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Revisiting the Craig-Gordon Model Four Decades after its Formulation

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Pieter Brueghel the Elder:" The gloomy day" (1565), Detail
Courtesy of Kunsthistorisches Museum, Vienna.

Extended Abstracts

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Small isotope effect of evaporation when the rate of evaporation is very high: soil salinization on Nyírő-lapos (Hortobágy, Hungary)

István Fórizs[1], Tibor Tóth[2], László Palcsu[3], Gabriella Barna[1]

[1] Institute for Geochemical Research, Hungarian Academy of Sciences, H-1112 Budapest, Budaörsi út 45., Hungary
[2] Research Institute for Soil Science and Agricultural Chemistry, Hungarian Academy of Sciences, H-1022 Budapest, Herman O. út 15., Hungary
[3] Institute of Nuclear Research, Hungarian Academy of Sciences, H-4026 Debrecen, Bem tér 18/c, Hungary

Introduction

The classical effect of evaporation on the stable isotopic composition of surface water has been studied by many authors (one of the most detailed studies was made by Gonfiantini 1986). The evaporation in the unsaturated zone has been studied less intensely (e.g. Allison et al. 1984; Braud et al. 2005a,b) and the precipitation-infiltration-evaporation-soil salinization-groundwater system is even less studied.

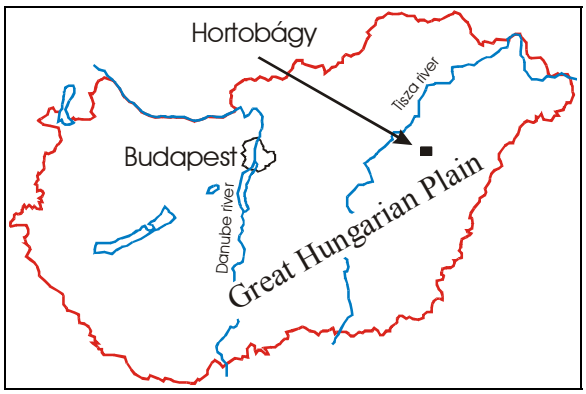

Fig. 1 The sketch map of Hungary with the indication of the studied area.

Salt accumulation in soil is usually linked with significant rate of evaporation, so the isotopic effect of evaporation on the groundwater is expected. One of the most characteristic native sodic grassland of Hungary, the Nyírő-lapos, a small area of 600x800 m^2 site on Hortobágy (Great Hungarian Plain, Fig. 1) was selected for studying the relation between the salt accumulation, evaporation and stable isotopic composition of groundwater.

Precipitation

The Great Hungarian Plain (GHP) is characterized by cca. 500 mm/a precipitation, and continental climate (warm summer, cold winter). The rate of actual evaporation is also cca.500 mm/a. Because of the low amount of yearly precipitation the isotope effect of secondary evaporation on the precipitation (evaporation during the fall of raindrops through dry air) is significant in the warm period of the year. Figure 2 shows the stable isotopic composition of the precipitation events collected nearby Debrecen (about 30 km from the study area) during the years 2001-2004. The year 2002 was dryer than the average and the year 2003 was even dryer. The long term average amount of precipitation on the GHP is 527 mm/a, and it was 492 mm in 2002, and 406 mm in 2003 at the place where the precipitation was collected. The effect of the dryness of the air on the isotopic composition of the precipitation is well manifested in the *d*-excess value (see Figure 3), since secondary evaporation decreases the *d*-excess. So average *d*-excess was significantly lower in 2002, and even lower in 2003 than in the years of 2001 and 2004. If we calculate the relationship between δD and $\delta^{18}O$ values of monthly data for the period of 2001-2004 we get: $\delta D = 7.5*\delta^{18}O - 7.4$ ‰. Deák J (1995) reported $\delta D = 7.2*\delta^{18}O + 0.1$ ‰ for precipitation collected at another part of the GHP (at Abádszalók Meteorological Station) between 1979 and 1985. Both equations show the effect of secondary evaporation (low slope and intercept). The multi-annual mean $\delta^{18}O$ value of the precipitation is -9.1‰ (Deák 1995).

