Interpreting the daily cycle of H_2 Venting in the Sao Francisco Basin of Brazil

Lawrence M. Cathles, Cornell University, Ithaca, NY 14853 and Alain Prinzhofer, GEO4U, Rio de Janeiro, Brazil

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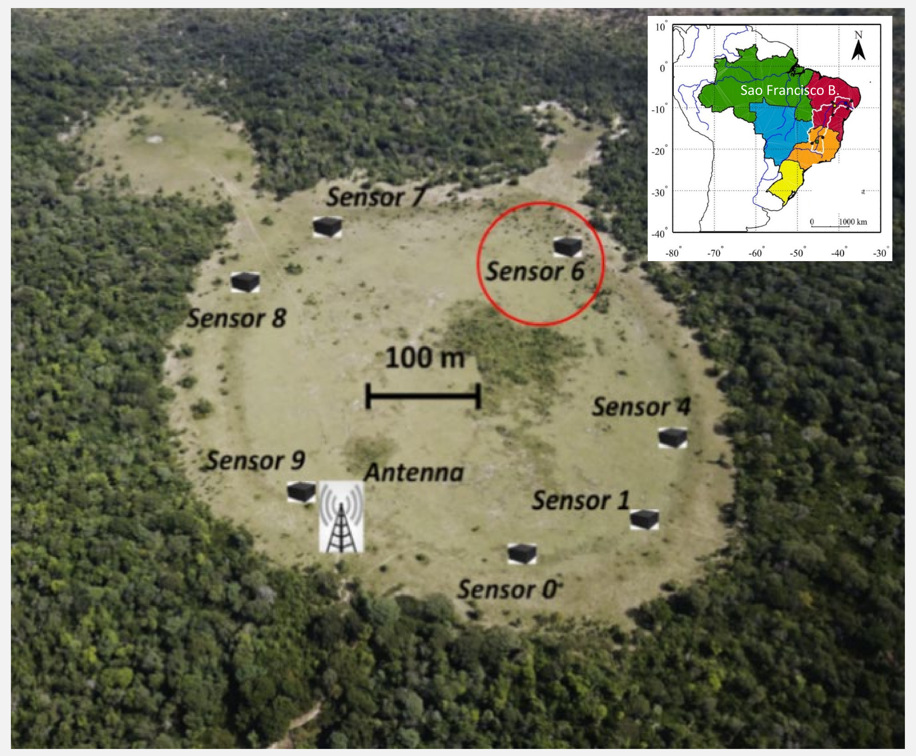
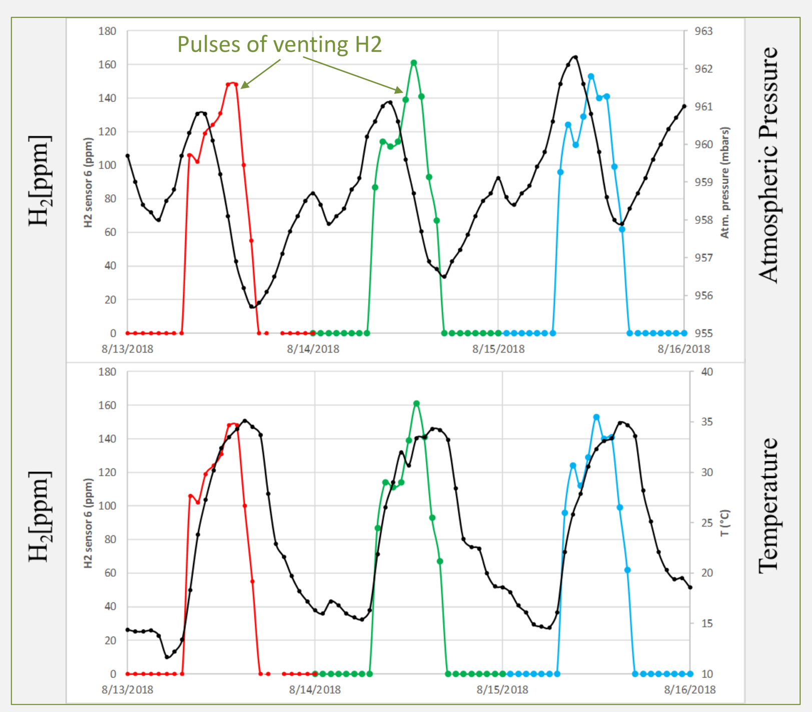
Introduction

