



## Natural CO<sub>2</sub> emissions - mofettes in Slovenia

Several mineral water spring areas in Slovenia evolved where the CO<sub>2</sub> gas emits from the Earth's mantle to the surface along deep and well-permeable fault zones. These are found in north Slovenia at Jezersko, in east at town Rogaška Slatina, but they are most abundant in north-east Slovenia (Rman et al. 2016). Such springs occur in the alluvial valleys of the Slovenske gorice hills, at elevation between 200 and 300 m a.s.l., in Ščavnica Valley and Radenci (Fig. 1), and in Nuskova. Natural springs of mineral water rich in CO<sub>2</sub>, also named soda springs (slatina), were often the only drinking water sources for local inhabitants. Today, they still mix it with wine into spritz. Nowadays, many springs are protected as valuable natural features (<https://www.naravovarstveni-atlas.si/>).

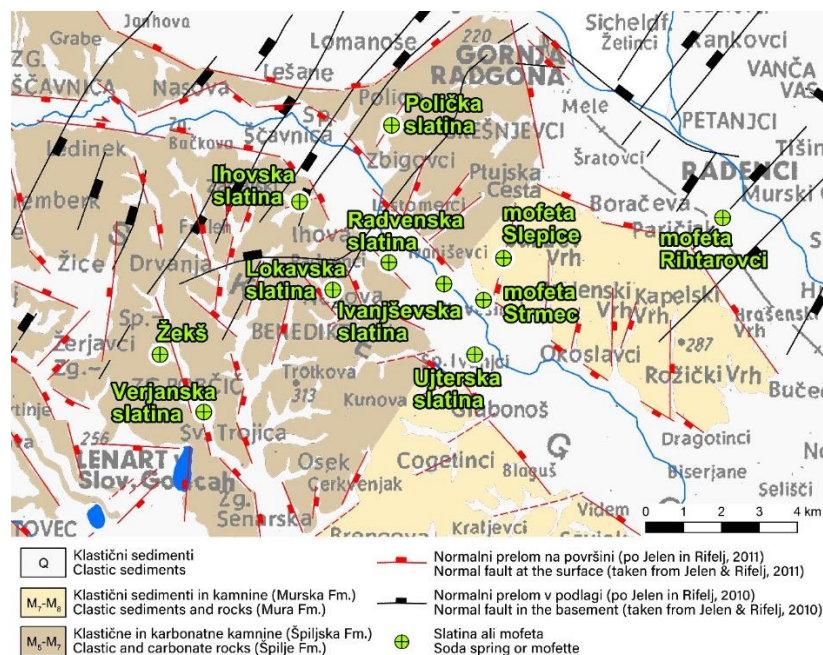


Fig. 1. Simplified lithostratigraphic map of the investigated area with sites of which some are true mofettes. Geological map is modified after Jelen, 2010; Jelen & Rifelj, 2011.



## Anomalies

A mofette is a natural spring of carbon dioxide (CO<sub>2</sub>) which most often occurs in volcanic areas. Even though there are no active volcanoes in Slovenia, we do have mofettes. On the other hand, they are not reported to exist in the other parts of the Mura-Zala Basin nor in Croatia nor in Hungary. Mofettes emerge here along the deep-seated Raba Fault Zone running through the Earth's crust to its mantle. This zone is delineated from Benedikt to Radenci and Hodoš and continues to Hungary. Its permeability enables constant emission of large amounts of mantle gases with CO<sub>2</sub> being the most abundant. The most interesting of these natural features are included in the interpretative trails Med vrelni življenja (Among the Springs of Life).

Emitted geogene gas is predominately very pure CO<sub>2</sub>, but methane may also be present locally. The isotope signatures of gases indicate an origin of helium and CO<sub>2</sub> predominantly (>75%) in the subcontinental mantle (Brauer et al. 2016). The measured <sup>3</sup>He/<sup>4</sup>He ratios range from 4.62 to 5.97 Ra and include the highest ones recorded in the whole Pannonian Basin system, while the gaseous δ<sup>13</sup>C is between -5.1 to -3.5 ‰. Carbon dioxide is a colourless and odourless gas that is heavier than air. It is poisonous if inhaled in large quantities as it lowers the pH of blood; a headache and dizziness ensue and may even lead to death. As such, it is not advised to stay close to the mofettes for a long period of time or breathe next to the ground. Since animals do not know about these health dangers, it is quite common to find dead insects, birds or even roe deer near mofettes.

Systematic overview was done in 2016 for the Geological Atlas of Slovenia (many of its maps are freely available at portal eGeologija (Rman et al. 2016)). We distinguished among mofettes and mineral waters among 11 investigated springs (Gabor & Rman, 2016). Two were classified as wet mofettes (Polička slatina (Fig. 2) and Slepice (Fig. 3 right)) and three as dry mofettes (Rihtarovci, Strmec (Fig. 3 left), mofette at Lokavska slatina). These constantly emit cold CO<sub>2</sub>, cold acid surface or meteoric water, and bare soil or changed vegetation may also be present. Mineral water consisting of more than 1 g/l of total dissolved solids outflows at Ihovska, Ivanjševska and Radvenska slatina, and Žekš. It is rich in free CO<sub>2</sub> and has a strong free gas flux. At Žekš and Polička slatina, we later found also several new vents, which are evident only after heavy rain. Later, we classified also Verjanska slatina as a wet mofette but it is not a typical one. Ujterska slatina was neither a mofette nor mineral water. The first, like most others, may be a »slatina« (=soda spring), having more than 250 mg/l of free CO<sub>2</sub>. We found no connection between the depth of the springs and the intensity of gas emissions.





Fig. 2. Polička slatina as the main mofette is filled with rain water (left). In surroundings, there are several minor usually dry diffuse CO<sub>2</sub> vents (right)





Fig. 3. Left: Mofette Strmec is a dry mofette. CO<sub>2</sub> springs are most noticeable on a meadow south of the local road between Ivanjševci and Stavešinci. Distinctive vegetation can be noted at an area of approximately 2,500 m<sup>2</sup> and no crops grow in the vicinity. Where the flux of CO<sub>2</sub> is strong and concentrated, areas of about one metre in diameter have no vegetation. When shallow holes in them fill with rainwater, it becomes muddy and its surface bubbles. After heavy rains, gas bubbles can also be observed in a creek channel to the west, and in a roadside channel north of this area.

Fig. 3 Right: Outstanding Slepice are situated along the creek Stavešinski potok. Two mofettes of oval shape are located 6 m apart. The larger one has a diameter of 1.4 m and a depth of 50 cm. The smaller one reaches only about one metre in diameter but is deeper at about 80 cm. Depressions are filled mostly by rainwater and the water surface constantly bubbles and froths due to the strong inflow of free gas. This water is acidic and not drinkable. Gas emits from the ground in a wide area around the two features. West of them, walk to the creek and observe its water surface. Individual gas bubbles occur at a length of few tens of metres.



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