Distinguishing Signal from Noise in the Near Surface Using Simple Soil-Gas Measurements: Lessons from Natural and Industrial Analogs

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IT'S NOT ABOUT CONCENTRATION ... IT'S ABOUT PROCESS!

Introduction and Problem Statement

Question: How can a CO_2 release from a storage formation be identified in the near surface, where CO_2 is naturally abundant, temporally and spatially variable, and difficult to quantify?

Current Approach: Measure natural "background" CO_2 concentrations over 1 year to explain range of seasonal CO_2 variation. Anything different signals a release.

Problem:

- 1 year cannot capture the full magnitude of variation in natural CO_2 concentrations.
- Background measurements are time, cost, and labor intensive.
- Background concentrations cannot be measured everywhere.
- Concentration variations cannot be used to detect a release in the early stages.

Answer: Focus on process to identify the origin of CO_2. The various processes that produce and consume CO_2 also affect O_2, CH_4, and N_2 in predictable ways. Chemical ratios can identify whether a signal is natural background noise or a leakage signal.

NO BACKGROUND MEASUREMENTS REQUIRED!

Methods and Materials

1. Semipermanent Soil-Gas Wells

- Provide depth profiles that show subsurface gas distribution.
- Provide soil cores for analysis.
- Allow for repeat sampling.
- Require a driller ($).
- Require a targeted approach with limited spatial coverage.

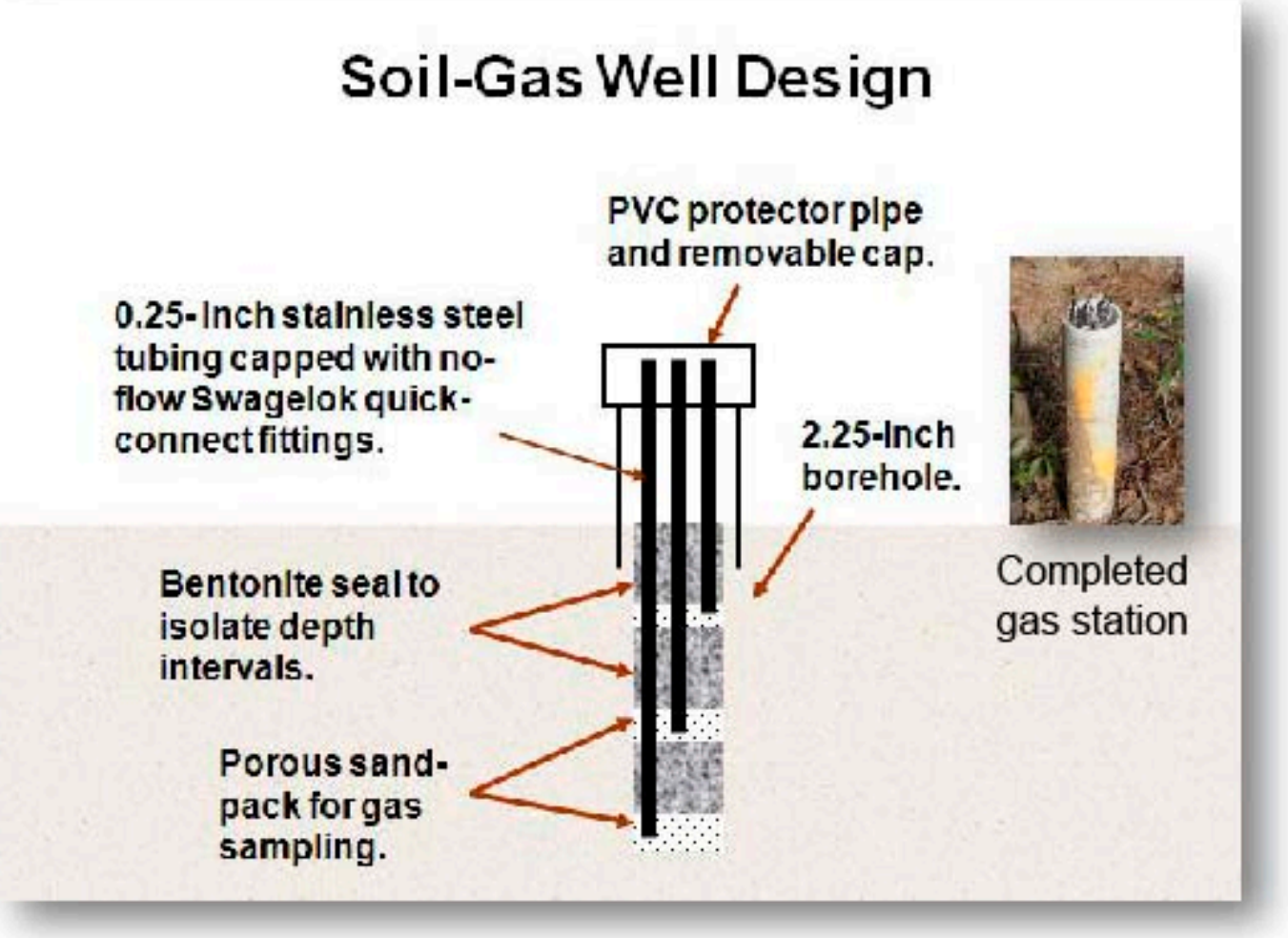
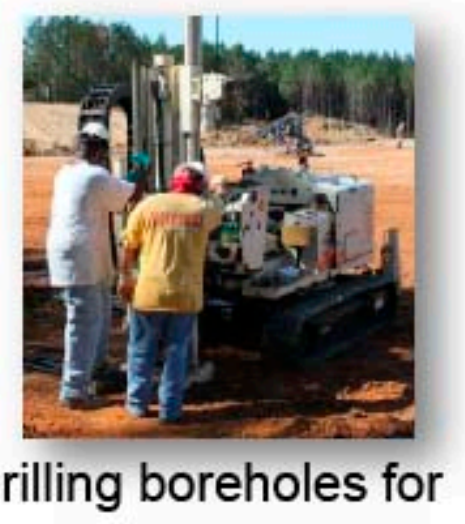


Fig. 1. Semipermanent soil-gas station design.



Drilling boreholes for gas station installation.

Installing gas wells.