H_2 gas, a Greenhouse-Friendly fuel, is venting from the perimeter "fairy circle" depressions in the Sao Francisco Basin of Brazil.

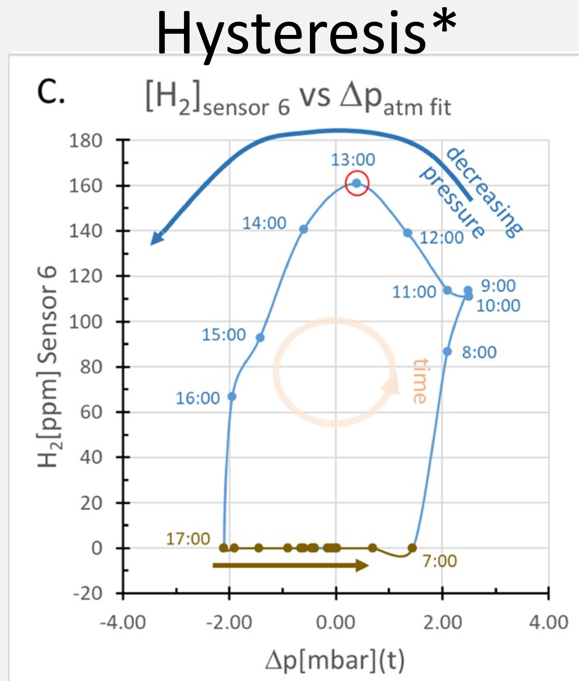


- 600 x 500 m barren depression
- 7000 to 178,000 m^3 H_2 d^{-1}
- $[H_2]$ ~100 ppm (max 1000ppm) in sensors at 1m depth
- Peak $[H_2]$ at 13:00 h
- T (15°C at night, 35°C in afternoon)
- Daily atm. P(t) cycle 2 mbar amplitude
- $[H_2]$(t) related to P(t) and T(t) but with hysteresis
- Average (over entire circle) venting rate is 0.05 to 1.2 m d^{-1}
- Water table at 3-5 m depth

P(t) and T(t) in Sensor #6



Hysteresis*



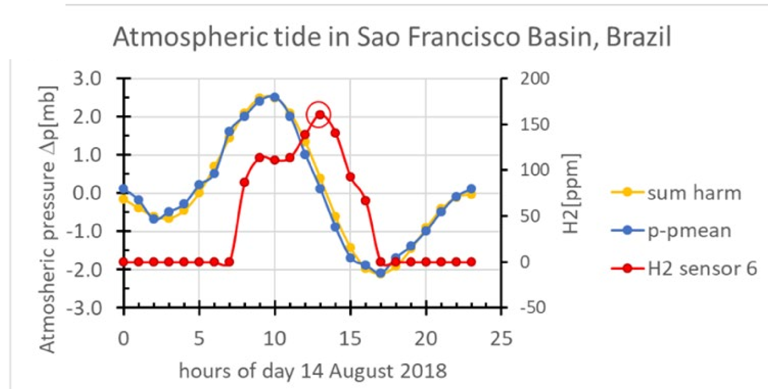
* Path of increasing $[H_2]$ ≠ decreasing path

Question: What causes daily H_2 venting pulses and their hysteresis?

