Hydrogen gas (H_2) artificially generated during soil-gas sampling - Technical report

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Abstract

Surface gas geochemistry methods, including soil gas measurements, are widely used for natural hydrogen (H_2) exploration. It is known that H_2 can be artificially generated by mechanical friction during installation of soil-gas probes. However, it is frequently considered that artificial H_2 is produced only by drill bit rotation, although there are no systematic studies about its generation during soil-gas probe insertions by less invasive probing techniques, such as manual hammering. Accordingly, the H_2 detected in the soil by portable sensors or gas chromatography is often cursorily interpreted as an indication of geological H_2 emanation. The aim of this report is to provide a demonstration of artificial H_2 generation during soil gas probe hammering in a control site, within an urban park in Cluj-Napoca (Romania), where natural H_2 is absent. Soil-gas measurements were performed throughout an area of about 1850 m^2 and, in more detail, in a site where small pebbles were buried in the soil to simulate a soil with higher strength. Two hammering techniques were tested: (a) sledgehammer and (b) sliding hammer. Four permanent probes were also installed to monitor H_2 over time, unaffected by mechanical friction. Portable electrochemical sensors (Dräger X-am 8000) were used to measure H_2 and CO, which is a proxy for artificial gas generation. We measured H_2 concentrations ranging from below detection limits (10 ppmv) to 385 ppmv (associated with 50 ppmv CO), using the sledgehammer technique. The less invasive sliding hammer method produced up to 200 ppmv H_2. We observed that the H_2 concentration was not stable, decreasing to zero ppmv after 2-3 minutes using the sliding hammer technique, and at least 4 minutes with the sledgehammer. The permanent probes never showed H_2. The test is documented by videos available at https://engagelab.granturi.ubbcluj.ro/media/. This study confirms that artificial H_2 can be generated by any type of soil-gas technique implying mechanical friction within the soil, a phenomenon that should be considered in exploration activities. More exhaustive research, including soil analyses in wider areas, in the absence of natural H_2, is in progress.

Keywords: Natural hydrogen, Artificial hydrogen generation, Soil-gas, Gas Geochemistry

1. Introduction

Soil-gas prospection is currently widely used as a surface geochemical exploration method for natural hydrogen (H_2) produced in crustal and mantle rocks, which is considered a potential energy resource with a lesser climatic impact than hydrocarbons (e.g., The Royal Society, 2025 and references therein). Historically employed for hydrocarbon, radon, helium, geothermal and even mineral exploration (e.g., Jones and Drozd, 1983; McCarthy and Reimer, 1986; Klusman, 1993; Tedesco, 1995; Schumacher and Abrams, 1996), soil-gas analysis is aimed at detecting, in aerated soils, gases of geological origin (i.e., gas seepage), which can potentially indicate subsurface fluid accumulations or source rocks related to the resource being searched. Soil-gas interpretation criteria and recommendations are fundamentally based on a combination of geochemical and environmental factors (including multiple gas detection, isotopic analyses, and geological and surface ecosystem contextualisation; e.g., Schumacher and Abrams, 1996; Etiope et al., 2026; Etiope and Orban, 2025). Although well established for the various resources, those rigorous interpretation criteria are quite marginally applied to natural H_2.

Multiple studies have suggested that soil can host microbial H_2, produced by fermentation or N_2 fixation in wet soil layers, agricultural soil, shallow aquifers and wetlands (bogs, swamps), which may exist in proximity of the soil-gas survey areas (e.g., Etiope et al., 2024; Pengg et al., 2026). A specific problem, however, lies in the artificial production of H_2 during the insertion of the probe for soil-gas sampling. Soil-gas probing, both through rotative or percussion drilling, can induce artificial H_2 generation due to mechanical stress within the soil pores (Halas et al., 2021; Boreham et al., 2024; Davies et al., 2025), similar to what is observed during borehole or rock drilling (drill-bit metamorphism; Leon et al., 2024; Pengg et al., 2025). Artificial H_2 concentrations in soil-gas sampling generally reach several hundred ppmv: up to 464 ppmv was reported by Davies et al. (2025) by drilling with a stainless steel auger drill bit; up to 309 ppmv was reported by Boreham et al. (2024) using a cordless rotary drill and slide hammer; up to 10% was reported by Halas et al. (2021) in a “fairy circle” in France, using a portable perforator. Nevertheless, other authors assume that only rotative drilling can produce artificial H_2, or that artefact effects during drilling are minimal, since the majority of the measurements provide “zero” ppmv values (Lefeuvre et al., 2021; Lévy et al., 2023). Artificial H_2 in soil-gas is often ignored in exploration surveys and proposed workflows (e.g., Elío et al., 2026; Xu et al., 2026); therefore, soil H_2 concentration data, generally from tens to several hundred ppmv, are often cursorily interpreted as evidence of geological H_2 seepage (e.g., Zgonnik et al., 2015; Larin et al., 2015; Moretti et al., 2021; Moretti et al., 2022; Mathur et al., 2024).