2. On-Site Analysis

- SRI portable gas chromatograph.
- Dual column (molecular sieve and porapak Q) splits the sample.
- FID and TCD measures CO_2, N_2, O_2+Ar, and CH_4 in one 6-minute run.
- Methanizer allows for low CO_2 detection limits.
- Real-time results.

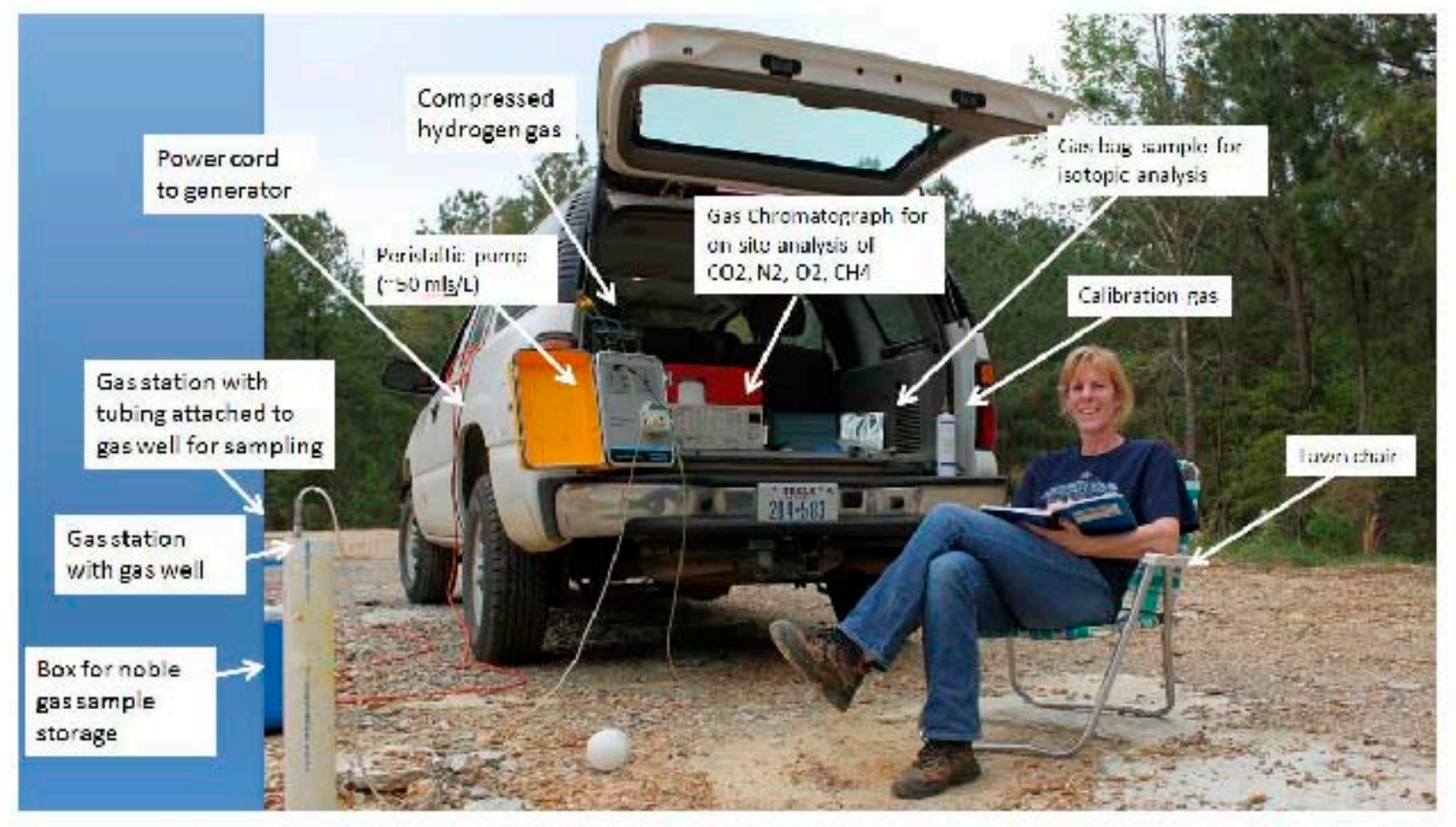


Fig. 2. Real-time soil-gas analysis.

CO_2 Cycling in the Vadose Zone

3. Processes:

- Root respiration
- Methanogenesis
- Methane oxidation
- Evapotranspiration
- Dissolution and reaction with soil carbonate
- Atmospheric mixing/dilution

- Gas concentrations are measured in percent (volume or molar), so any nonreactive addition or subtraction of a gas component will, by definition, dilute or concentrate, respectively, all other gases in similar proportions.
- Assume starting composition is air (78% N_2, 21% O_2, 0.035% CO_2, 1.7 ppm CH_4).