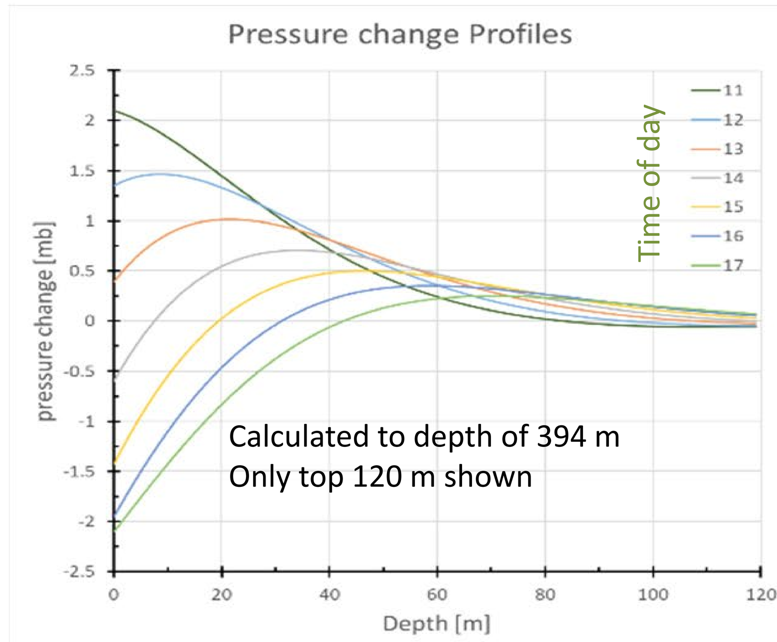
Answer: Atmospheric-pressure-tide-driven subsurface pressure changes.

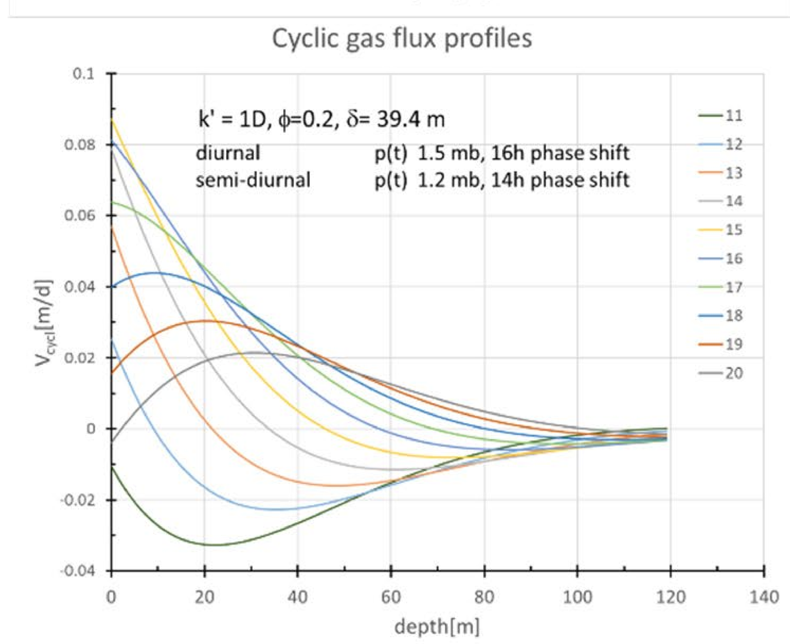
Method of Analysis: Whole region is subject to surface p(t) and air flow in and out of subsurface is calculated. (1D pressure wave calculation)