This technical report shows preliminary data on H_2 artificially generated during soil-gas sampling, obtained in a control site where microbial and geological H_2 are not present. We unambiguously demonstrate that even the less invasive soil probing, through manual hammering and not drilling, can induce artificial H_2. Our observations are pivotal for natural H_2 exploration and should be considered as a basic constraint for interpreting H_2 in the soil as an expression of geological seepage. A more extensive investigation, with H_2 measurements in different types of soil (including analysis of soil properties), will be published elsewhere.

2. Description of the control site

The soil-gas H_2 measurement tests were conducted in the urban park of the Faculty of Environmental Science and Engineering (FESE; Babeș-Bolyai University), in Cluj-Napoca, Romania (Figure 1).

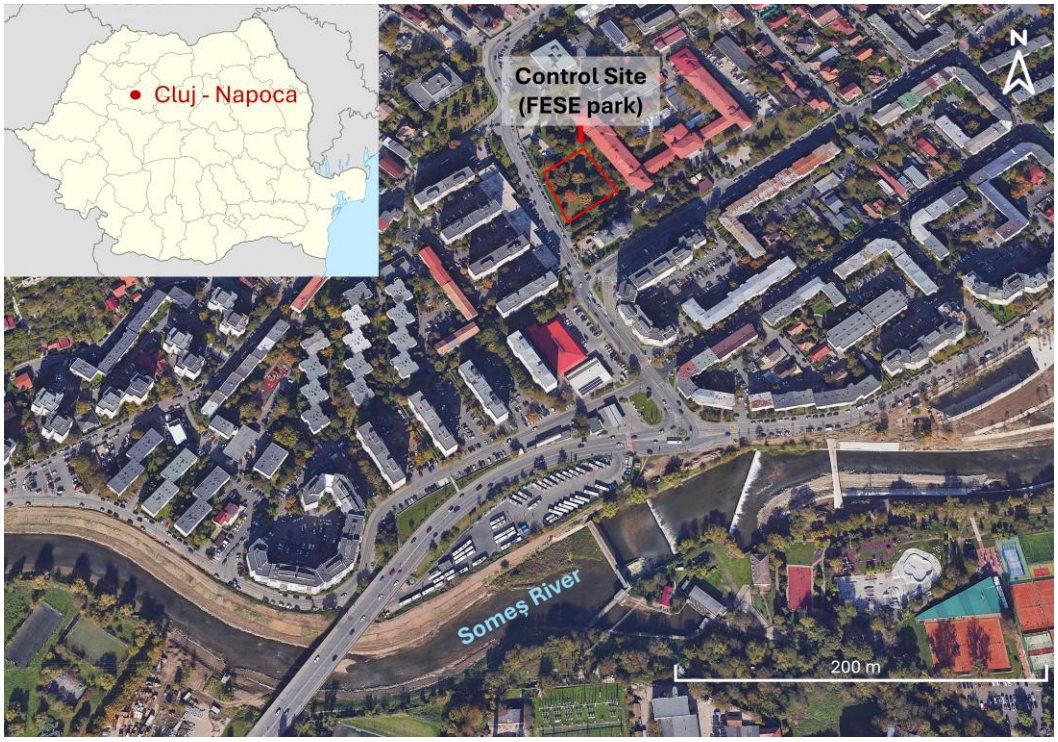

Figure 1. Location of the study area (FESE: Faculty of Environmental Science and Engineering).

