# Origine and tranport of radon in wet and dry mofettes of Covasna Town, Romania

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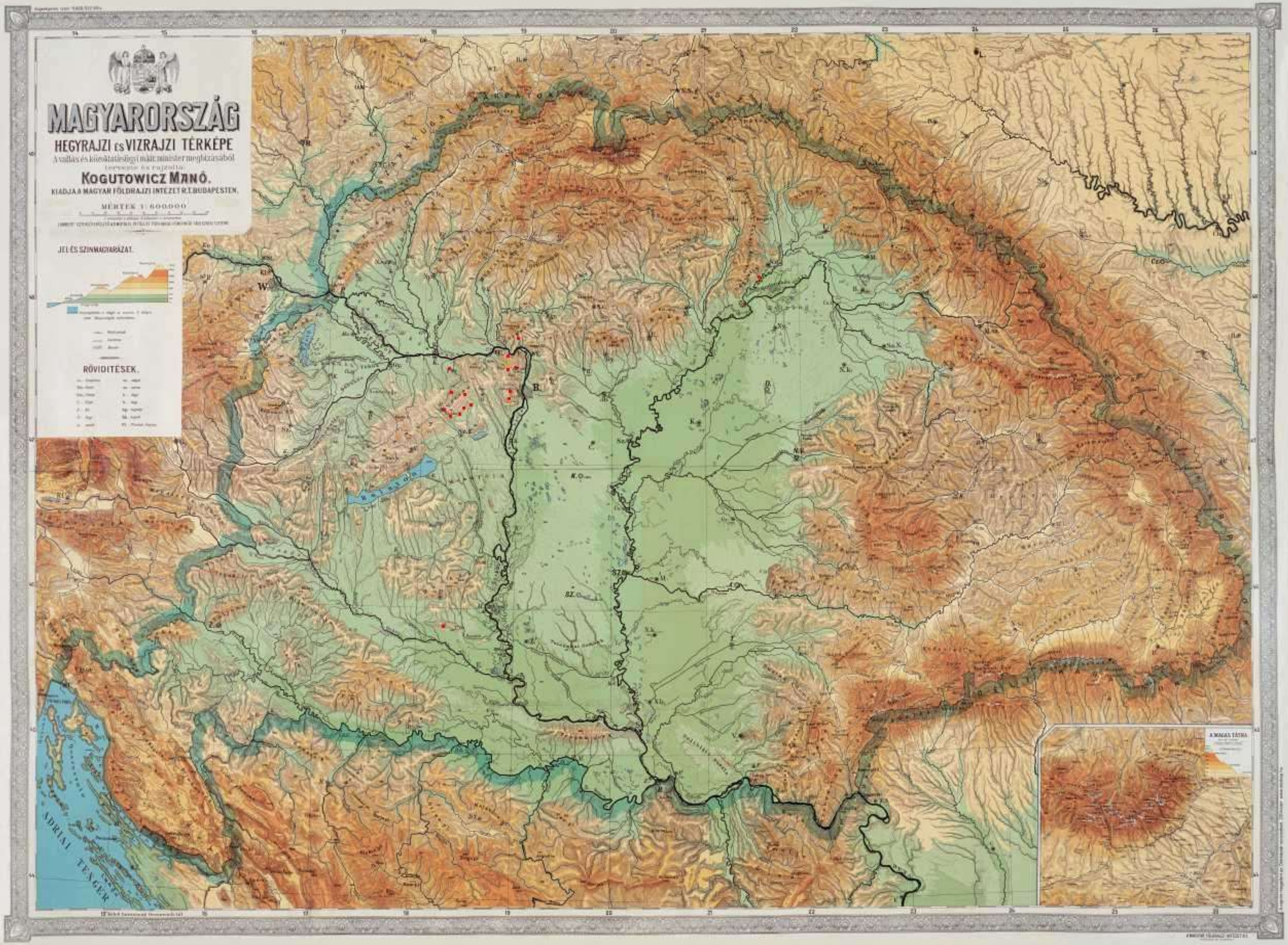
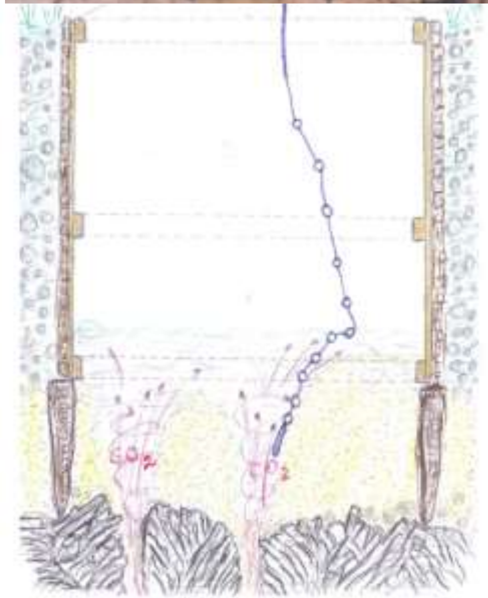
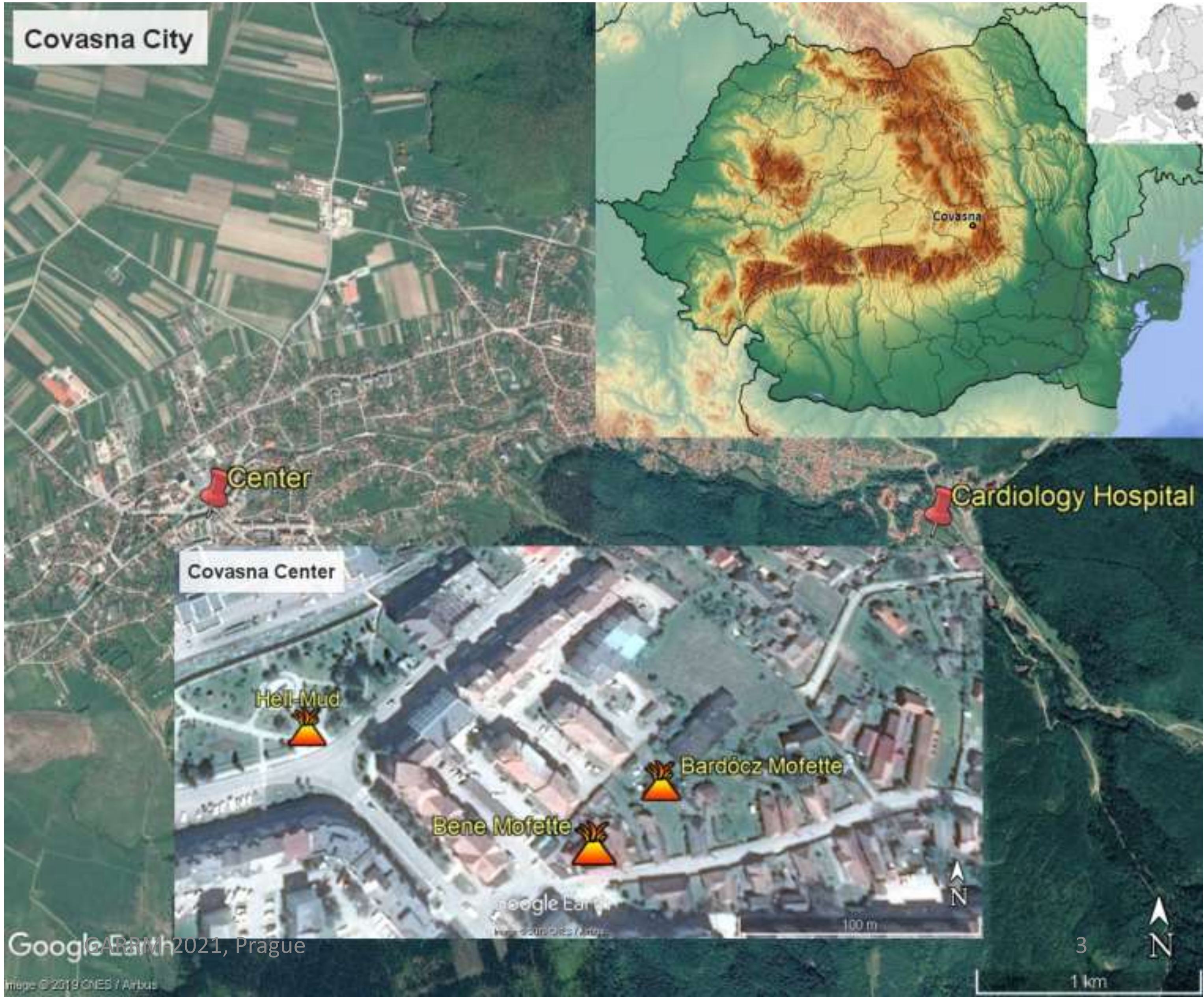
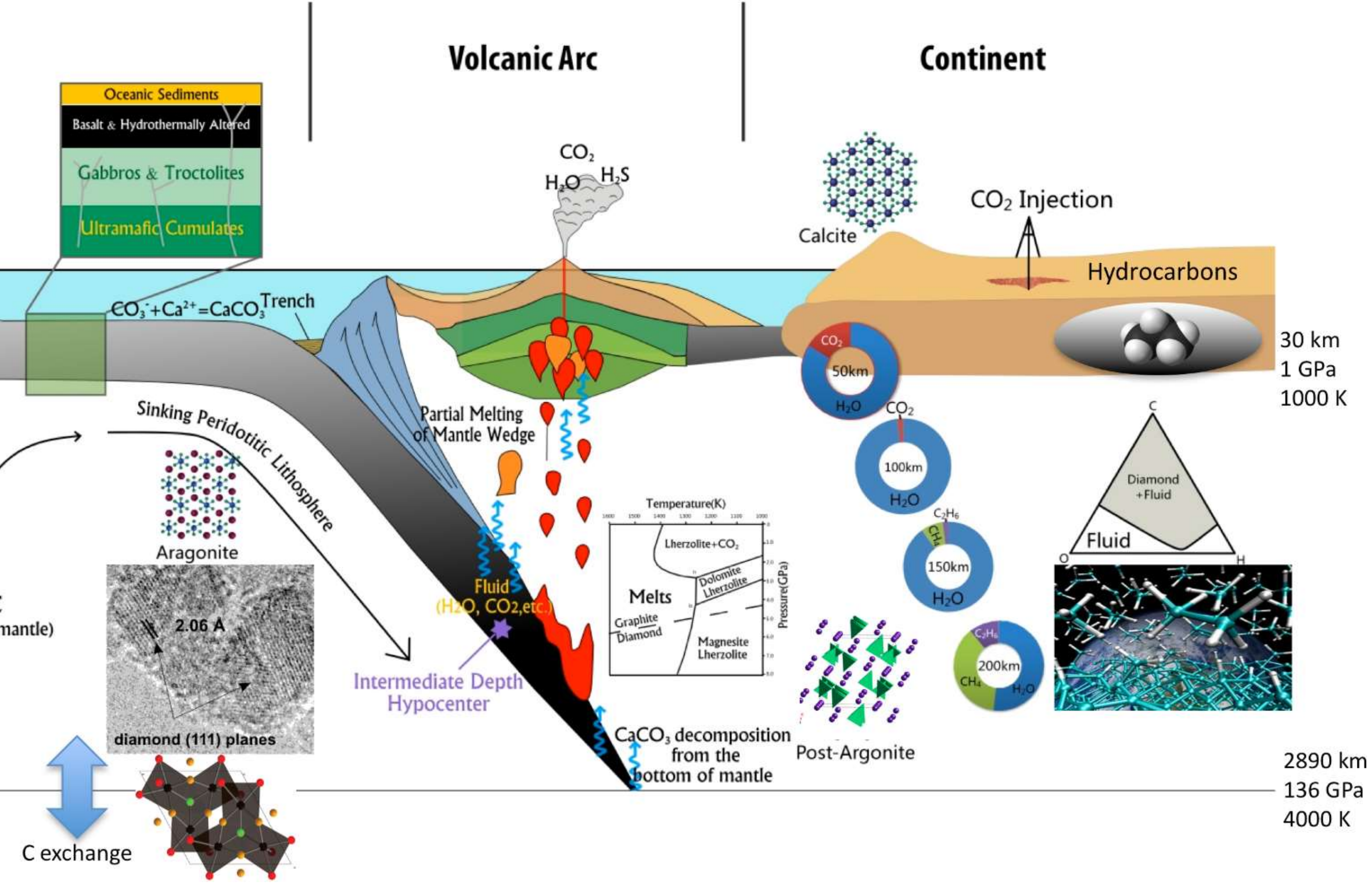