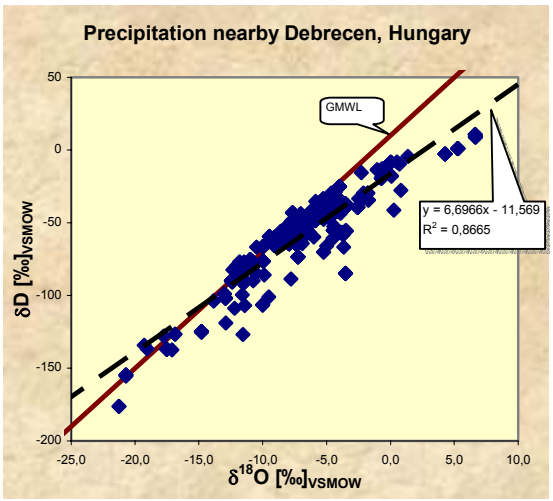

Fig. 2 Stable isotopic composition of precipitation events nearby Debrecen, Great Hungarian Plain, Hungary in the period of 2001-2004. GMWL = Global Meteoric Water Line.

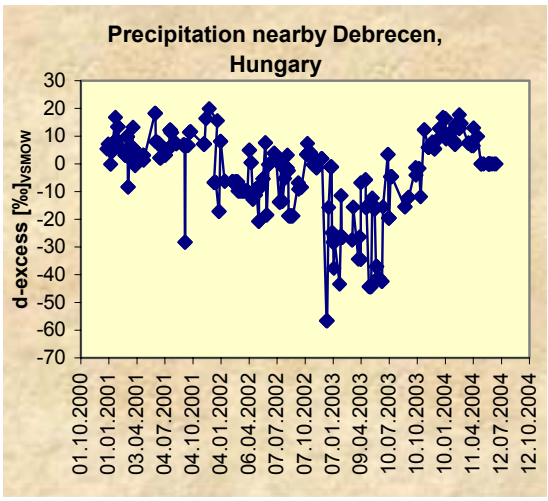

Fig. 3 The deuterium excess (*d*-excess) of precipitation events nearby Debrecen, Great Hungarian Plain, Hungary in the period of 2001-2004.

Isotope effect of evaporation on surface waters in Hungary

We have determined the isotopic water line of Lake Balaton on samples collected in the period of July-September, 2005: $\delta D = 5.20*\delta^{18}O - 13.75‰$. Since the year of 2005 was significantly more humid than the average, it is reasonable to expect a slope of <5.2 for evaporation water line of surface water on the GHP. Fórizs et al. (2005) reported data on isotopic composition of the Lake Kavicsos (Csepel Island near Budapest, samples collected in 2001). Based on these data the calculated slope is 5.04, which is similar to that above, but somewhat lower, because the year 2001 was dryer then 2005.

Soil salt accumulation on Nyírő-lapos and the effect of evaporation

Nyírő-lapos, a small area of 600x800 m^2 on Hortobágy (Hungary) is characteristic of salt accumulation. The study area is a discharge area of a regional flow system, and there is no surface drainage (no run off). So all kinds of water (rain, snow) fallen to the area evaporates sooner or later. Some of the precipitation infiltrates and mixes with the upwelling old groundwater, and summertime this mixed water moves upward by capillary effect to the upper soil layers and evaporates. The salt content of the water remains in the soil or on the surface in patches with diameter from 0.5 m to few meters resulting in salt accumulation. Usually in springtime when the snow is melted the lower parts of Nyírő-lapos (maximum difference in elevation is 2 m) is covered by water, and later on these plashes dry up forming places of surface salt accumulation. The majority of the salt accumulates in the soil horizon. The chemistry of the shallow groundwater shows very high heterogeneity (for more details see Tóth et al. 2002).

The $\delta^{18}O$ values of the ascending old groundwater nearby the studied area are between -11.5‰ and -11.8‰ in the depth range of 30-60 meters, which clearly indicates that this ascending groundwater was infiltrated during the Ice Age (Ice Age infiltrated groundwaters in Hungary are characterised by $\delta^{18}O < -11.0‰$; Deák & Coplen 1996). The significant difference between the $\delta^{18}O$ values of the ascending old groundwater and the infiltrating precipitation provides a tool for tracing the mixing processes.