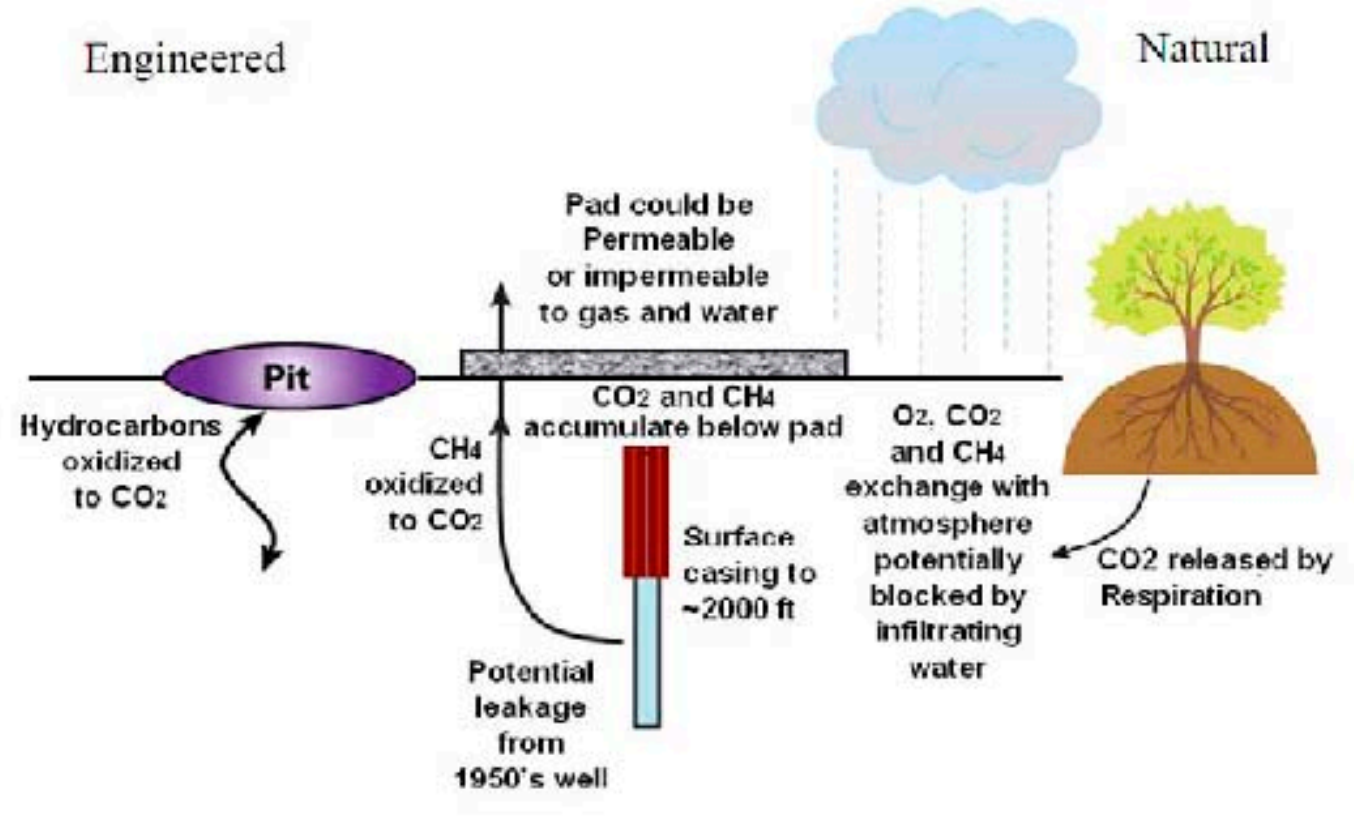


Fig. 3. Schematic of CO_2 cycling processes in natural and industrial settings.

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Natural Analog: West Texas Playa Lake, USA

4. Playa Lake

- Location: Southern High Plains, West Texas, USA.
- Playas are broad, gently sloping, circular basins that perch surface runoff before infiltration.
- Systematic variations in environmental factors among geomorphic zones (figs. 4 and 5) provide an opportunity to study the effects of environmental variability on soil-gas geochemistry.

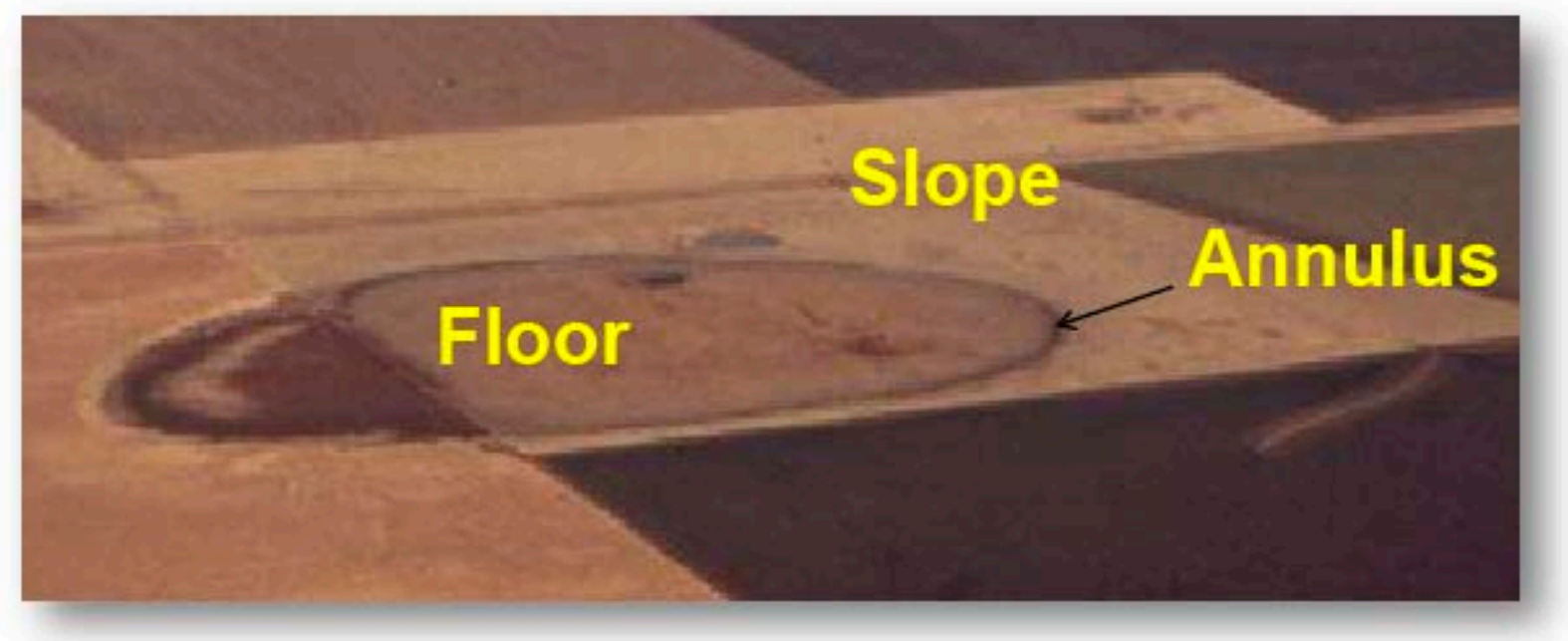

Fig. 4. Playa geomorphic zones.

	Floor	Annulus	Slope
Water Flux	High, through cracks in clay floor	Only during high water levels	Little flux, mostly evapotranspiration
Organic Carbon	High, oxidized to CO_2	Moderate	Low, concentrated mostly at surface
Soil Carbonate	Very high but flushed to depth	Moderate	Low, concentrated mostly at surface

Fig. 5. Environmental variability in playa zones.

- 3 years' monitoring soil gas during historic water-level fluctuations.
- 24 gas stations, 54 gas wells.
- Wells ≤15 m deep.
- >1000 real-time analyses of CO_2, CH_4, N_2, O_2.
- CH_4 is produced when microbial respiration outpaces O_2 influx, forming anoxic conditions.

