Surface denudation and weathering of gypsum in a cold humid climate and their influence on soil formation

I.A. Spiridonova & S.V. Goryachkin

Institute of Geography, Russian Academy of Sciences

What we already know:

Gypsum solubility – 2.4 g/l (*Mineralogy guide books*)

The whole dissolution of gypsum blocks within surface streams of the Pinega Region takes place in 10-15 years (*monitoring of exogenous processes by Shavrina & Malkov, 2008*)

Karst denudation of gypsum within underground streams of the Pinega Region – from 30 to 70 t/km^2 per month (*experimental study by Shavrina, 2002*)

Cold humid climate parameters: one meter-deep soil freezing, annual precipitation 650 mm, P/ET ratio 1.3 (*Pinega Meteorological Station*).

Questions to be answered:

What is the rate of dissolution of gypsum on the surface, i.e., within soils?

What is the rate of cryogenic weathering (disintegration) of gypsum within soils?

Our long-term experiment with gypsum blocks

1997: 9 gypsum blocks, 15-30 kg each, were placed in a karst landscape

4 blocks were covered with moss and 5 left exposed

1997-2010: changes in weight and surface morphology were recorded


An open gypsum block
overgrown with moss in 12 years


Litter and humic layers on gypsum (O horizon)


Gypsum weathering under the litter

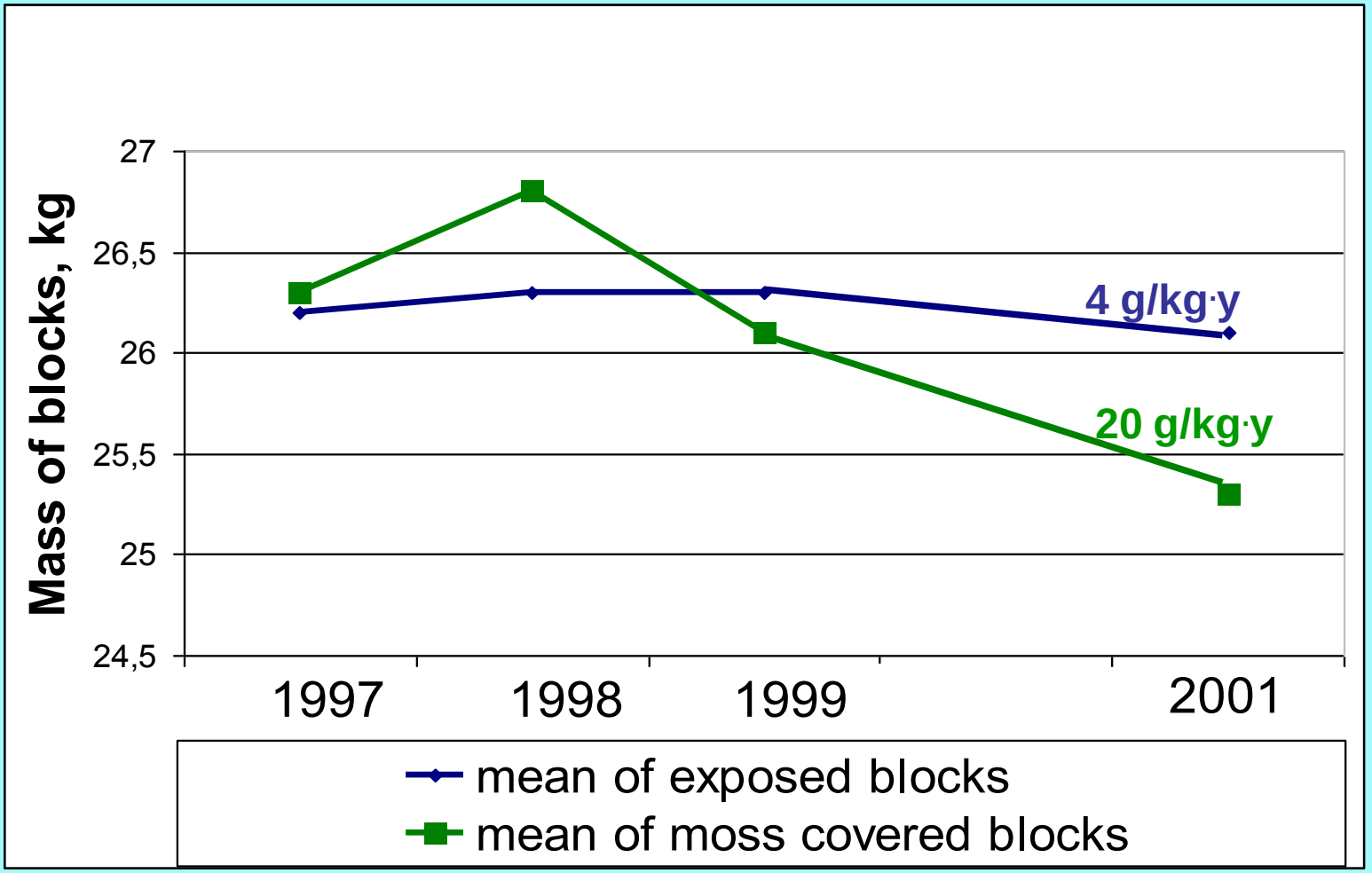
Morphology of gypsum blocks surface after 12 years of experiment

