.*

One hundred millilitre water from each samples collected during the period of 1998-2000 were carried to the Laboratory for Geochemical Research of the Hungarian Academy of Sciences (Budapest), where their stable oxygen isotope composition was determined by a Finnigan MAT delta S mass spectrometer equipped with a water-$CO_2$ equilibration device described by Roether (1970). The uncertainty of the results is ±0.15‰.

## *Results and interpretation of the isotope data*

### *Precipitation*

The stable oxygen isotope composition of the precipitation (AK-10) is shown on the Figure 4. The variation pattern is the usual; the seasonal variation is obvious; the most negative $\delta^{18}O$ values occur in wintertime, while the least negative ones in summertime. The $\delta^{18}O$ values range between -3‰ and -20‰. The average $\delta^{18}O$ value for the period of 1998-2000 is -9.29‰, which is practically identical with that of the above mentioned multi-annual mean of the precipitation in Hungary.

There is a short time series for the water dripping down (AK-6) from a karren-like rock covered by moss on about 50% surface area. Its $\delta^{18}O$ value is rather close to that of the precipitation (Fig. 4) as it was expected.

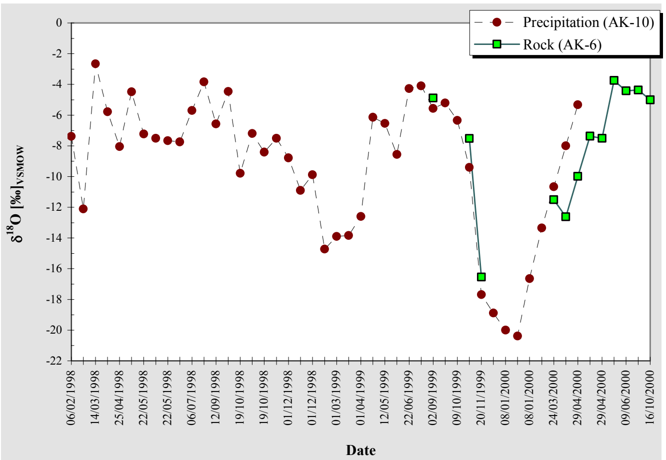


*Fig. 4 The $\delta^{18}O$ time series of the precipitation (AK-10) and the dripping water (AK-6) from a karren-like rock in the Béke Doline.*

### *Soil horizon of the sediment-filling of the dissolution doline*

In the soil horizon of the sediment-filling of the dissolution doline samples were taken from two, morphologically different places; AK-1 is at the centre of doline, AK-5 is at the rim of doline. The $\delta^{18}O$ values of the infiltrating water collected at these two places are shown on the Figure 5. We can see that the range in which the $\delta^{18}O$ value varies is narrower than in the case of the precipitation. Precipitation: $\delta^{18}O$ varies between -3‰ and -20‰; soil horizon: $\delta^{18}O$ varies between -5‰ and -15‰. This smaller range is a result of dispersion and mixing processes. The infiltrating water mixes with the water film on the surface of grains or on the wall of the pores. The latter water film always is a remnant from the infiltration from the previous precipitation. The $\delta^{18}O$ time series curve of the precipitation (Fig. 4) can be regarded as an input function, and in the soil horizon this function is modified by the mixing processes (Fig. 5). The 'positive' peak of the summer of 1999 and the 'negative' peak of the winter of 1999/2000 on the Fig. 4 can be identified on the Fig. 5 as well, but with different shapes and amplitudes.

Comparing the AK-5 curve to the AK-1 curve on the Figure 5, we can notice that the two curves go together, and the $\delta^{18}O$ values on the curve of doline-centre (AK-1) many times more negative than those on the curve of doline-rim (AK-5). The reason for this difference is most probably comes from the difference in the source of water at the two points. At the centre of the doline water originates only from the precipitation fallen to the surface of the sediment-filling, while at the rim of the doline water flowing down on the rock surface contributes as well. This latter water can be affected by evaporation, which process can shift the $\delta^{18}O$ value to the 'positive' direction.