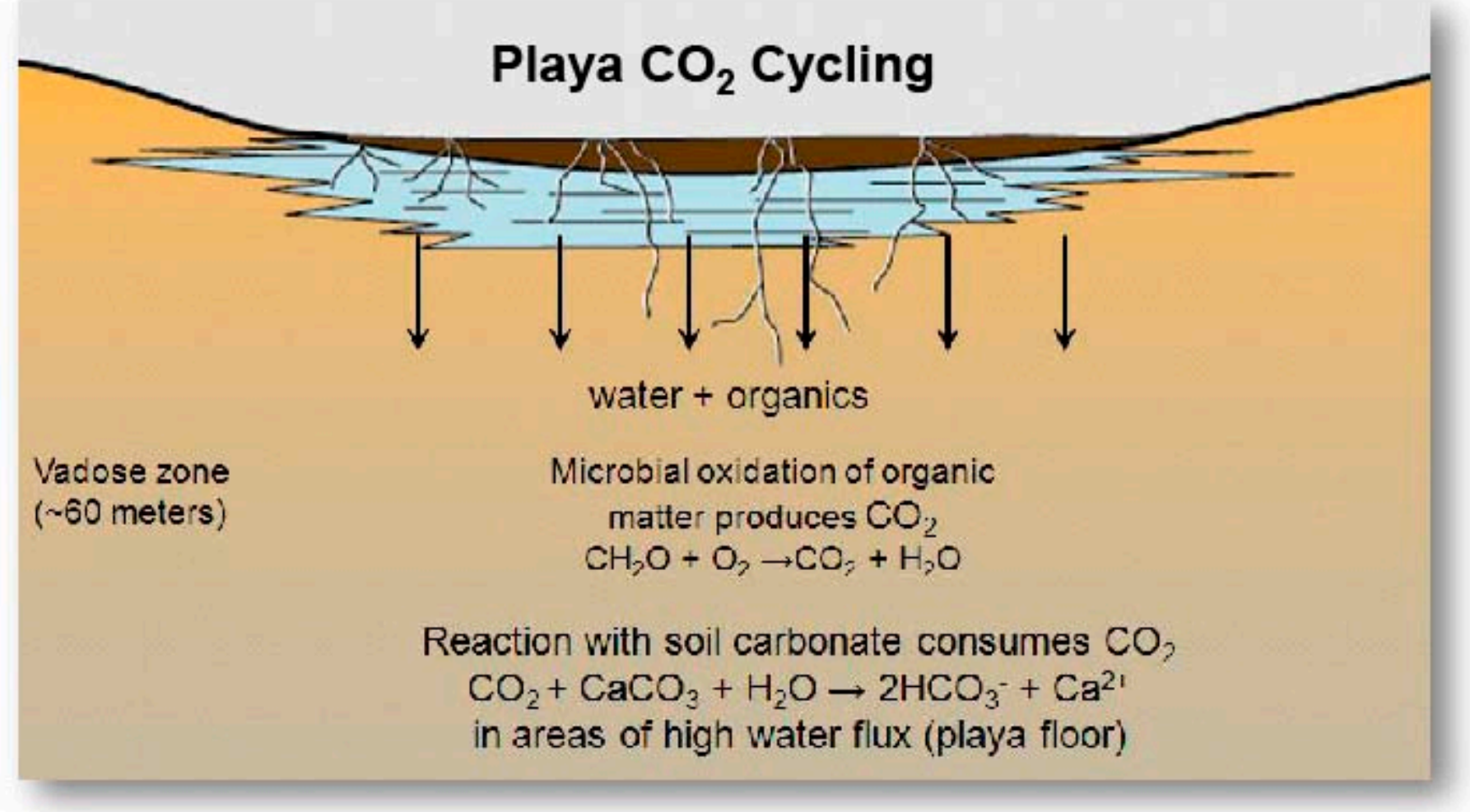

Fig. 6. Schematic of playa-floor processes, which also occur in the annulus during high water levels.

5. Results

Slope and most annulus samples are consistent with biologic respiration and/or oxidation of methane to CO_2 and fall between the lines representing these processes (fig. 7). However, floor samples show CO_2 less than expected for their O_2 compositions, indicating a CO_2 sink. The same samples show N_2 > atmosphere (78%) and correlate with CO_2 (fig. 8). Nitrogen isotopes indicate that denitrification is not responsible for high N_2 concentrations.