Gypsum blocks initially covered with moss layer:

Gypsum blocks initially exposed:

All acquire the similar appearance due to the soil development processes

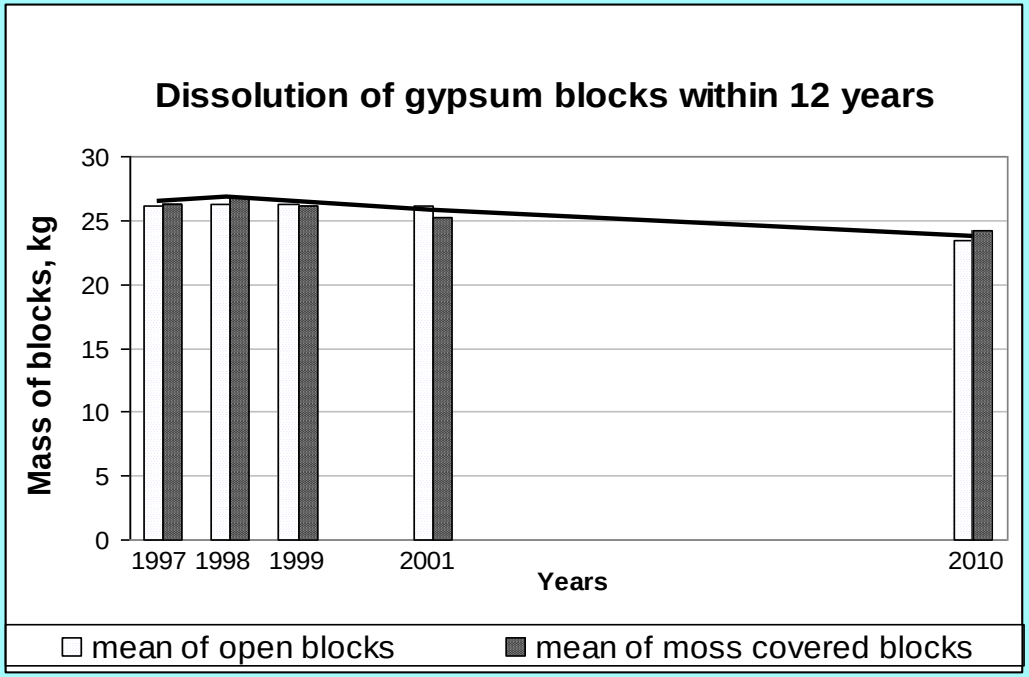
Early stages of gypsum blocks dissolution