Atmospheric Pressure Tide

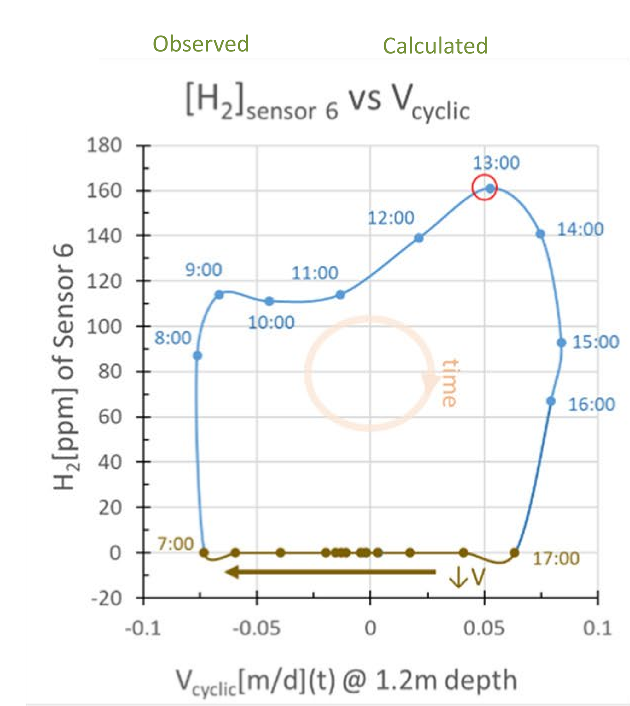


1. Sum of two components of atmospheric pressure tide (yellow) match observed P(t) (blue).
2. $[H_2]_{vent\ 6}$ (red) peaks at 13:00 hours.





3. Calculated venting flux at low end of observed range



4. Vent flux hysteresis similar to observed pressure hysteresis

1D Analysis

The flux of heat is described by Fourier's Law:

$$j = -K\frac{\partial T}{\partial z}\hat{z} \qquad \textbf{(1a)}$$

Conservation of mass requires:

$$\rho_T c_T \frac{\partial T}{\partial t} = -\nabla \bullet j = K_T \frac{\partial^2 T}{\partial z^2}$$

$$\frac{\partial T}{\partial t} = \kappa_T \frac{\partial^2 T}{\partial z^2} \qquad \textbf{(2a)}$$

Thermal dispersivity media $\kappa_T = \frac{K_T}{\rho_T c_T}$

The flux of gas is described by Darcy's Law:

$$V = -\frac{k'}{\mu}\frac{\partial p'}{\partial z}\hat{z} \qquad \textbf{(1b)}$$

Conservation of mass requires:

$$(\beta_m + \varphi\beta_f)\frac{\partial p'}{\partial t} = -\nabla \bullet V = \frac{k'}{\mu_{air}}\frac{\partial^2 p'}{\partial z^2}$$

$$\frac{\partial p'}{\partial t} = \kappa_p \frac{\partial^2 p'}{\partial z^2} \qquad \textbf{(2b)}$$

Hydraulic dispersivity media $\kappa_p = \frac{k'}{\mu_{air}(\beta_m + \varphi\beta_{air})} \cong \frac{k'}{\mu_{air}\varphi\beta_{air}}$

Permeability =1 Darcy; Dynamic viscosity

$$T(z,\bar{t}) = \alpha_o e^{z/\delta}\cos(2\pi\bar{t} + z/\delta_T) \qquad \delta_T = \sqrt{\frac{\kappa_T P}{\pi}}$$

ϕ	δ_T
0.1	0.107m
0.2	0.102
0.4	0.098

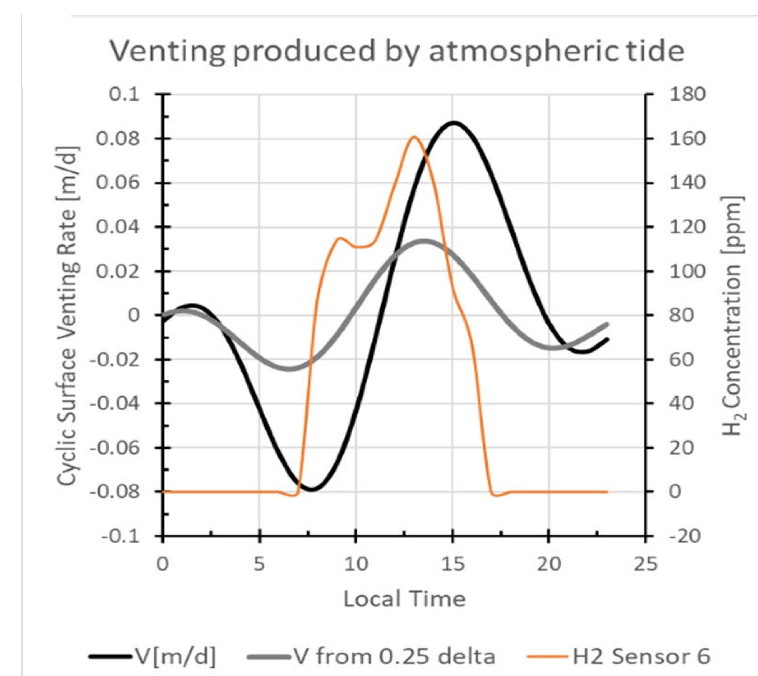
δ_T is the temperature skin depth: the depth at which the temperature change = 1/e that at the surface.