The soil has a depth of 70-80 cm over coarse compacted sediments (gravel and sand) related to the alluvium of the Someș River. The soil type is a combination of rendzic and luvisol (ICPA, 1963-1994).

The geology of Cluj-Napoca region includes a basement of Precambrian metamorphic rocks, which supports Late Cretaceous sedimentary units, and a thick Cenozoic succession of Paleogene, Neogene, and Quaternary deposits. The sedimentary sequence includes marine and continental clastic and carbonate rocks, locally accompanied by gypsum and salt deposits, while andesitic and dacitic dykes occur in the western part of the area. Quaternary deposits are mainly represented by alluvial sediments and river terraces developed along the Someș and Nadăș valleys (Mészáros and Clichici, 1976; Popescu et al., 1978). There are no indications of geological gas seepage, geothermal manifestations or potential sources of natural H_2. In the area of the FESE park (Grigorescu zone in Cluj-Napoca), the groundwater table is expected to be approximately between 3 and 5 m deep (SC Institutul Proiect Cluj SA, n.d.).

The soil-gas measurements were performed throughout the park (covering an area of about 1850 m^2) and repeatedly in one specific site, where small pebbles (including carbonate, sandstone and quartz-rich gravel collected from the bed of the Someș River) have been buried and mixed with the soil sediments down to a depth of 0.8 - 0.9 m in a 1 m^2 area (Figure 2). This experiment was intended to verify whether soils hosting rock fragments, as frequently occurring in areas with shallow bedrocks, can more easily generate artificial H_2. In addition, four permanent soil probes (at a depth of 0.8 m) were installed at the same site to verify the occurrence of H_2 not related to mechanical friction.

Figure 2. a: Soil profile at the site with buried pebbles (0.8 m depth); b: Rock fragments used; c-d: Permanent probes (0.8 m deep) within the site with pebbles.

3. Methodology

3.1. Soil-gas probes

Two types of soil-gas stainless steel probes were tested:

(a) Probe with an external diameter of 22 mm, inserted by sledgehammer (Figure 3 - left)

(b) Probe with an external diameter of 8 mm, inserted by sliding hammer (Figure 3 - right).

In the sledgehammer technique, a snap conical head rivet is inserted at the base of the probe, and the probe is lifted using a jack. This method was employed, for example, in Pengg et al. (2025).

The sliding hammer technique simply uses a cylindrical metal weight to drive the probe into the soil; a small nail is positioned within the bottom opening of the probe, preventing soil from clogging the pipe during

hammering and ensuring gas flow after the probe is lifted by a few centimetres. This technique, with some variants, was widely used in soil-gas surveys for H_2, radon, hydrocarbon and helium prospections (e.g., McCarthy and Reimer, 1986; Ciotoli et al., 2016; Etiope et al., 2024; Mathur et al., 2024; Ghiorghiu et al., 2025). In both cases, soil-gas is intercepted at a depth of about 60-80 cm, and the gas analyser equipped with an internal pump is directly connected to the probe through a valve. The two techniques were employed sequentially at adjacent sampling points spaced 30–40 cm apart. The operations are shown in two videos available at https://engagelab.granturi.ubbcluj.ro/media/.

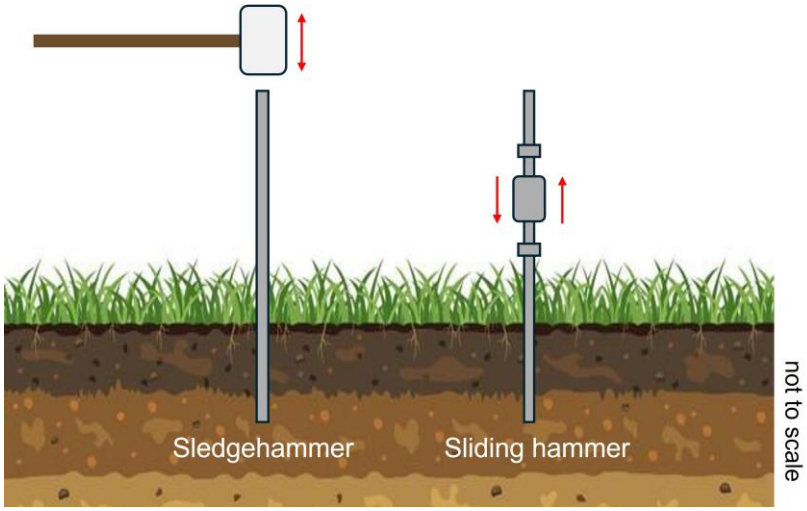

Figure 3. Sketch showing sledgehammer (left) and sliding hammer (right) methods.