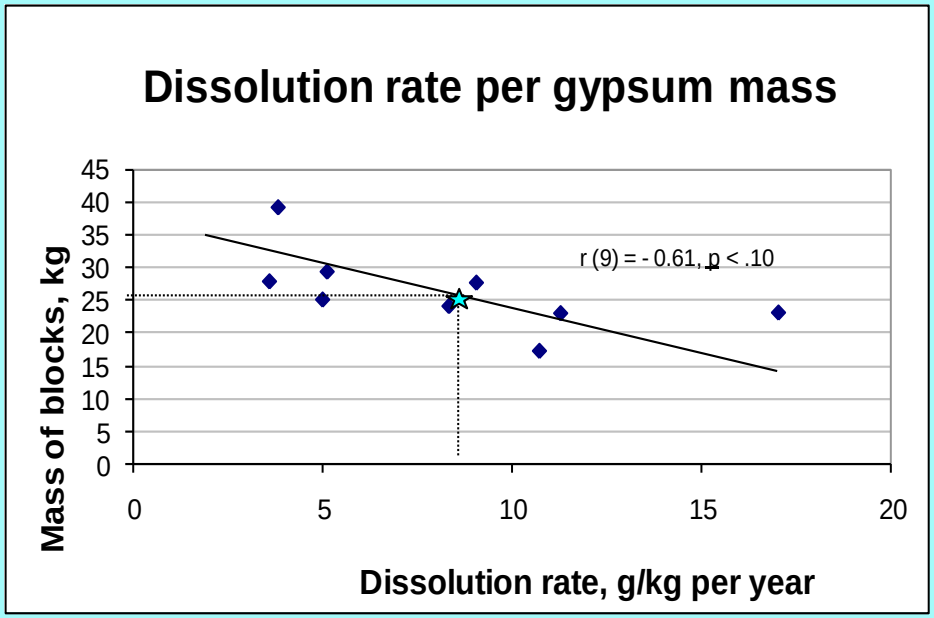
The mass INCREASED by 1% within the 1st year, especially in moss-covered blocks – due to hydration of relict anhydrite inclusions.

Moss-covered gypsum blocks dissolved faster.

Gypsum blocks dissolution within a 12 year period



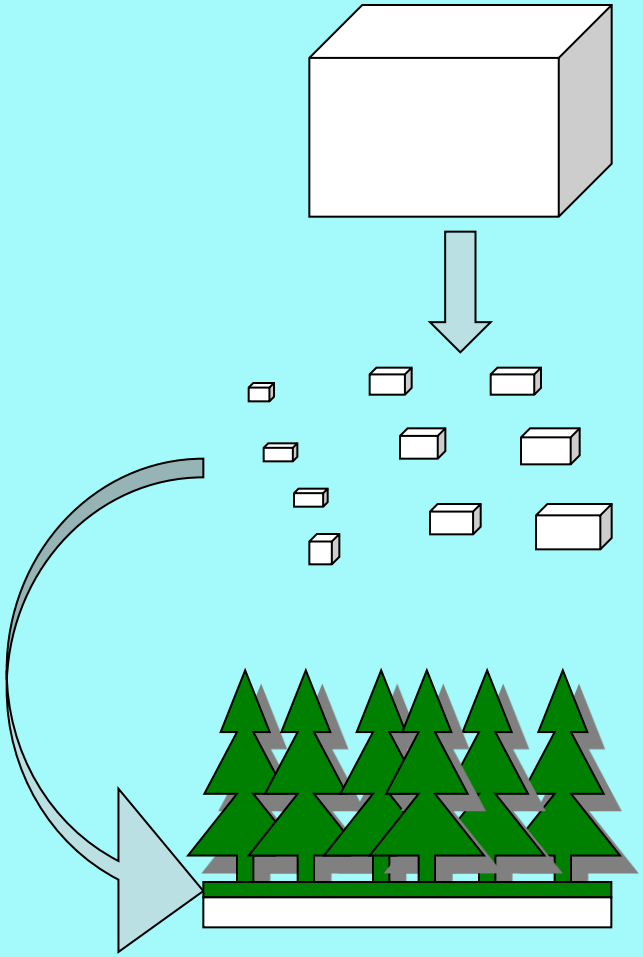
Insignificant difference between initially exposed and covered blocks



Mean dissolution rate for 9 blocks = 8 ± 4 g/kg·y
(mean mass of block = 26 kg)

Complete dissolution in 130 years i.e. **10 times slower than within a river flow** *(Shavrina & Malkov, 2008)*

Our two-year experiment with gypsum tablets (2007)