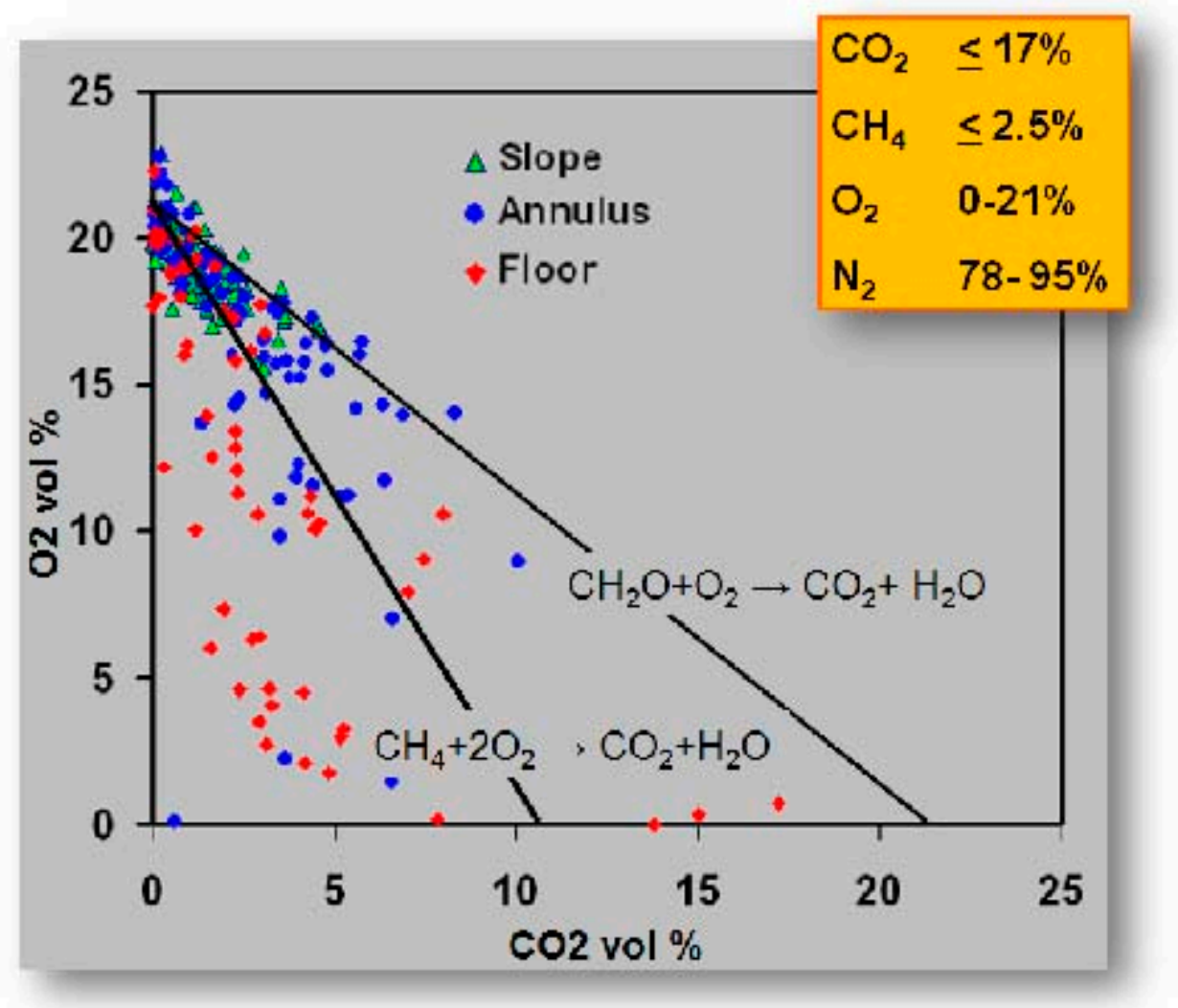

Fig. 7. CO_2 vs. O_2 for various biogenic processes.

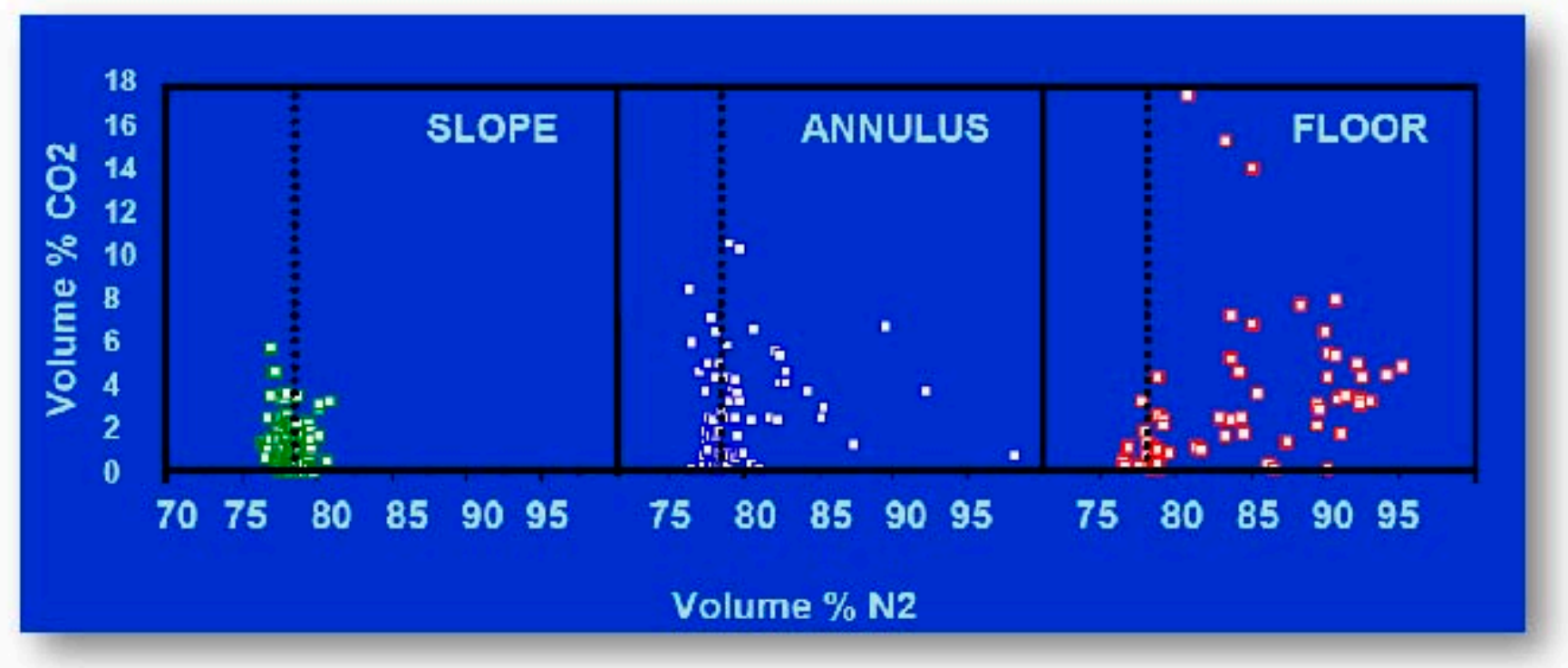

Fig. 8. CO_2 and N_2 concentrations correlate in the annulus during high water levels and in the playa floor where CO_2, water flux, and soil carbonate are high.

- CO_2 dissolves into recharging water and reacts with soil carbonate. Total pore pressure drops, causing advection of atmosphere (78% N_2) into soil pores, increasing the volume % of N_2 substantially above atmospheric (fig. 9).