a. Temperature wave does not penetrate deeply enough. T(t) cannot be explanation of periodic venting.

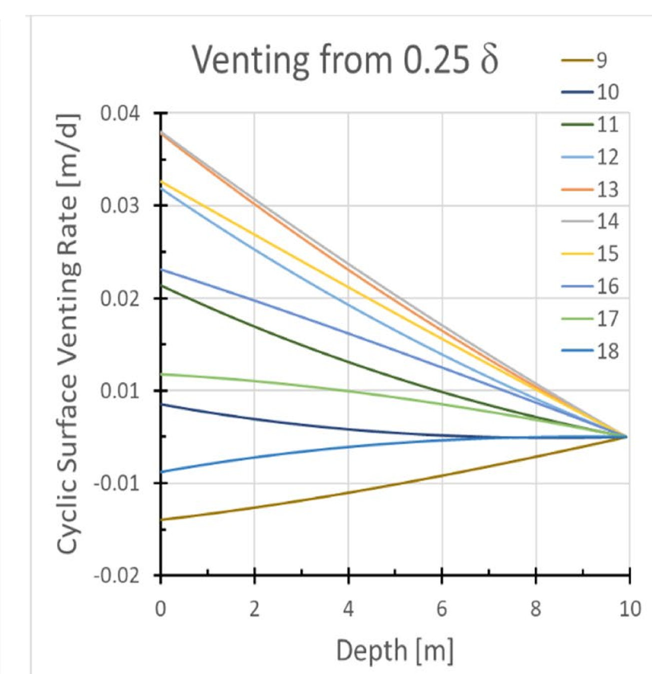
$$p(z,\bar{t}) = \alpha_o e^{z/\delta_p}\cos(2\pi\bar{t} + z/\delta_p) \qquad \delta_p = \sqrt{\frac{\kappa_p P}{\pi}}$$

ϕ	δ_p
0.1	56.1m
0.2	39.7
0.4	28.0

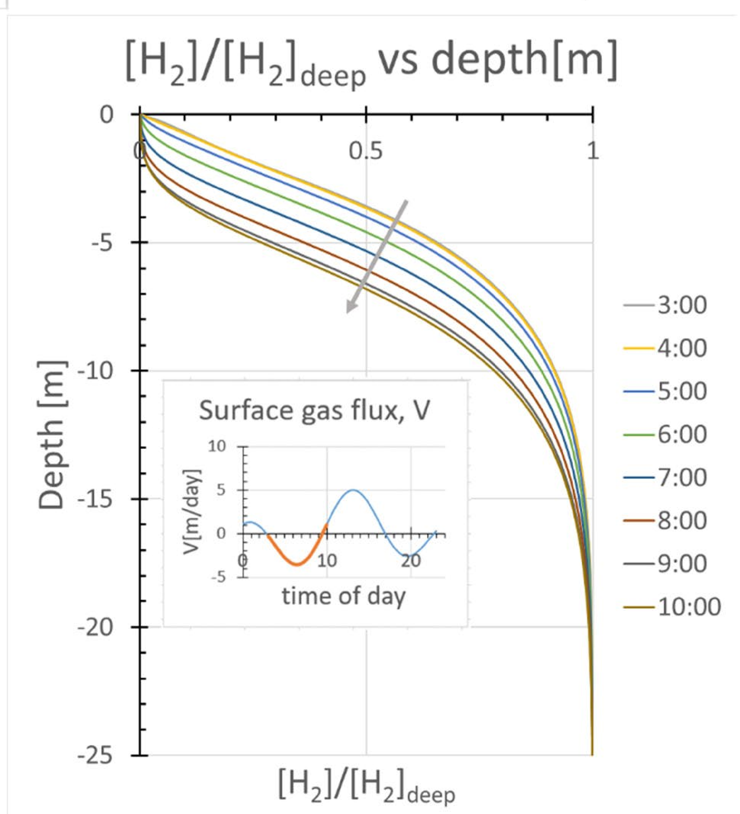
b. Pressure penetrates deeply enough to modulate venting