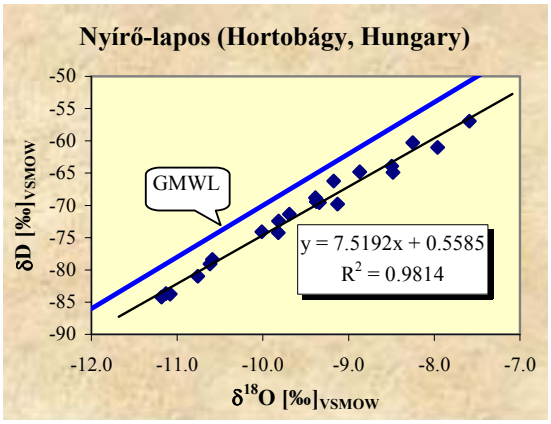

Fig. 4 Stable isotope composition of the shallow groundwater samples of Nyírő-lapos (Hortobágy, Great Hungarian Plain, Hungary) with the reference GMWL = Global Meteoric Water Line (Craig 1961).

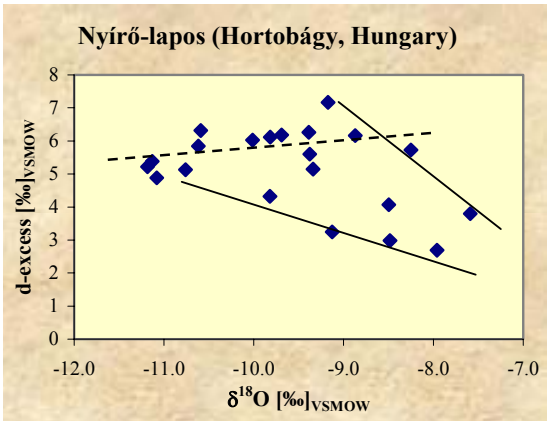

Fig. 5 Deuterium excess (*d*-excess) vs. of $\delta^{18}O$ values of the shallow groundwater samples of Nyírő-lapos (Hortobágy, Great Hungarian Plain, Hungary). Dashed line indicates mixing between the ascending old groundwater and the infiltrating modern precipitation, while solid lines indicate the mixing between the evaporation affected and non-affected end members.

The isotopic compositions of the shallow groundwater samples (3-10 m depth from the surface, collected in June, 2002) plot along a line under the GMWL with a slope of 7.5 (Figure 4). This line itself represents a mixing between the ascending old groundwater and the infiltrating precipitation. Samples with $\delta^{18}O$ > -8.9‰ are definitely isotopically enriched by evaporation, although they are along the trend line fitted to all points. The effect of evaporation is more noticeable on the *d*-excess data (Fig. 5), because evaporation decreases the *d*-excess. The *d*-excess values of groundwater not affected by evaporation are between 5 and 8‰, while those affected by evaporation possess *d*-excess < 5‰. On Figure 5 we can detect two kinds of mixing. One mixing process takes place between the ascending old groundwater and the infiltrating modern precipitation not affected by evaporation (dashed line). The other mixing takes place between any groundwater along the dashed line and the evaporation affected modern precipitation. This mixing defines not a line but a lane on Figure 5 indicated by solid lines.

Samples affected by evaporation have $\delta^{18}O$ values >-10‰ as indicated by Figure 5. If we calculate a regression line for these samples of $\delta^{18}O$ >-10‰, then we get a slope of 6.9, which is lower then the slope of the regression line fitted all the data (s=7.5) indicating the effect of evaporation, but it is higher than those slopes got for surface water evaporation (s=5.0-5.2, see the previous paragraph). Latter observation means that the isotope effect of evaporation on open surface water is significantly higher than in the case of evaporation of soil water.

Conclusions

The rate of evaporation on the study area is very high, actually more water evaporates than the amount of precipitation. Despite of this high rate of evaporation the effect of evaporation on the stable isotopic composition of the shallow groundwater is small. The reason is most probably that this area is a regional discharge area, the rate of infiltration of precipitation is low, and mixing between ascending old groundwater and infiltrating modern water is driven by diffusion. The other argument for this low isotopic effect of evaporation is that in this kind of soil (clay loam Solonetz soil) below 40-50 cm the evaporation of groundwater takes place at no isotopic fractionation (Allison et al. 1984; Gazis & Feng 2004), water moves upward mostly by capillary effect.

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