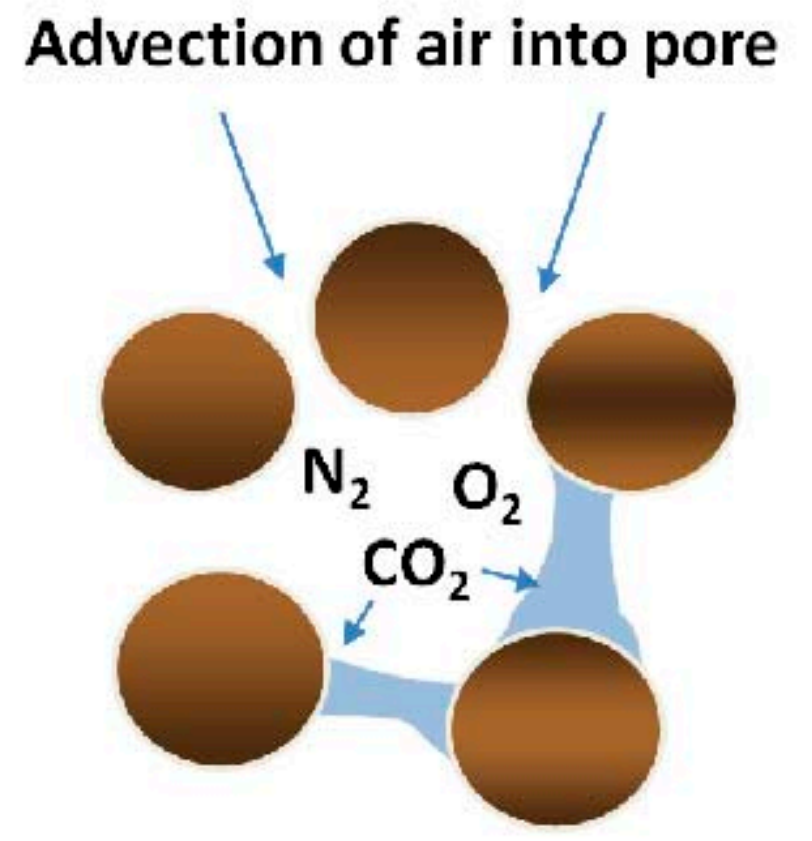

Fig. 9. Model of N_2 enrichment in soil gas due to the large amounts of CO_2 dissolution that are possible in the presence of soil carbonate.

6. Playa Conclusions

- Relationships among CO_2, O_2, and N_2 can be used to distinguish among the processes of biogenic CO_2 production, CH_4 oxidation, and dissolution of soil carbonate. Identification of these processes is independent of concentration. Can we use this approach to separate a CO_2 release from natural background?

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Industrial Analog: Cranfield Oilfield, Mississippi, USA

7. Cranfield Oilfield

- Oil production from 1944 through 1967.
- 94 plugged and abandoned wells.
- Field reentered in 2008 for CO_2-EOR.

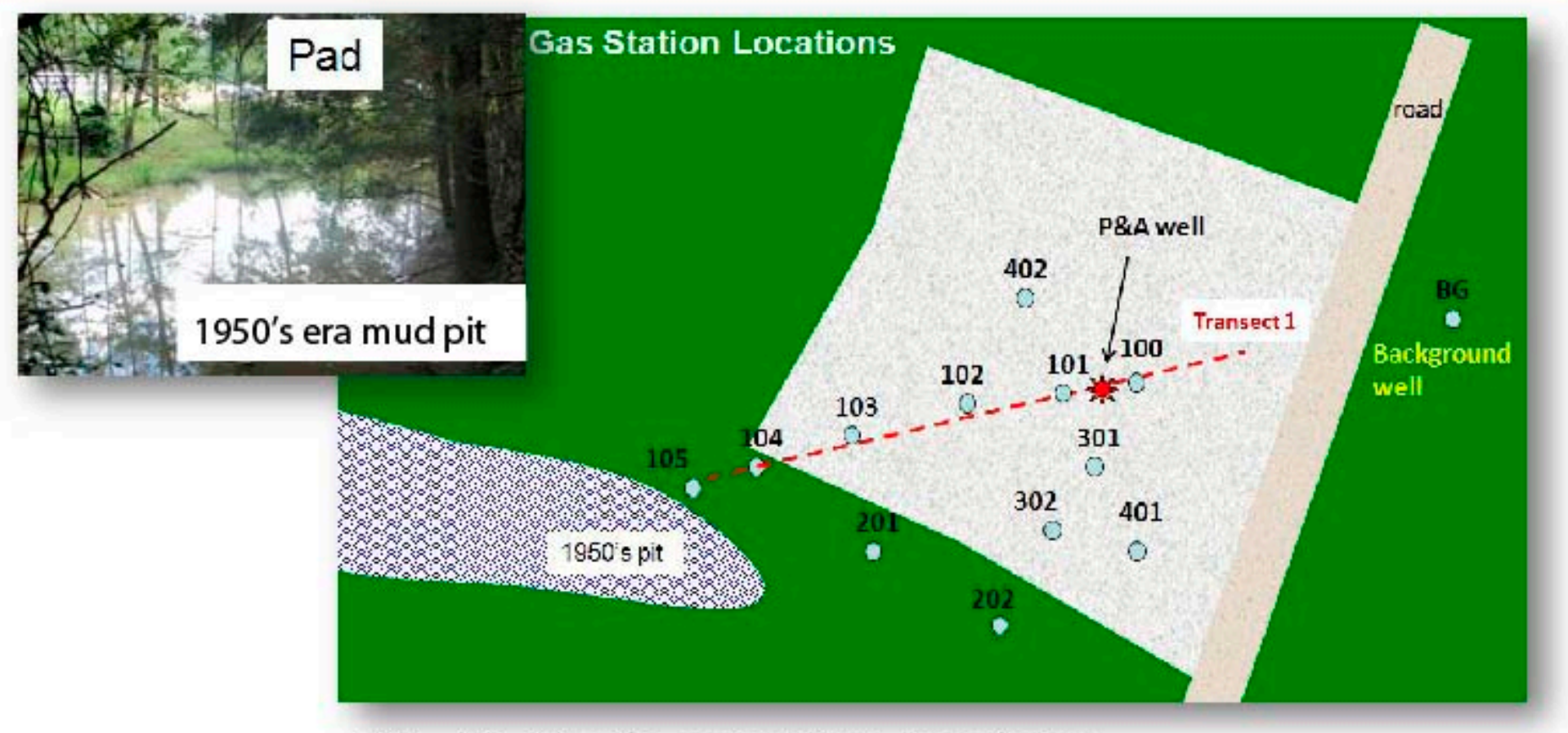


Fig. 10. P-site sampling locations.