3.2. H_2 measurements

Soil-gas measurements were performed using two Dräger X-am 8000 multigas detectors (Germany), equipped with the following sensors for H_2 and CO concentration measurement:

(a) Dräger #1, equipped with an electrochemical DrägerSensor® XXS H_2 (detection limit of 10 ppmv, resolution of 5 ppmv and a measurement range of 0 to 2000 ppmv).

(b) Dräger #2 equipped with:

- electrochemical DrägerSensor® XXS H_2 HC, with a detection limit of 0.02 vol.%, a resolution of 0.01 vol.% and a measurement range of 0 to 4 vol.%.
- Electrochemical DrägerSensor® XXS H_2, with a detection limit of 10 ppmv, a resolution of 5 ppmv and a measurement range of 0 to 2000 ppmv.
- Electrochemical DrägerSensor® XXS CO H_2 - CP, with a detection limit of 6 ppmv, a resolution of 2 ppmv, and a measurement range of 0 to 2000 ppmv. This sensor is H_2 compensated (cross-sensitivity with H_2 of <1%, i.e., less than 10 ppmv CO with 1000 ppmv H_2).

Both detectors are also equipped with CH_4, CO_2, O_2 and H_2S sensors, whose results are not of interest for this report (CO_2 detection, up to 2.9 vol%, was related to soil respiration, CH_4 and H_2S were always below detection limit, and O_2 concentrations were typical of aerated soil, ranging from 17.2 to 20.9 vol%).
The two detectors were used simultaneously, in series along the sampling pipe connected to the soil-gas probe. All sensors were calibrated about two months before the tests and routinely checked against certified H_2 standards prior to measurements.

3.3. H_2 concentration dissipation test

The temporal evolution of the H_2 concentration during soil gas measurements is an important parameter that significantly helps the interpretation of the H_2 origin. The H_2 concentration evolution can be observed only by H_2 detectors equipped with an internal pump, and not by discrete gas sampling. The objective is to evaluate how long the H_2 signal takes to dissipate towards zero ppmv (H_2 dissipation test, as performed by Davies et al., 2025). As described in Etiope and Oehler (2019), geological gas seepage can be continuous, intermittent (with short-term -seconds, minutes, hours- variations), or episodic (sporadic, long-term -days to years- oscillations). In general, the resulting amount of geological gas trapped in the soil pores or pockets can be substantial, and it can decrease due to exhalation into the atmosphere induced by barometric pumping (Wyatt et al., 1995; Etiope and Oehler, 2019). During soil-gas measurements with continuous reading, the duration of the geological gas signal will depend on the amount of gas available in the soil pores that can be drawn by the sensor pump and the pumping flow rate. Soil-gas measurements in areas where geological seepage is obvious (e.g., near seeps) showed patterns of geological gas in the form of multiple peaks or relatively stable plateaus (Figure 4; e.g., Ciotoli et al., 2016; Prinzhofer et al., 2019; Ghiorghiu et al., 2025). The presence in the soil of microbial H_2 due to fermentation (a phenomenon that appears to be more common than generally thought; Etiope et al., 2024; Pengg et al., 2026) is an additional factor complicating the data interpretation: depending on the amount of microbial H_2 in soil pores and pockets, and on the flow rate of the sensor pump, the signal can be a single peak with slow decline, or a more continuous plateau. The amount of H_2 artificially generated by the probe is relatively small, and with a pump flow of 0.3-0.5 L/min (as in the portable detectors generally employed for soil-gas H_2 measurements, such as Dräger X-am 8000 and BIOGAS5000), it should exhibit a single peak followed by a rapid decline. However, it cannot be excluded that single peaks may also be produced by drawing small amounts of geological H_2 from soil pores or pockets. The co-existence of CO, a proxy of artificial gas generation by mechanical friction (Leon et al., 2024; Boreham et al., 2024) would confirm the non-natural H_2 origin.