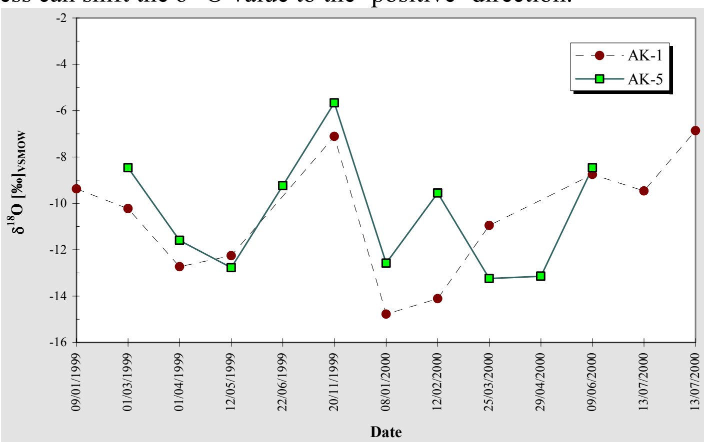


*Figure 5 The $\delta^{18}O$ time series of the infiltrating water collected in the soil horizon of the sediment-filling of the dissolution doline (AK-1: centre of doline, AK-5: rim of doline).*

## *Sediment-filling of the dissolution doline*

Comparing the $\delta^{18}O$ values of the seeping water at different depth we can see some characteristics (Figure 6). In the deeper horizon (from AK-2 at 2.5m down to AK-4 at 9m) the variation of the $\delta^{18}O$ value is rather small (~3‰) relative to the 17‰ of the precipitation, or to the 8‰ in the soil horizon. This small variation is a result of the above-mentioned mixing processes, where the infiltrating water from the newly fallen precipitation mixes to the water from the previous precipitation remained in the capillaries or on the surface of the grains. Of course the flowing velocity depends on the rate of precipitation; it is smaller in the dry season and it is higher in the wet season.

The mean $\delta^{18}O$ values of the infiltrating water at the deeper zones (AK-2: -8.98‰, AK-3: -9.11‰, AK-4: -8.56‰) are more positive than the mean $\delta^{18}O$ value of the precipitation (-9.23‰) or the infiltrating water in the soil horizon (AK-1: -10.60‰, AK-5:

-10.47‰). Although stable hydrogen isotope measurements have not been carried out to prove the idea, but we suppose that evaporation affected the evolution of the infiltrating water. Water leaving by evaporation is depleted in heavy stable isotopes (in $^{18}O$), so the remaining water is enriched in $^{18}O$, its $\delta^{18}O$ value become less negative, as in the case of the deeper zones.

The variation of the AK-2, AK-3, AK-4 curves are more or less parallel, but there are important differences (Figure 6). The year 1999 was an exceptionally rainy year. The $\delta^{18}O$ value of this summer rain was between -4‰ and -8‰ (Figure 4). Water infiltrated from this summer rain in 1999 is well seen on the curve of AK-1 on Figure 6, at the date 02/09/1999 the $\delta^{18}O$ value was around -7‰. There is a smaller positive shift in the $\delta^{18}O$ values of the curves AK-2 (2.5m) and AK-4 (9m) in this summer period, but the $\delta^{18}O$ value of the depth of 6m (AK-3) was almost the same from April to September in 1999. The infiltrating water from the 1999 summer precipitation did affected the seepage water at 2.5m and 9m, but did not affected it at the depth of 6m. It means that a part of the infiltrating summer water did not move vertically to the 9m depth through the layers at the 6m depth, but somehow it went round, most probably through the fissures of the limestone wall of the doline, where the fissure discharged the water into the sediment-filling at a greater than 6m depth. This is a clear indication that beside vertical infiltration water can move in horizontal direction as well.

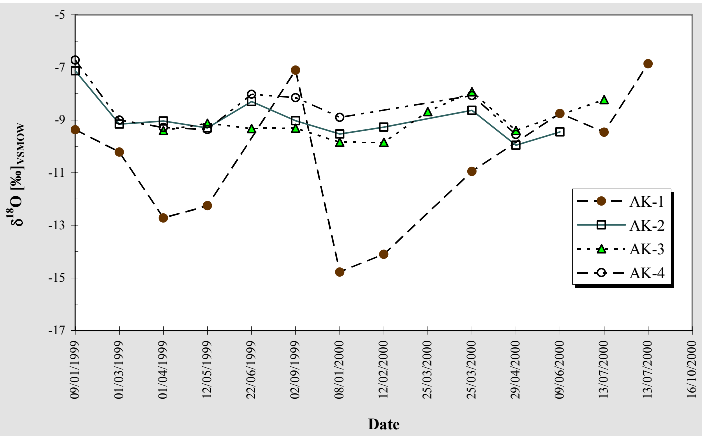


*Figure 6 The $\delta^{18}O$ time series of the infiltrating water collected at different depths in the sediment-filling of the dissolution doline (Béke Doline).*

## *The zone of karstification: drip water in the Béke Cave*

The infiltrating/seeping water of the karstification zone over the karstic water table has been studied by measuring the stable oxygen isotope composition of the drip water in the Béke Cave (Figure 7). The variation of the $\delta^{18}O$ values of the drip water at four stations is about 3‰, the same as was observed in the deeper zones of the sediment-filling of the dissolution doline, which is practically the catchment area of the drip water.