8. P-Site

- Targeted area to test soil gas at an engineered site (fig. 10).
- 13 gas stations with 27 gas wells.
- Monitored since September 2008, before injected CO_2 reached the area.

8. Results

- CO_2 and CH_4 anomaly concentrated at well 103 (fig. 11).
- Isotopes indicate that CH_4 is exogenous from the oil and gas reservoir and CO_2 is from oxidation of methane.

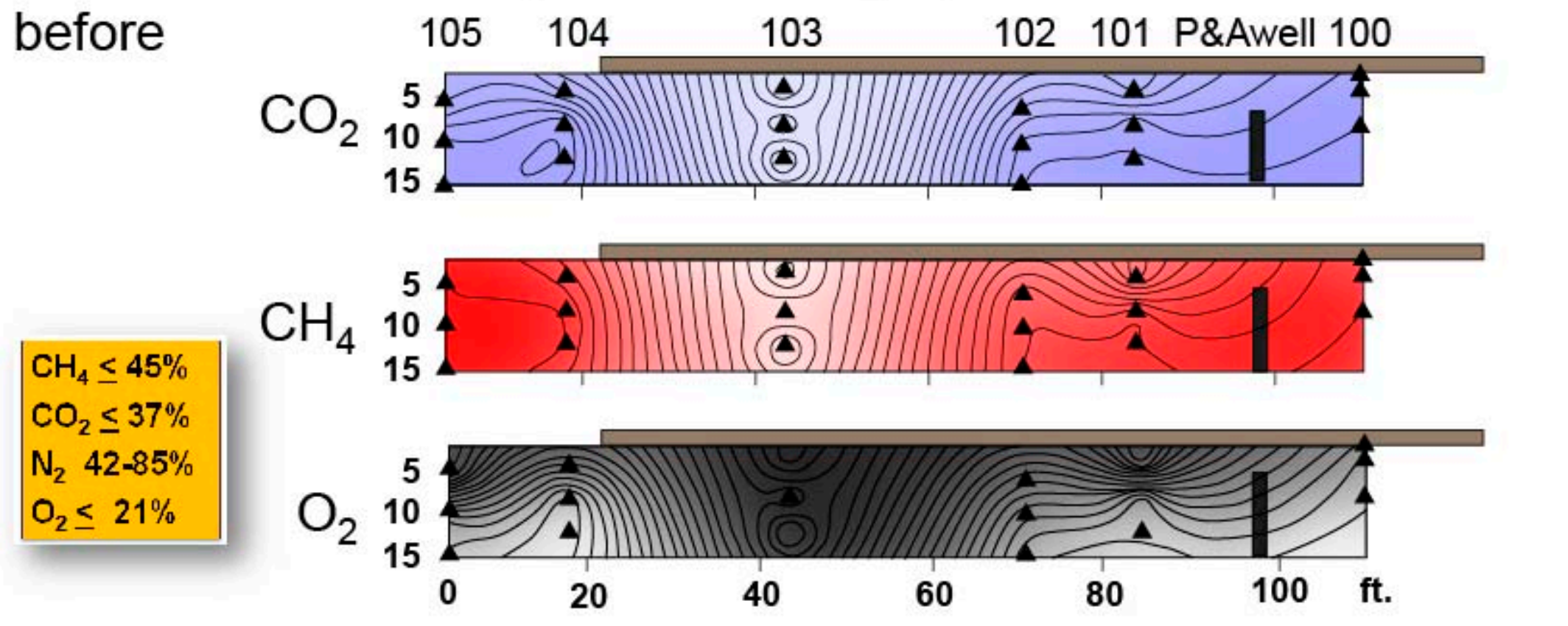


Fig. 11. Cross section of gas concentrations along transect 1 at the P-site. Light colors = high concentrations.