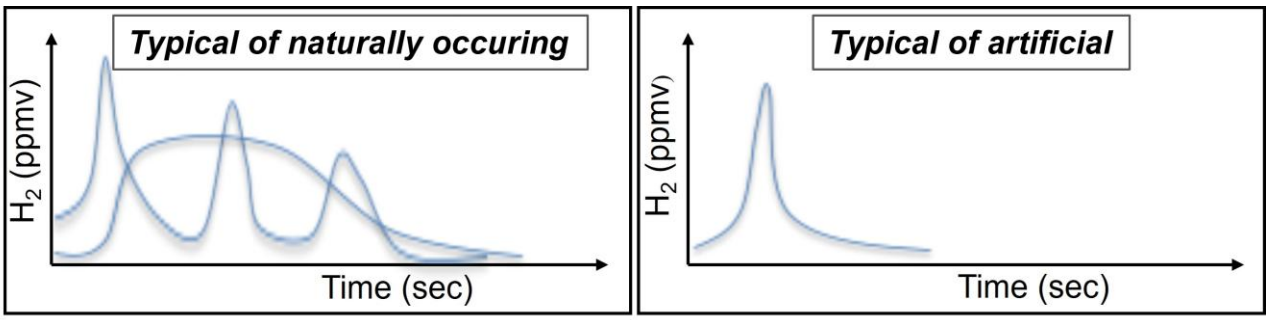

Figure 4. Conceptual diagram of the concentration patterns of H_2 in soil-gas over time, generally expected for naturally occurring (geological and microbial) and artificial H_2, using gas detectors with an internal pump. Geological gas seepage can result in intermittent or prolonged signals with slow decline; microbial gas may form prolonged signals. Artificial H_2 generally results in a single peak with more rapid decline.

For the studied control site, the existence of geological H_2 is excluded, as discussed in section 2, and microbial H_2 is not expected, given the absence of H_2 in the permanent probes (as described below) and the lack of humid ecosystems nearby. In our dissipation tests, the Dräger X-am 8000 pump flow rate was 0.35 L/min, and the time-series data were downloaded from the internal datalogger using the GasVision™ software. The H_2 concentration was measured immediately after the probe insertion (the ”0-time method”) and starting 5 minutes after the probe installation (”5-min method”). It is expected that after 5 minutes the artificial H_2 peak will be substantially dissipated. The 5-min method was specifically employed when the readings with the 0-time method exceeded ~50 ppmv H_2.

3.4. Sequence of H_2 measurements

The soil-gas measurements were conducted during 7 different periods, starting from March 2025 to September 2026. In the first set of measurements (March 2025), only the Dräger #1 was used. The Dräger #2 was used simultaneously with Dräger #1 starting from February 2026. CO was also detected from this date onwards.

4. Results

4.1. Areal measurements

In the FESE Park, a total of 25 areal measurements were performed, 12 using the sliding hammer probe and 13 using the sledgehammering method (Table 1). In the sliding hammer approach, when the 0-time method is applied, H_2 levels range from below detection limit (bdl) to 25 ppmv, and CO remains undetected (bdl), while in the case of the 5-min method, H_2 and CO were never detected. Using the sledgehammer,

and applying the 0-time method, H_2 concentrations ranged from bdl to 280 ppmv, and CO ranged from bdl to 36 ppmv, while both gases were never detected when using the 5-min method.

Table 1. Descriptive statistics of H_2 and CO concentrations during the areal measurements in the FESE Park. bdl - below detection limit

Descriptive statistics	Sliding hammer				Sledgehammer			
	0-time method – H_2 (ppmv)	5-min method – H_2 (ppmv)	0-time method – CO (ppmv)	5-min method – CO (ppmv)	0-time method – H_2 (ppmv)	5-min method – H_2 (ppmv)	0-time method – CO (ppmv)	5-min method – CO (ppmv)
N	11	1	11	1	9	4	9	4
Min	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
Max	25	bdl	bdl	bdl	280	bdl	36	bdl
Mean	8.1	-	-	-	59.4	-	6.4	-
Median	10	-	-	-	15	-	0	-

It is worth noting that artificial H_2 is not systematically generated; H_2 concentrations bdl were observed in 52% of the measurements. This confirms that artificial H_2 generation depends on soil characteristics, including its strength, presence of hard rocky fragments, silicate minerals, and organic matter, and, likely, humidity, as suggested by Davies et al. (2025), who used drilling methods, and by laboratory experiments on mechano-radical H_2 generation (Lefeuvre et al., 2025). Accordingly, the lack of H_2 observations in soil-gas surveys is not an indication of total absence of artificial gas generation by a given soil-gas method.