MAGYARORSZÁG
HEGYRAJZI ÉS VIZRAJZI TÉRKÉPE
A vallás és közoktatásügyi m. kir. minister megbízásából
tervezte és rajzolta
KOGUTOWICZ MANÓ.
KIADJA A MAGYAR FÖLDRAJZI INTÉZET R.T. BUDAPESTEN.
MÉRTEK 1 : 600000
JEL ÉS SZINMAGYARÁZAT.
RÖVIDITÉSEK.
ADRIAI TENGER
A MAGAS TÁTRA

# Pokolsár, wet mofette of Covasna, Romania

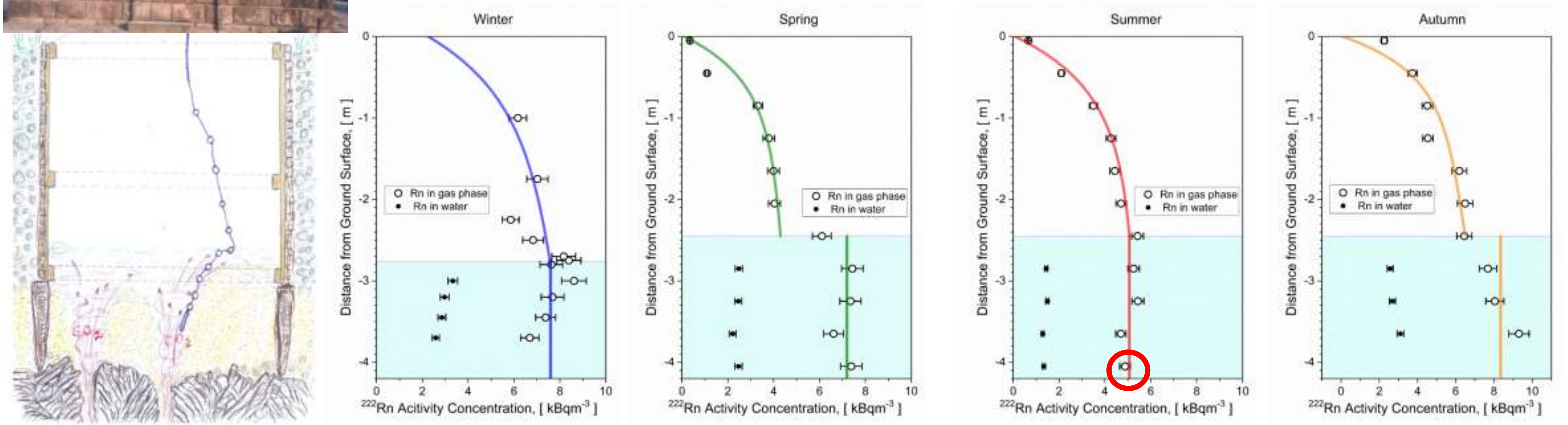




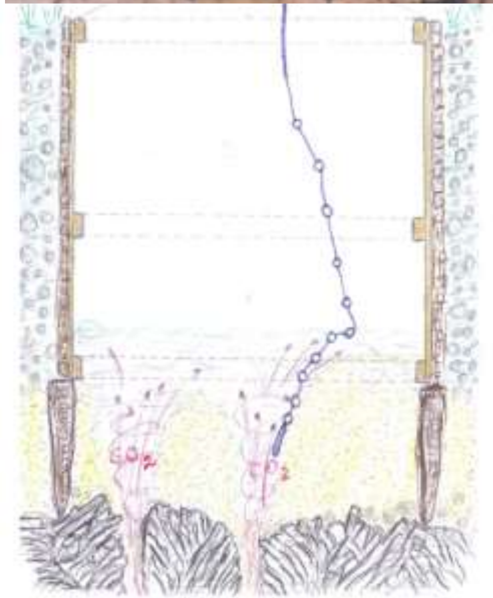

Volcanic Arc
Continent
Oceanic Sediments
Basalt & Hydrothermally Altered
Gabbros & Troctolites
Ultramafic Cumulates
$CO_2$
$H_2O$
$H_2S$
Calcite
$CO_2$ Injection
Hydrocarbons
$CO_3^- + Ca^{2+} = CaCO_3$
Trench
30 km
1 GPa
1000 K
Sinking Peridotitic Lithosphere
Partial Melting of Mantle Wedge
Aragonite
2.06 Å
diamond (111) planes
Fluid ($H_2O$, $CO_2$,etc.)
Intermediate Depth Hypocenter
Temperature(K)
Lherzolite+$CO_2$
Melts
Dolomite Lherzolite
Graphite Diamond
Magnesite Lherzolite
Pressure(GPa)
$CO_2$
50km
$H_2O$
100km
$C_2H_6$
$CH_4$
150km
200km
Diamond +Fluid
Fluid
C
O
H
$CaCO_3$ decomposition from the bottom of mantle
Post-Argonite
mantle)
C exchange
2890 km
136 GPa
4000 K