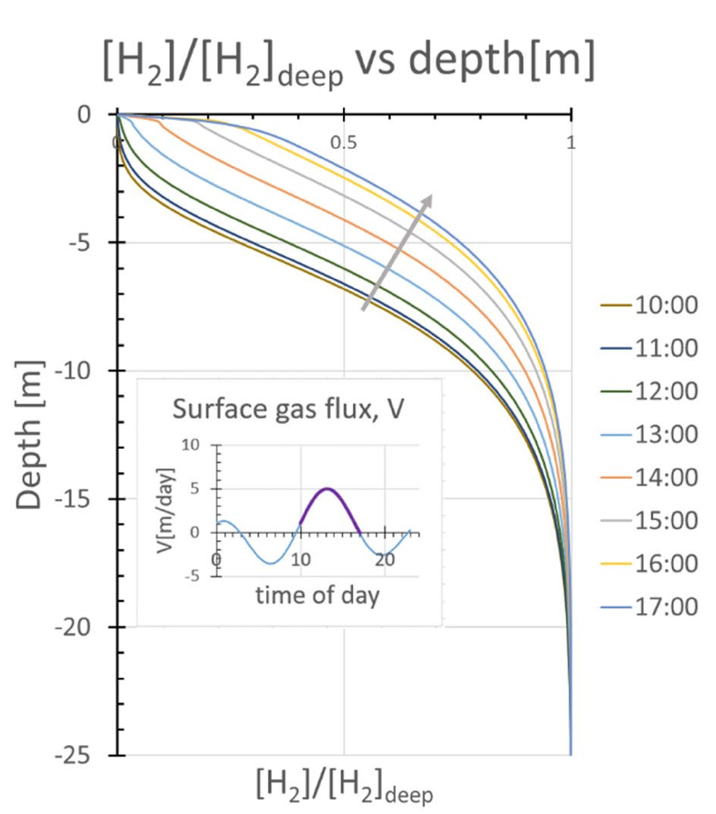


5. Vent flux (black) peaks at 15:00 hours.
6. Pressure penetration must be partial to peak at ~13:00 hours
7. Grey curve shows peak position for 10m penetration.
8. Surface air flux at lower end of range observed.