4.2. Measurements at the permanent probe site

In the FESE Park, at the site with permanent probes, a total of 64 measurements were performed from the permanent probes and 56 using the two hammering techniques. In the permanent probes, H_2 was never detected (multiple measurements from March 2025 to September 2026). With the sliding hammering (37 measurements), H_2 levels range between bdl and 200 ppmv, and CO remains undetected (bdl) using the 0-time method. Using the 5-min method, both H_2 and CO were never detected. Using the sledgehammer, and applying the 0-time method, H_2 concentrations ranged from 25 to 385 ppmv, and CO quantities ranged from bdl to 50 ppmv, while with the 5-min method H_2 and CO were never detected. Two short videos showing soil-gas H_2 measurements in the control site with both methods are available at https://engagelab.granturi.ubbcluj.ro/media/.

Table 2. Descriptive statistics of H_2 and CO concentrations when using the 0-time and 5-min methods at the permanent probe site. bdl - below detection limit.

Descriptive statistics	Sliding hammer				Sledgehammer			
	0-time method – H_2 (ppmv)	5-min method – H_2 (ppmv)	0-time method – CO (ppmv)	5-min method – CO (ppmv)	0-time method – H_2 (ppmv)	5-min method – H_2 (ppmv)	0-time method – CO (ppmv)	5-min method – CO (ppmv)
N	20	17	7	2	17	2	17	2
Min	bdl	bdl	bdl	bdl	25	bdl	bdl	bdl
Max	200	bdl	bdl	bdl	385	bdl	50	bdl
Mean	46	-	-	-	142.3	-	13.4	-
Median	37.5	-	-	-	87.5	-	0	-

Dissipation tests indicate that, for the sliding hammering method, H_2 levels exhibit a swift peak followed by a more rapid decline to zero compared to sledgehammering (Figure 5). In the latter case, H_2 concentrations are still at 40-50 ppmv levels after 3 minutes. This artificial “tail” is not noticeable using discrete gas sampling, for example, for analysis by gas chromatography. Using drilling methods, the artificial tail can last several days (Davies et al., 2025).

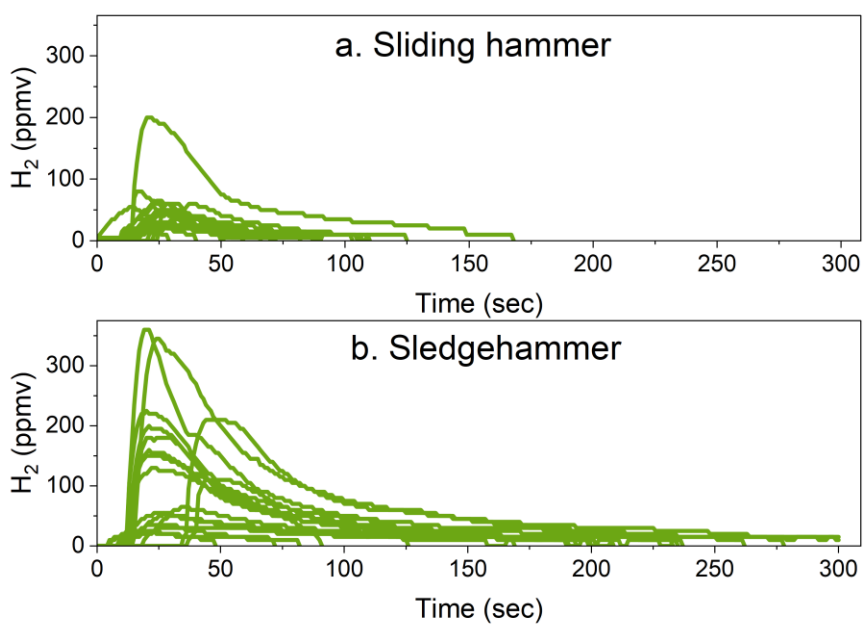

Figure 5. Dissipation test results showing H_2 concentrations over time (0-time method).