# Pokolsár, wet mofette of Covasna, Romania

Results of measurements and model calculations



# Pokolsár, wet mofette of Covasna, Romania



## Model

Spatial variation of $^{222}$Rn activity concentration in deep bedrock and sedimentary rocks:

$$D_i \frac{d^2C}{dz^2} - v\frac{dC}{dz} + G_i - \lambda C = 0$$

where

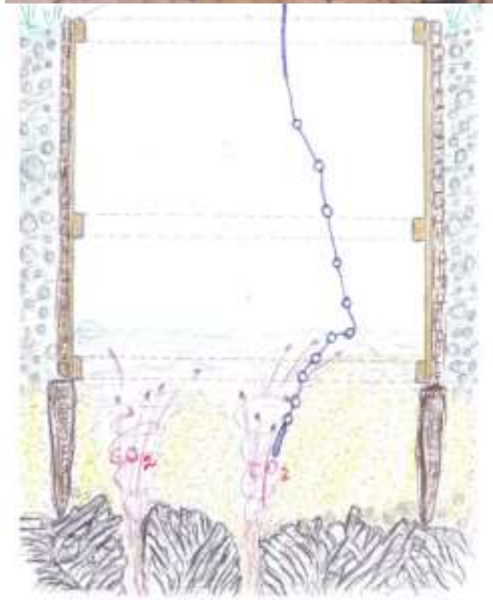
$C(z)$ is the $^{222}$Rn activity concentration in the liquid phase that completely fills the pore space ($Bq\ m^{-3}$),

$D_i$ is dispersion coefficient,

$G_i$ is Rn-source term,

$v$ is the average interstitial velocity of groundwater.

# Pokolsár, wet mofette of Covasna, Romania



## Model

The radon balance equation for the water in the pool of the Hell-mud (Pokolsár) is:

$$\frac{dC_w}{dt} = \frac{1}{z_2 - z_1}\left(j_2(z_2) - j_b - v\phi C_w\right) - \lambda C_w \,.$$

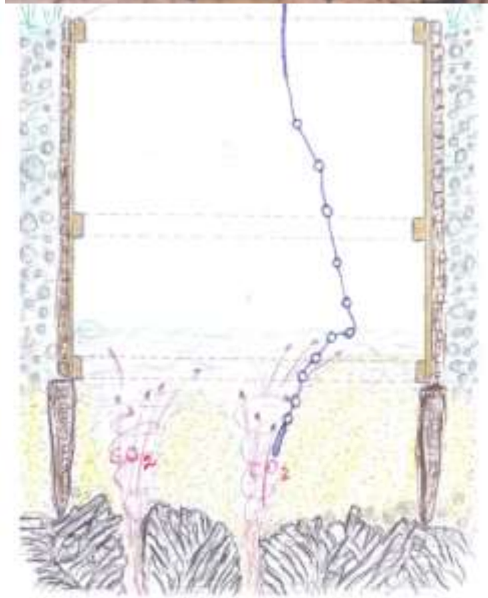
Here $j_2(z_2)$ is the bulk $^{222}$Rn activity flux density at the bottom of the pool, which can be specified as:

$$j_2(z_2) = (v - D\gamma_2)e^{\gamma_2 z_2}\phi C_{s0} + v\phi\frac{G_s}{\lambda} \,.$$

$j_b$ is the $^{222}$Rn activity flux density transported from the water to the gas phase of the pool by bubbles. This term is obtained by multiplying the volume flux density $Q_{bV}$ of carbon dioxide gas in the bubbles ($m^3/m^2s$) and the $^{222}$Rn activity concentration in bubbles ($C_b = C_w/H^{cc}$).

$$j_b = Q_{bV}C_b \,.$$

# Pokolsár, wet mofette of Covasna, Romania



**Model**

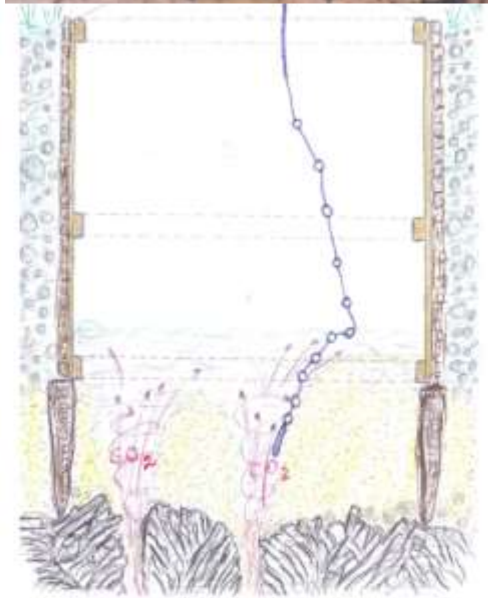
The $^{222}$Rn activity concentration in bubbles is related to the $^{222}$Rn activity concentration in the water ($C_w$) through the Henry's partition coefficient ($H^{cc}$), the temperature dependence of which is given as

$$H^{cc}(T) = \frac{C_w}{C_b} = H^{cp}(T)\; R\; T = H_0^{cp} R T e^{\alpha\left(\frac{1}{T} - \frac{1}{T_0}\right)}$$

$R = 8.314\ J/(mol\ K)$ is the ideal gas constant,
$T, [K\ ]$ is the absolute temperature and
$T_0 = 298.15\ K$ is a reference temperature.
$H_0^{cp}$ and $\alpha$ are constants that can be determined experimentally.

There is a similar relationship between carbon dioxide dissolved in molecular form in water and the concentration of carbon dioxide in gas phase.

# Pokolsár, wet mofette of Covasna, Romania



**Model**

Volumetric flux density (Darcy velocity) of water entering the pool at the bottom is:

$$q = v\phi \,, [m^3/m^2s] \,.$$

Flux density of dissolved carbon dioxide transported by water is:

$$Q = q * [CO_2]_w \,, [mol/m^2s].$$

Flux density of carbon dioxide gas that separates from water in the form of gas bubbles is

$$Q_b = q([CO_2]_w - [CO_2]_t) \,, [\, mol/m^2s] \,,$$

where $[CO_2]_t = H_{CO_2}^{cp}(T)p_{CO_2}$ is the equilibrium concentration of carbon dioxide dissolved in water at partial pressure of carbon dioxide in bubbles of $p_{CO_2} = 10^5\ Pa$ and at temperature $T$. Finally we need to convert the material flux density into a volume flux density. This requires the use of molar concentration of carbon dioxide in the bubbles. According to the ideal gas equation: $p_{CO_2} = [CO_2]_b RT$, from which $[CO_2]_b = p_{CO_2}/(RT)$.