1) Selected gypsum monolith

2) cut out 10 tablets

3) measured the mass and surface area of each tablet

4) buried the tablets under the litter horizon of soil for a 2-year period

5) retrieved the tablets from soil for remeasuring

Dissolution of the gypsum tablets under the soil litter

Mean mass of gypsum tablet = 39 g,
Mean dissolution rate = **21.8 ± 18.5 g/kg·y**

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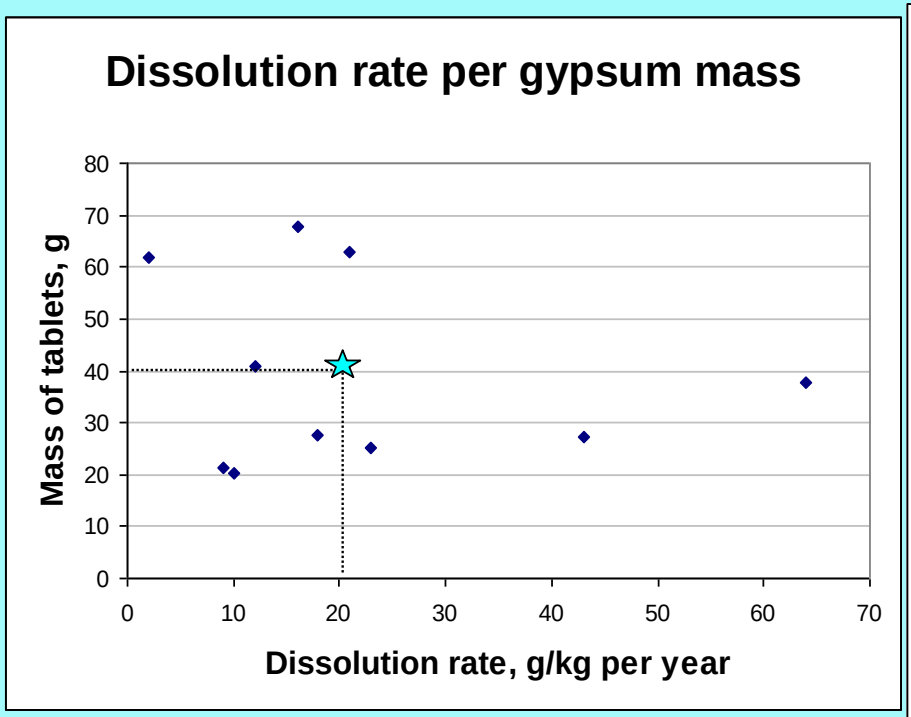

Mean surface area of gypsum tablets = 38 cm^2,
Mean dissolution rate = **0.024 ± 0.019 g/cm^2·y**
(~3 times slower than within underground streams)

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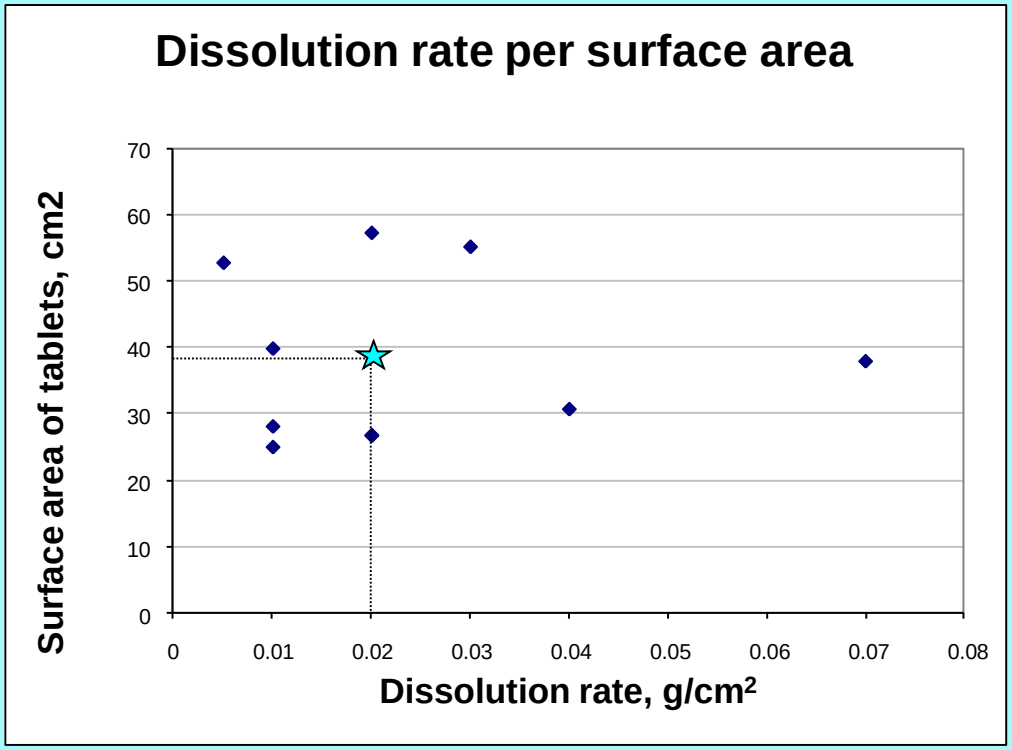