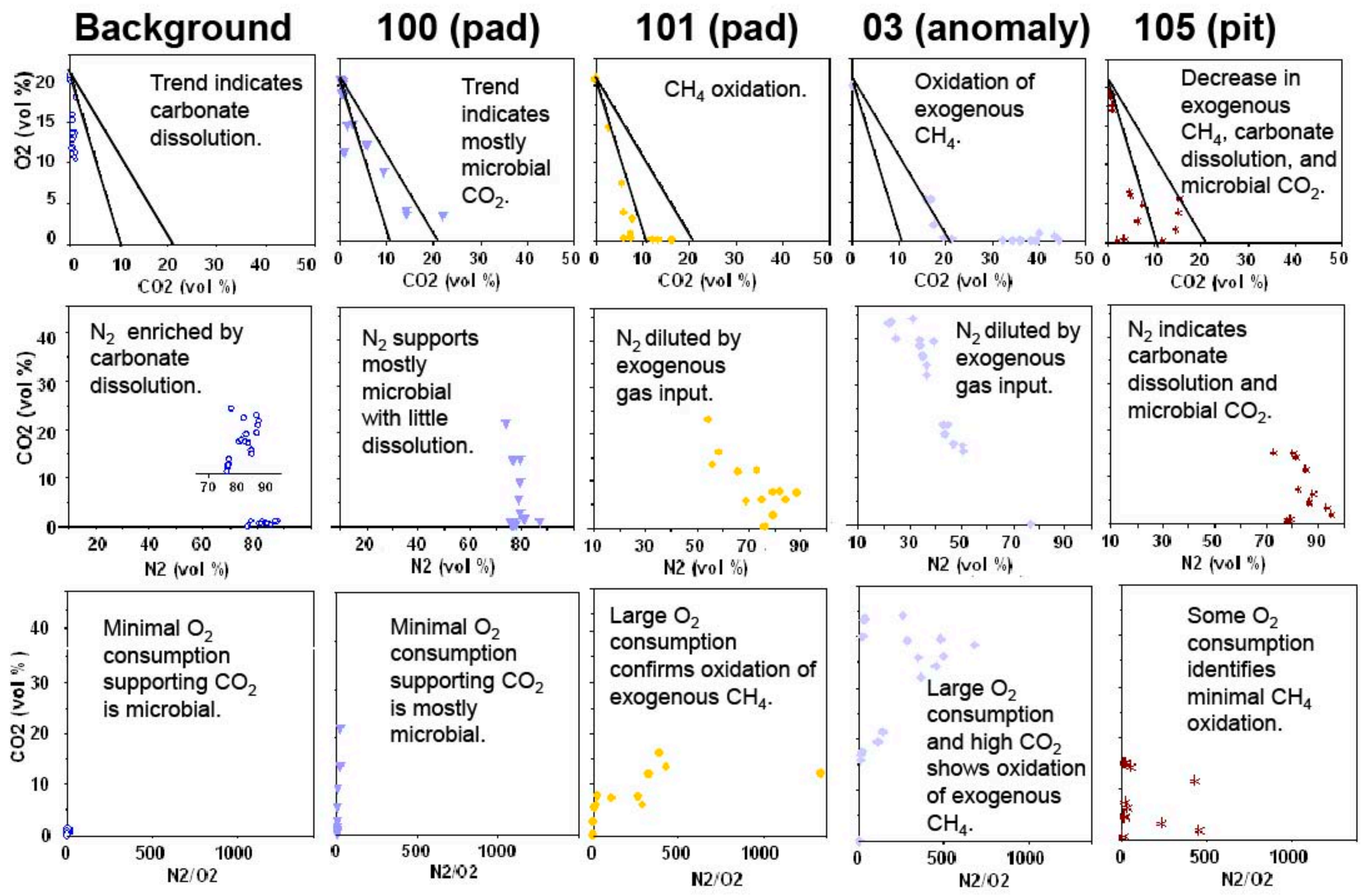
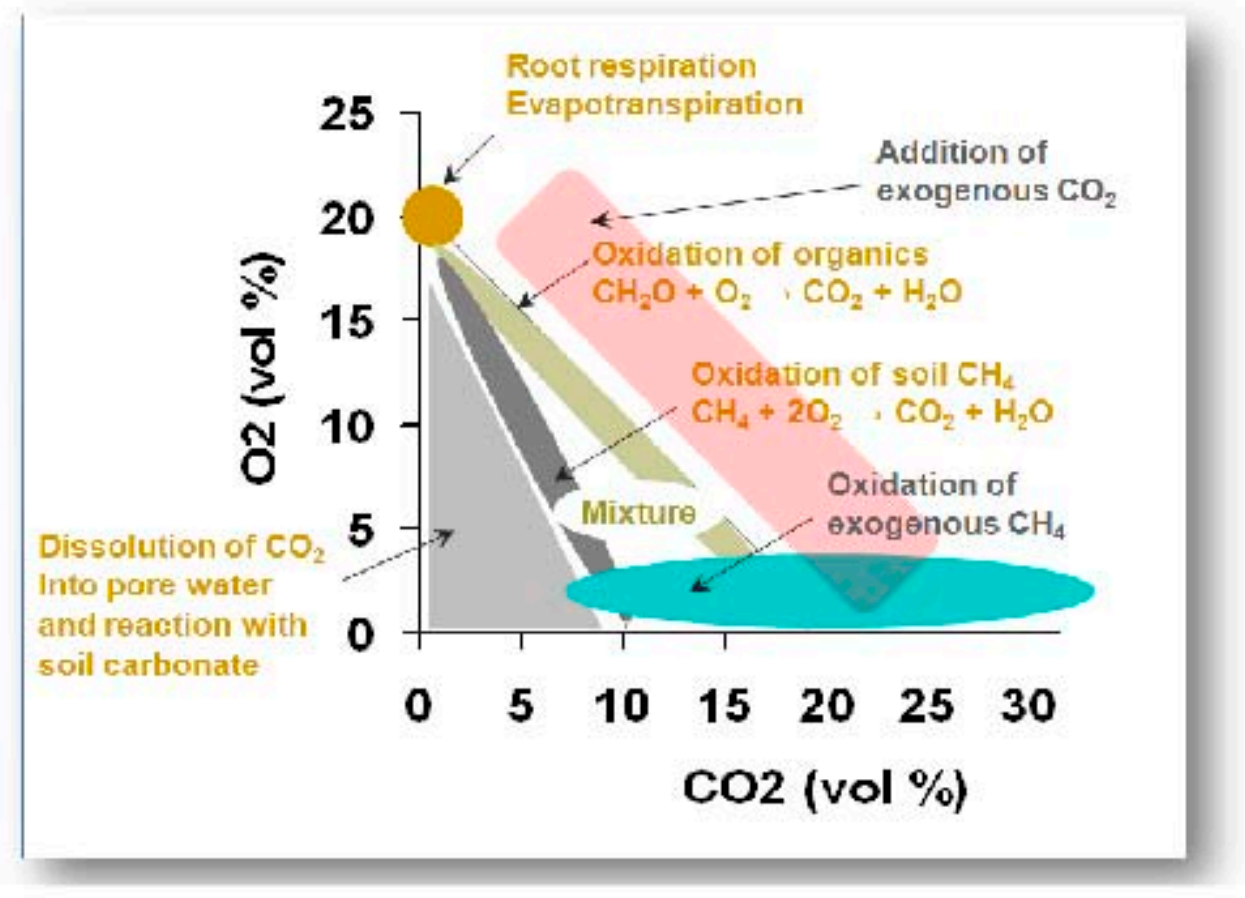


Fig. 12. Gas-concentration relationships identify processes affecting CO_2 at the P-site.

Conclusions



- Relationships among simple soil-gas parameters can identify carbon-cycling processes.
- Process can distinguish between background noise and leakage signal.
- Identifying process may eliminate the need for background measurements at carbon storage sites.
- More sites are needed to validate this approach, especially controlled release sites.

Fig. 12. Approach for separating leakage signal (gray) from background (tan) processes.

Acknowledgments: This research is funded by the U.S. Department of Energy, NETL, as part of the Southeast Regional Carbon Sequestration Partnership, managed by Southern States Energy Board, under contract DE-FC26-05NT42590. Additional support comes from the Gulf Coast Carbon Center and the Bureau of Economic Geology at The University of Texas at Austin. Many thanks to Denbury Resources Inc., operator of the Cranfield CO_2-EOR project, for collaboration and support.

Note: This work is currently in review for submission to *Geophysical Research Letters* as: Geochemical Approach for Separating Leakage Signal from Background Noise in the Near Surface at Geologic Carbon Storage Sites: Katherine D. Romanak, Philip C. Bennett, Changbing Yang, Susan D. Hovorka.

Reference: Whiticar, M. J., 1999, Carbon and hydrogen isotope systematics of bacterial formation and oxidation of methane: Chemical Geology, v. 16, no. 1, p. 291.

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