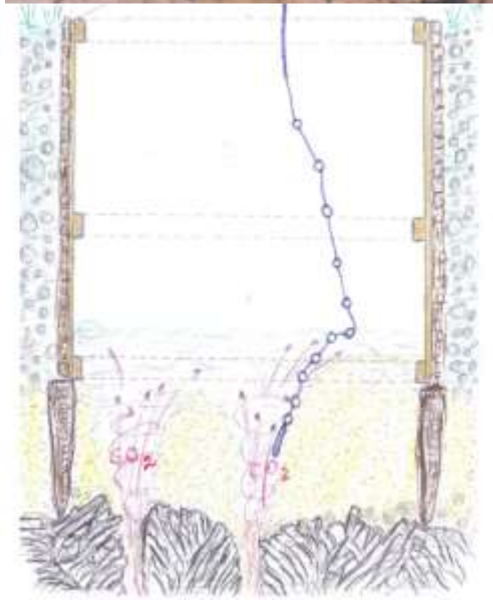
The volume flux density of carbon dioxide leaving through bubbles is:

$$Q_{bV} = \frac{Q_b}{[CO_2]_b} \,, \qquad [m^3/m^2s] \,.$$

The radon flux density leaving through bubbles is:

$$j_b = Q_{bV} C_b = Q_{bV} \frac{C_w}{H_{Rn}^{cc}(T)}$$

# Pokolsár, wet mofette of Covasna, Romania



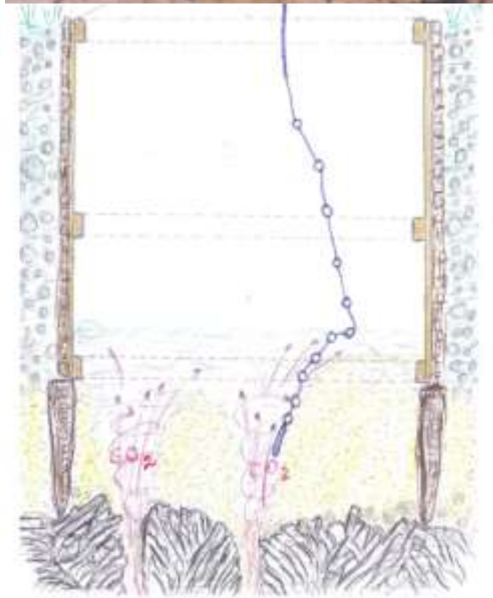
**Model**

Substituting all of these in the equation of radon balance of pool space in stationary case:

$$(v - D\gamma_2)e^{\gamma_2 z_2}\phi C_{s0} + v\phi\frac{G_s}{\lambda} - Q_{bV}\frac{C_w}{H_{Rn}^{cc}(T)} - v\phi C_w - \lambda(z_1 - z_2)C_w = 0\,.$$

from which:

# Pokolsár, wet mofette of Covasna, Romania



**Model**

The remaining radon content of the water:

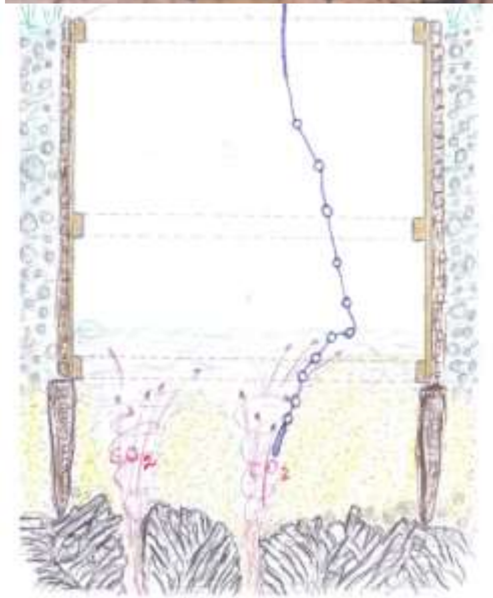
$$C_w = \frac{\dfrac{\phi}{\lambda}\left\{\dfrac{(v - D\gamma_2)\gamma_1}{\gamma_2 - \gamma_1}(G_s - G_d)e^{\gamma_2 h_s} + vG_s\right\}}{\dfrac{Q_{bV}}{H_{Rn}^{cc}(T)} + v\phi + \lambda h_w}$$

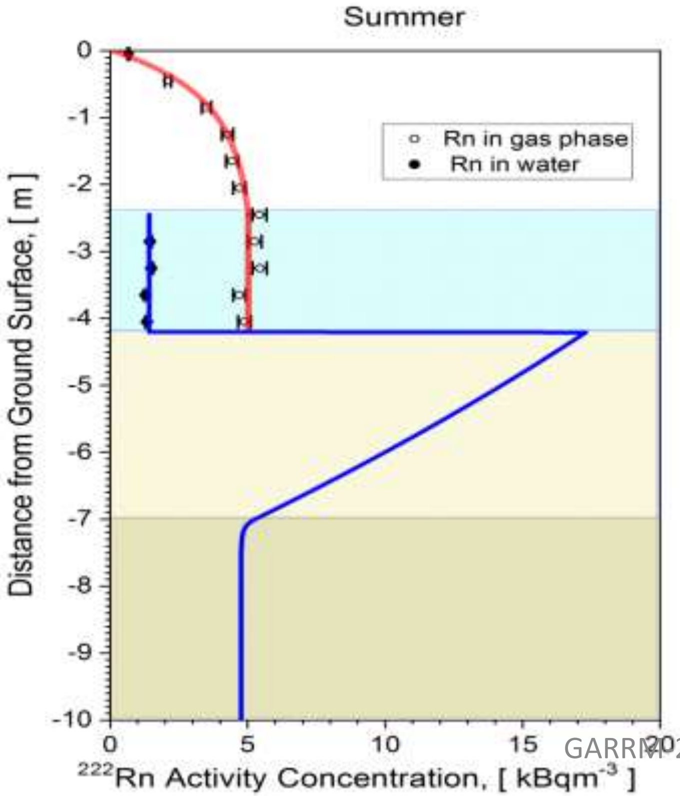
where
$h_s = (z_2 - z_3)$ is the thickness of the sediment under the bottom of the pool and

$h_w = (z_1 - z_2)$ is the thickness of the water layer in the pool.