Karst denudation of gypsum within underground streams of the Pinega Region (*Shavrina, 2002*) :
from 30 to 70 t/km^2 per month = **from 0.036 to 0.084 g/cm^2 per year**

Amount of water involved in gypsum dissolution within soils

Values: **Gypsum solubility – 2.4 g/l (*Mineralogy guide books*)**

Annual precipitation (P) = 650 mm, P/ET ratio = 1.3 (*Pinega Meteo Station*).

Dissolution rate per surface area of gypsum = 0.02 g/cm^2 *(our experiment)*

Percentage of annual precipitation spent on such dissolution is:

$$\frac{0.02\ g/cm^2 \times 1000\ cm^3 \times 100\%}{65\ cm \times 2.4\ g} = 13\%$$

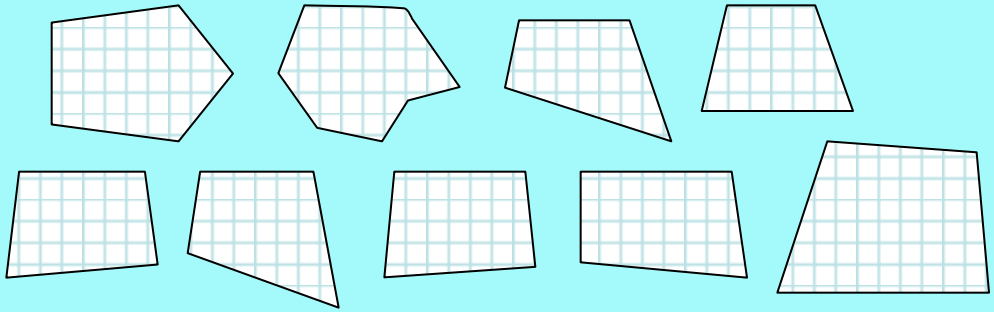
Taking into account the annual evapo-transpiration (ET = 65 cm/1.3 = 50 cm), then the percentage of actual soil moisture spent on gypsum dissolution is:

$$\frac{0.02\ g/cm^2 \times 1000\ cm^3 \times 100\%}{(65 - 50)\ cm \times 2.4\ g} = 55\%$$

The solution remains unsaturated by gypsum within the top soil horizon

Dissolution rate related to surface area of gypsum blocks

The gypsum blocks:



Mean top surface = 1062 cm^2

Total surface (with fissures) = $n \times 1062\ cm^2$

The dissolution rate of the gypsum blocks is comparable to our data on gypsum tablets:

$$\frac{8\ g/kg \times 26\ kg}{n \times 1062\ cm^2} = 0.02\ g/cm^2 \quad \Rightarrow n = 10$$