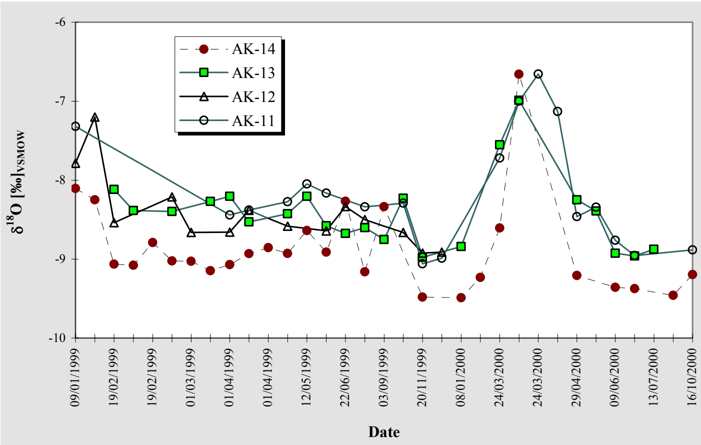


*Figure 7 The $\delta^{18}O$ time series of the drip water collected at different points of the Béke Cave.*

The mean $\delta^{18}O$ values of the drip waters at the four stations are: AK-11 -8.17, AK-12 -8.43, AK-13 -8.42, AK-14 -8.88. These values are very similar to those in the deeper zones of the sediment-filling above the Béke cave. If we disregard the data of March-April 2000, then the mean $\delta^{18}O$ values of the drip water and the seepage water in the sediment-filling are almost identical. All of these mean $\delta^{18}O$ values are less negative than that of the precipitation indicating the effect of evaporation. R.S. Harmon et al. (1983) observed the same phenomenon studying the drip water in the Castleguard Cave, Alberta, Canada. They stated (p. 514) "Drip waters from soda-straw stalactites and their associated catchment pools are slightly enriched in both D and $^{18}O$. They lie along an evaporation trend, confirming that evaporation has affected the evolution of the depositing drip and seepage waters." Although we have not measured the $\delta D$ values of the drip waters, based solely on the $\delta^{18}O$ values, we suppose the same phenomenon.

Comparing the four curves on Figure 7 we can notice that the $\delta^{18}O$ values of the AK-14 station is almost always more negative than those of the three others. The AK-14 has the highest dripping rate; here the collected amount of water is always a few times more than at the other water collecting points. Both of these observations support that this drip water is less affected by the evaporation than the others. Most probably this difference in the $\delta^{18}O$ value of water between the AK-14 and the other three points is reflected in the $\delta^{18}O$ values of the carbonates (drip-stones) as well.

During the period of March-April 2000 the $\delta^{18}O$ value of the drip water at all stations shifted to the positive direction. This indicates that a quick flow superimposed a rather slow flow. The fast flow may happen through wider fissures of the rock, while the slow base-flow happens through narrow fissures or capillaries.

## *Summary*

Details of the karstic infiltration processes are revealed by stable isotope study of water samples taken continuously from the karst-corrosion monitoring system installed in the catchment area of the Béke Cave in the Aggtelek Karst, Hungary.

We can draw conclusions about the infiltration processes of the vadose water movement of the karstic zone from the $\delta^{18}O$ values of water samples taken from the monitoring system installed into different zones of the sedimentary fillings of doline, and into the zone of descending water.

Altogether the monitoring system provided water samples and data from the total vertical profile of the karstic infiltration zone, from the surface through the corrosion and gravitation zones down to the karstic water table.

Conclusions:

- in the loose-structure sediment-filling of the dissolution doline different systems of infiltration paths developed
- in the sediment-filling from the surface down to the bottom of the doline at least 2 or eventually 3 directions of infiltration paths formed:
  - vertical infiltration
  - horizontal infiltration
  - on-slope infiltration
- mostly the infiltration of winter-spring precipitation reaches the karstic water table, but the process of infiltration is not continuous, there are some periods without seepage, when the percolating water is stored in the pores and smaller cavities. During this process the infiltrating water of winter-spring precipitation mixes with the infiltrating water of the other seasons in varying ratio resulting in mixing corrosion.
- in the cave at the level of karstic water table at least two components of the infiltrating water can be distinguished based on the $\delta^{18}O$ data: fast infiltrations through the wider fissures are superimposed on a slow basic-infiltration through the narrow fissures and capillaries.

## *Acknowledgements*

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