**In the water of the wet mofette, carbon dioxide is degassing, and flashes out much of the radon, too.**

# Pokolsár, wet mofette of Covasna, Romania






## Model

The remaining radon content of the water:

$$C_w = \frac{\frac{\phi}{\lambda}\left\{\frac{(v - D\gamma_2)\gamma_1}{\gamma_2 - \gamma_1}(G_s - G_d)e^{\gamma_2 h_s} + vG_s\right\}}{\frac{Q_{bV}}{H_{Rn}^{cc}(T)} + v\phi + \lambda h_w}$$

where

$h_s = (z_2 - z_3)$ is the thickness of the sediment under the bottom of the pool and

$h_w = (z_1 - z_2)$ is the thickness of the water layer in the pool.

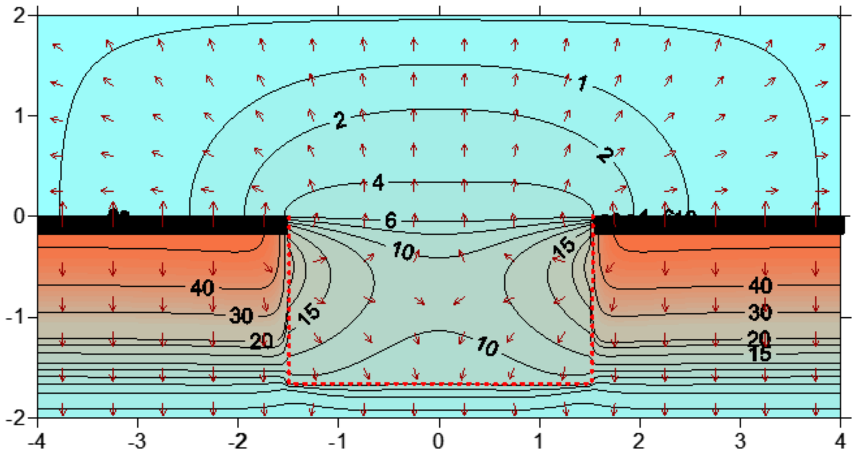
# Dry mofettes of Covasna, Romania

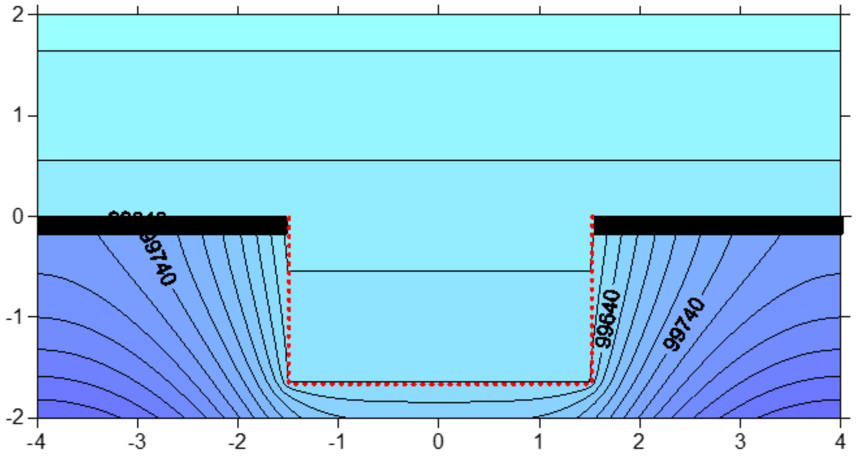



The very same hydrogeological and radon transport model can be applied to both wet and dry mofettes of Covasna!

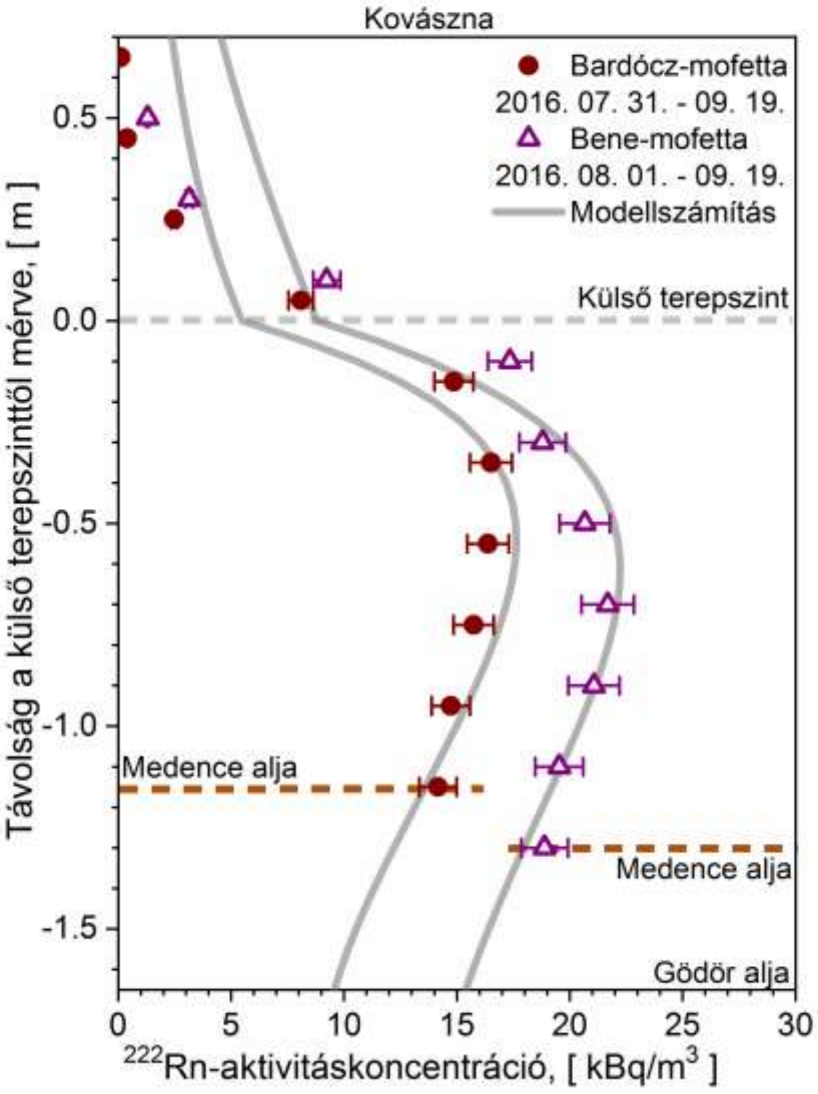
# Dry mofettes of Covasna, Romania

$^{222}$Rn activity concentration in soil gas and gas phase of the mofette, kBq/m$^3$