The concurrent detection of CO confirms the artificial gas generation (Figure 6). Using the sledgehammer method, a total of 9 out of 17 measurements had CO associated with H_2. Figure 6 shows a good correlation ($R^2 = 0.79$) between the measured H_2 and CO values, indicating that in general when higher H_2 is observed, CO is also coexisting. The CO values are beyond the levels induced by H_2 cross-sensitivity of the CO sensor, which is H_2 compensated (<1%, i.e., less than 10 ppmv CO can be artificially indicated with 1000 ppmv of H_2).

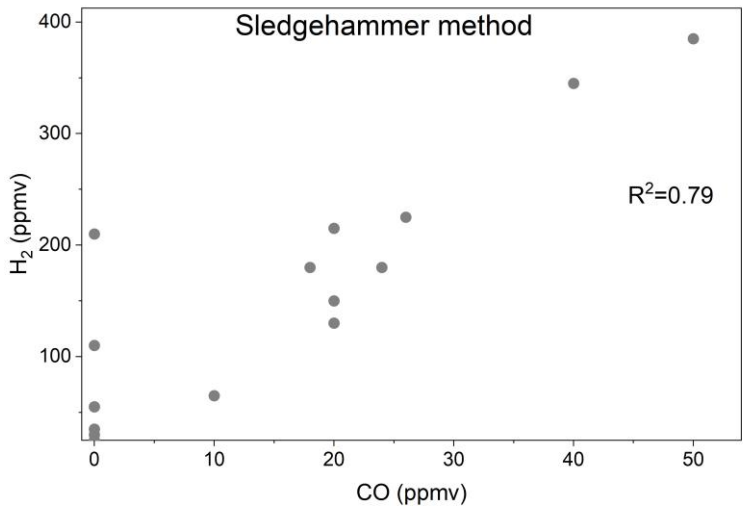

Figure 6. Graph showing H_2 vs. CO concentrations using the sledgehammer method.

CO associated with high H_2 values was also reported in several soil-gas surveys for natural H_2 exploration (e.g., Lefeuvre et al., 2021; Moretti et al., 2022; Pasquet et al., 2024; Roche et al., 2024), but the artificial gas generation was overlooked.

5. Conclusions and recommendations

The soil-gas measurement tests, performed in an urban park without geological H_2 occurrences, clearly showed that the sledgehammer technique produces higher concentrations of artificial H_2 (up to 385 ppmv) compared to the sliding hammer technique (up to 200 ppmv). Multiple lines of evidence, including (a) the detection of CO (up to 50 ppmv) beyond the threshold of cross sensitivity with H_2, (b) the H_2 concentration dissipation tests (single H_2 peak and zero H_2 after 5 minutes) and (c) the absence of H_2 in permanent probes, confirm the generation of artificial H_2.

The sliding hammer method is less invasive, with lower production of artificial H_2, compared to the sledgehammer method, and it is, therefore, recommended for soil-gas H_2 surveys whenever drilling is not necessary. If hard and compacted soil can only be penetrated by sledgehammer or drilling, discrete sampling (such as for gas chromatographic analyses) should be avoided, and portable gas detectors with continuous H_2 recording are preferable for monitoring the concentration pattern over time, although drilling

may create enduring artificial H_2 dissipation tails. Artificial H_2 generation during soil-gas sampling is not systematic (H_2 was below detection limit in 52% of our measurements) and depends on soil properties such as strength, presence of rock fragments, silicate minerals, organic matter, and humidity. Therefore, the widespread absence of H_2 during an areal survey does not rule out artificial gas production if H_2 is eventually measured. In any case, concentrations of several hundreds ppmv of H_2 in soil-gas cannot be cursorily interpreted as a geological gas emanation. We are currently extending this research with a detailed assessment of soil parameters to provide a more comprehensive understanding of the factors controlling the generation of artificial H_2 during soil-gas probing.

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