9. Venting rate as function of depth for barrier at 10 m depth (0.25 δ, where δ=39.7m). (p(z) is almost uniform)



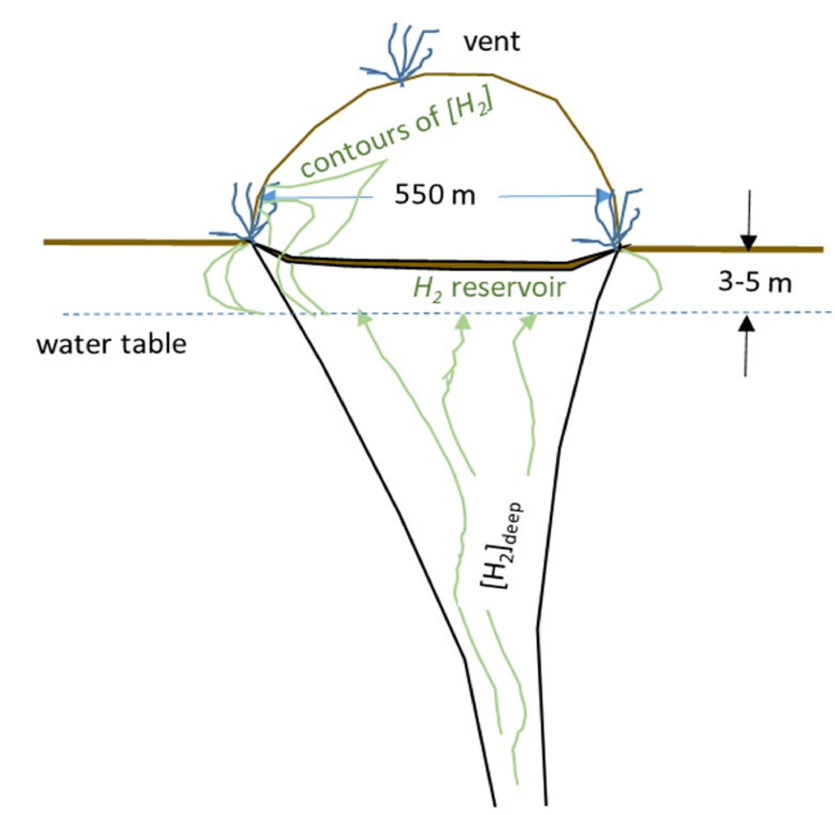


10. Calculated $[H_2]$(t) at 1 m depth. Pressure varied uniformly with atmospheric tide to 1000 m depth produces cyclic air velocities large enough to dilute $[H_2]$ at 1 m depth. 1D finite element advection-diffusion solution. This is more severe constraint than (8) above.

Conclusions from 1D analysis

1. Atmospheric pressure tide at San Francisco Basin could produce observed daily cycles in hydrogen gas venting (8). Daily T(t) cannot (a).
2. Barrier must truncate pressure wave penetration at a small fraction (~25%) of its potential penetration (6,7).
3. Changing $[H_2]_{1m}$ against even 1D dispersion requires reservoir volume 1000 times vent volume.
4. Reservoir permeable (1D) and of substantial volume.

Applications



1. An H_2 gas reservoir exists between surface and water table at 3-5 m depth
2. It is fed by H_2 gas leaking from depth
3. Atmospheric tidal pressure variations drive air into this reservoir through fractures on the "fairy circle" perimeter.
4. Fractures have volume <1/1000th that of the reservoir.

Testable Implications

1. $[H_2]$ concentration should be lowest near peripheral fractures, and possibly greatest under "fairy circle" center.
2. H_2 reservoir could extend outside "fairy circle".
3. Reservoir must empty (or be pushed to side) when water table rises and "fairy circle" depression floods.
4. H_2 recharge rate could be measured by rate of $[H_2]$ increase after water table subsides.
5. Surface of circle must be reservoir cap (e.g., be less permeable due to mud from periodic flooding?).
6. Earth tides have two equal daily peaks and thus cannot account for periodic $[H_2]$ venting (see ref 2 below).
7. Biologic modulation is only remaining hypothesis to explain $[H_2]$(t) .
8. 3D models needed for full analysis, but first $[H_2]$(x,t) away from vents needs to be better constrained.

References

1. Cathles and Prinzhofer, What pulsating H_2 Emissions suggest about the H_2 resource in the Sao Francisco Basin of Brazil, Geosciences **2020**, 10, 149; doi:10.3390/geosciences10040149
2. Simon et al, Earth tides and H_2 venting in the Sao Francisco Basin, Brazil. Geosciences **2020**, 10, 414; doi:10.3390/geosciences10100414