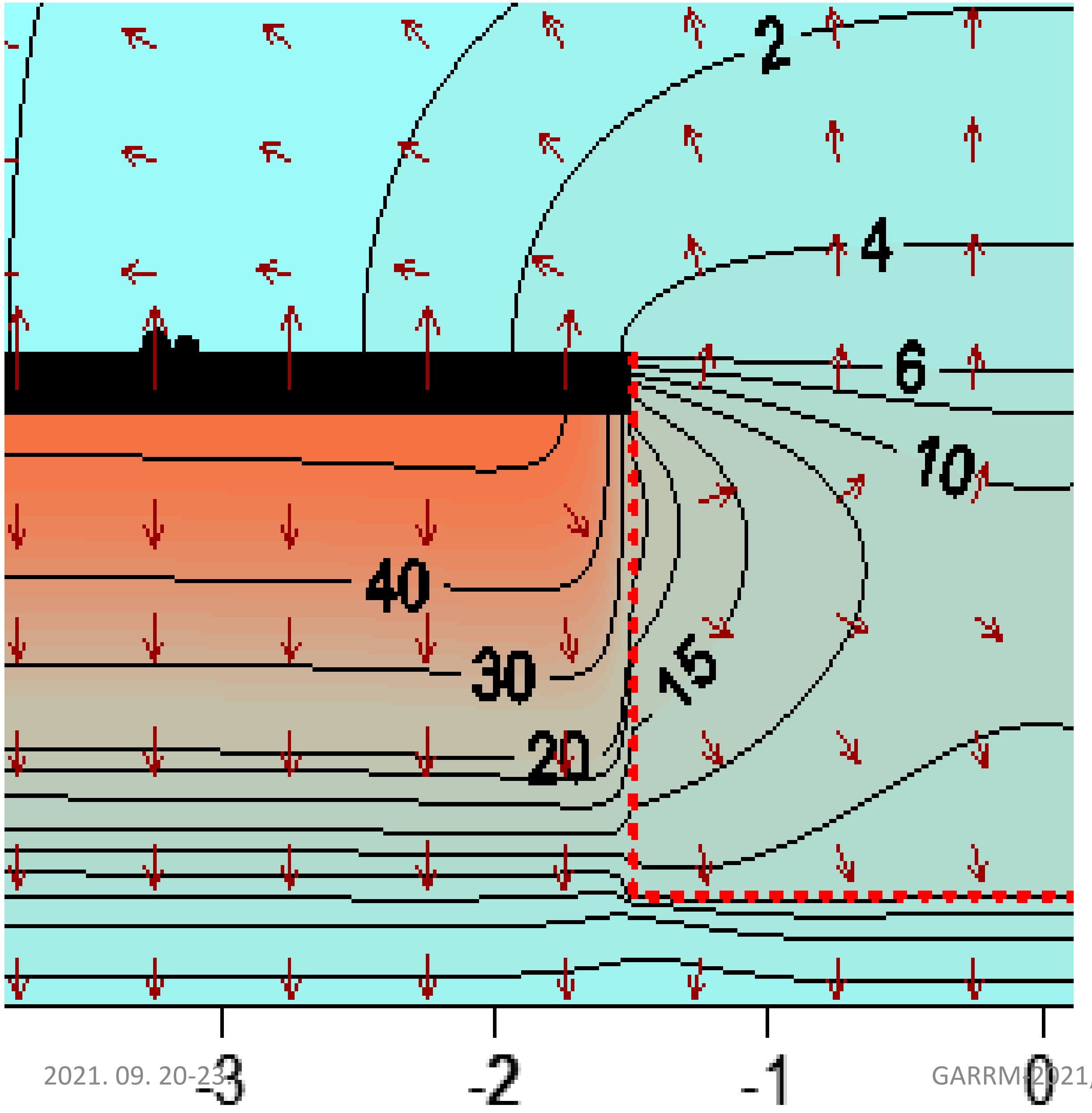


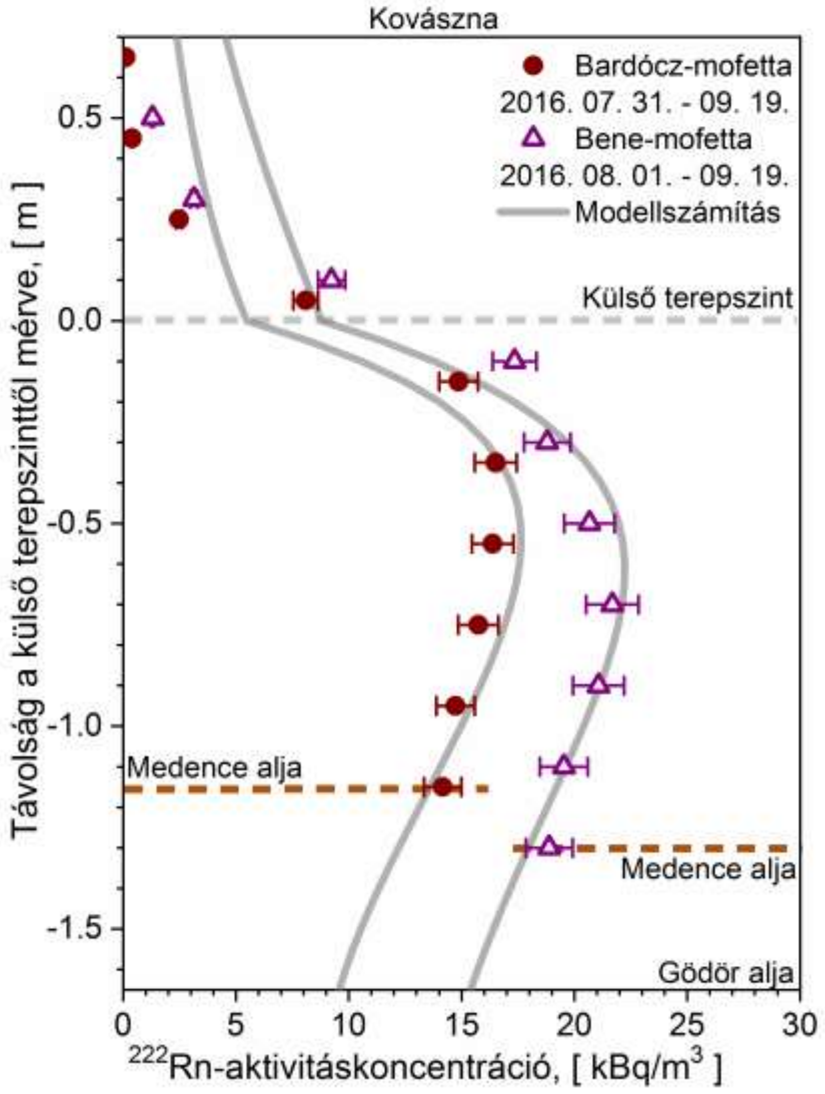


Pressure field, Pa

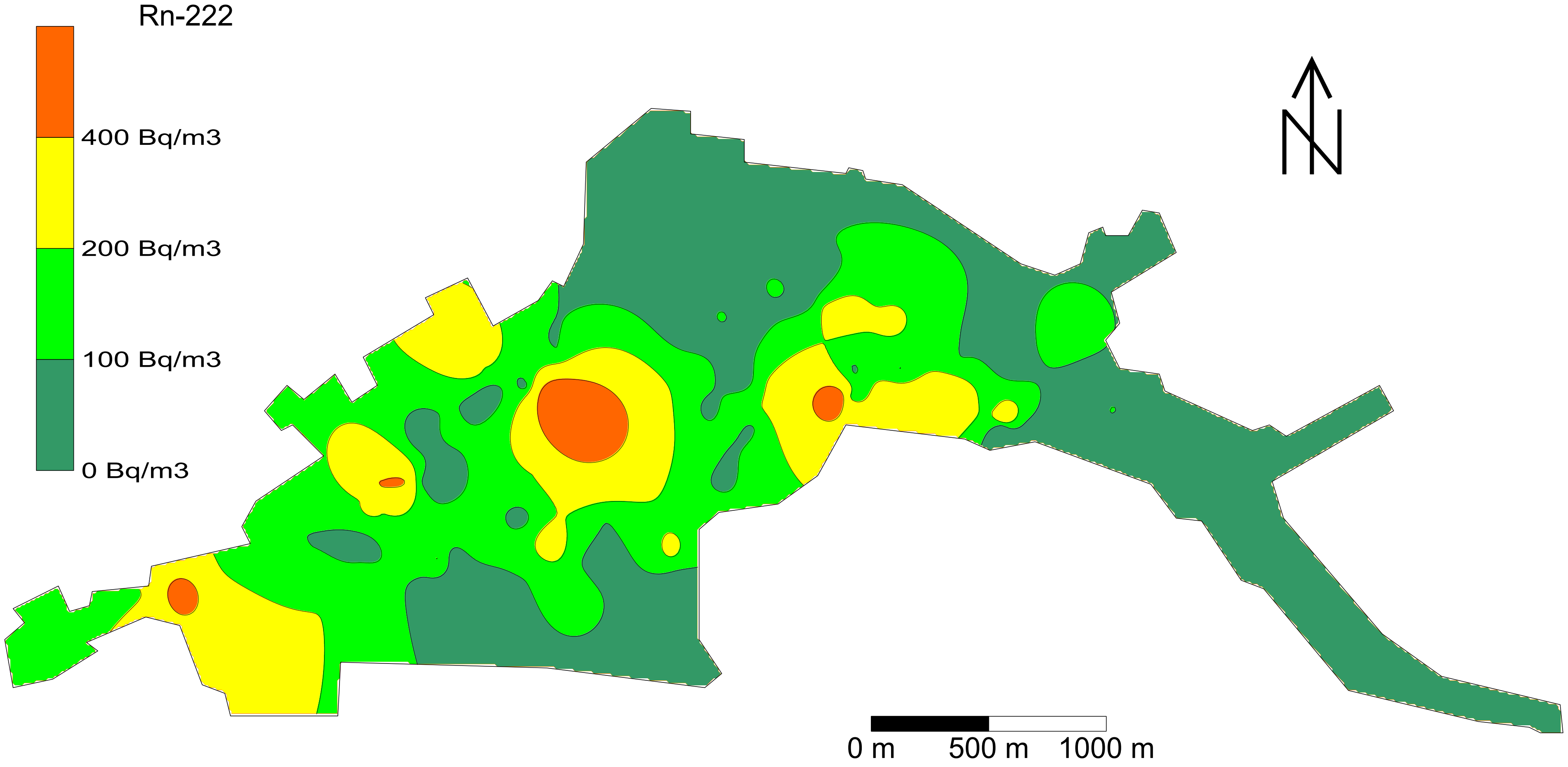


# Dry mofettes of Covasna, Romania



# Mapping of Indoor Radon in Kovászna




István Csige and Sándor Csegzi

**Acknowledgements**

The research was supported by the European Union and the State of Hungary, co-financed by the European Regional Development Fund in the project of GINOP-2.3.2-15-2016-00009 ‘ICER’. The research was also partly financed by the Higher Education Institutional Excellence Programme (20428-3/2018/FEKUTSTRAT) of the Ministry of Human Capacities in Hungary, within the framework of the 4. thematic programme of the University of Debrecen.