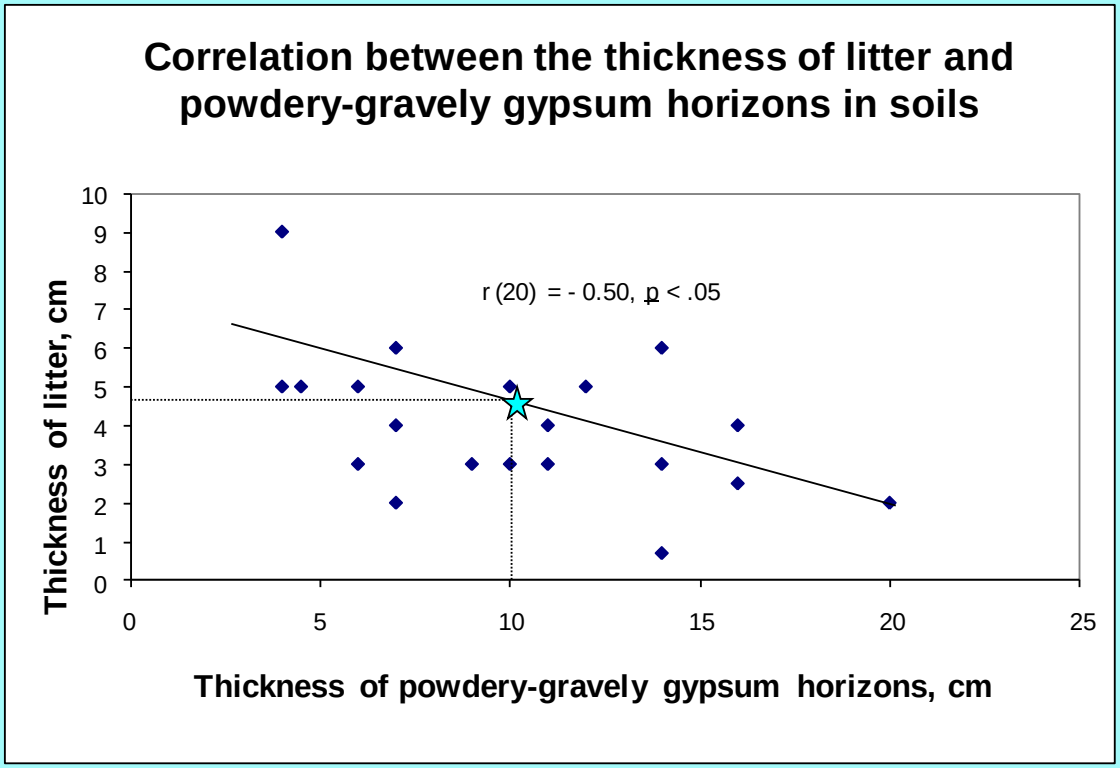
The total dissolution area of the blocks (all surfaces including fissures) is 10 times larger than their top surface.

Cryogenic disintegration of gypsum within soils

Gypsum disintegration under the soil litter on experimental block No. 1 (above)

The powdery-gravely gypsum horizons of soils – “disintegration-metamorphic horizons” (below)

The powdery-gravely gypsum horizons of soils



The disintegration is hindered by the moss layer and litter development, which acts to slow down the rate of temperature change.

The average thickness of powdery-gravely horizon = 10 cm.

Gypsum disintegration in soils is faster than its dissolution.

Estimation of gypsum disintegration rate relative to gypsum dissolution in soils

Values: **The density of gypsum = 2.2 g/cm^3**

The dissolution rate = 0.02 g/cm^2

The rate of soil surface loss through dissolution:

$$\frac{0.02\ \text{g/cm}^2}{2.2\ \text{g/cm}^3} = 0.009\ \text{cm per year, or 9 mm per 100 years}$$

Gypsum disintegration in soils should be faster than its dissolution, as indicated by the formation of powdery-gravely horizons

Therefore, the rate disintegration > 1 cm per 100 years

Conclusions

The experimentally found gypsum dissolution rates on the surface (in soils): ~ 8-22 g/kg per year and ~0.02 g/cm^2 per year.

Gypsum dissolution in soil is ~3 times slower than the underground gypsum denudation by karst waters and ~10 times slower than the dissolution of gypsum within a river flow system.

The rate of cryogenic disintegration of gypsum is greater than the rate of gypsum dissolution.

The powdery-gravely gypsum soil horizon is formed at a rate of more than 1 cm / 100 years.

This disintegration is hindered by the moss layer and litter development which acts to slow down the amplitude of temperature change.