Tracer Gas Diffusion in the Eagle Ford Shale, Austin Chalk, and Adjunct Vertical Formations in Southwestern Texas*

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Abstract

As one of the two critical transport mechanisms in shale gas reservoirs, gas diffusion can be quantified by the diffusion coefficient (m^2/s) within the shale matrix. To understand the diffusion behavior in rock matrices, 1-D short-duration (within 24 hours) tracer gas diffusion chamber tests at a room temperature were conducted on the major reservoirs (Eagle Ford B calcareous Shale and Austin Chalk), and adjunct vertical formations (Atoc Chalk, Buda Limestone, Eagle Ford A dolomitic ash bed, and Salmon Peak Limestone) in the Southerwetern Texas area. Associated with X-ray diffraction, thin section, and mercury intrusion porosimetry, the mineral composition, pore structure (both geometry and connectivity) were taken into the discussion of influencing factors. The results of gas diffusion tests show that the diffusion coefficients among these rocks with different lithologies vary in the magnitude of 10^{-8} to 10^{-7} m^2/s and is influenced by pore structure especially pore connectivity.

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Boquillas (Eagle Ford) outcrop, Del Rio, TX

Outline

- Diffusion in natural rocks
- Sample properties
- Tracer gas diffusion method
- Summary

Eagle Ford B Calcareous Shale

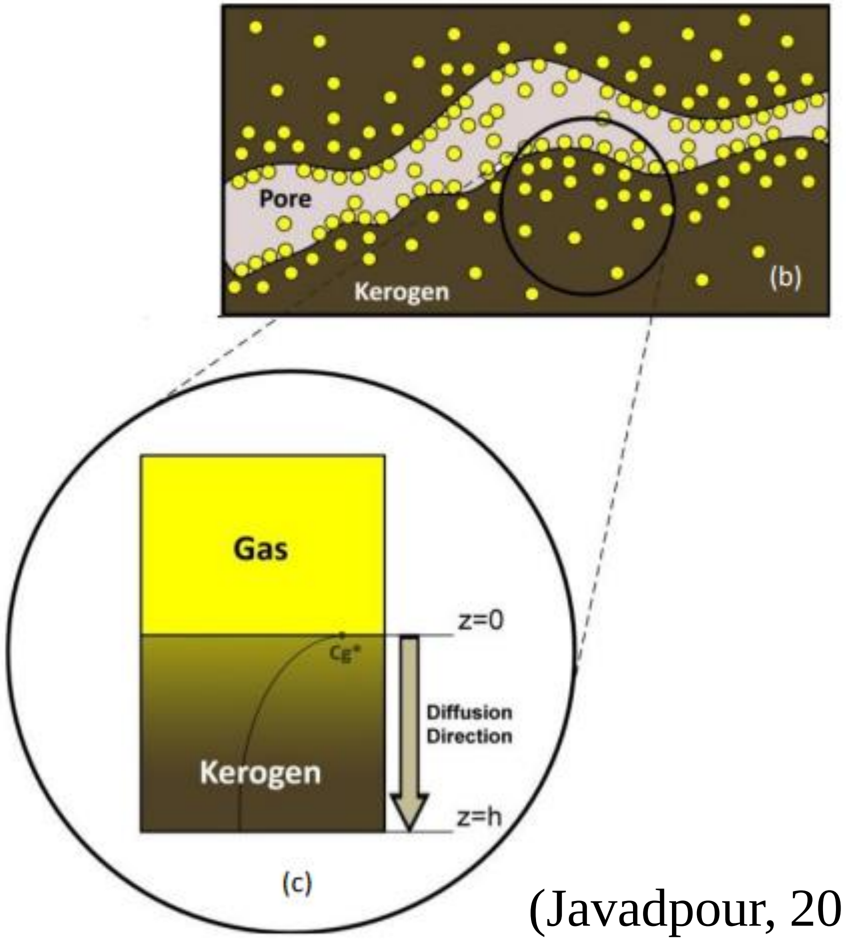
Diffusion in natural rocks

Why diffusion is important?

- Occur at gas or liquid phase
- Rate-limiting or dominate process of fluid flow and mass transport in low-permeability geological media

Distinguishing features

- Random particle walk
- Driven by concentration gradient, influenced by temperature

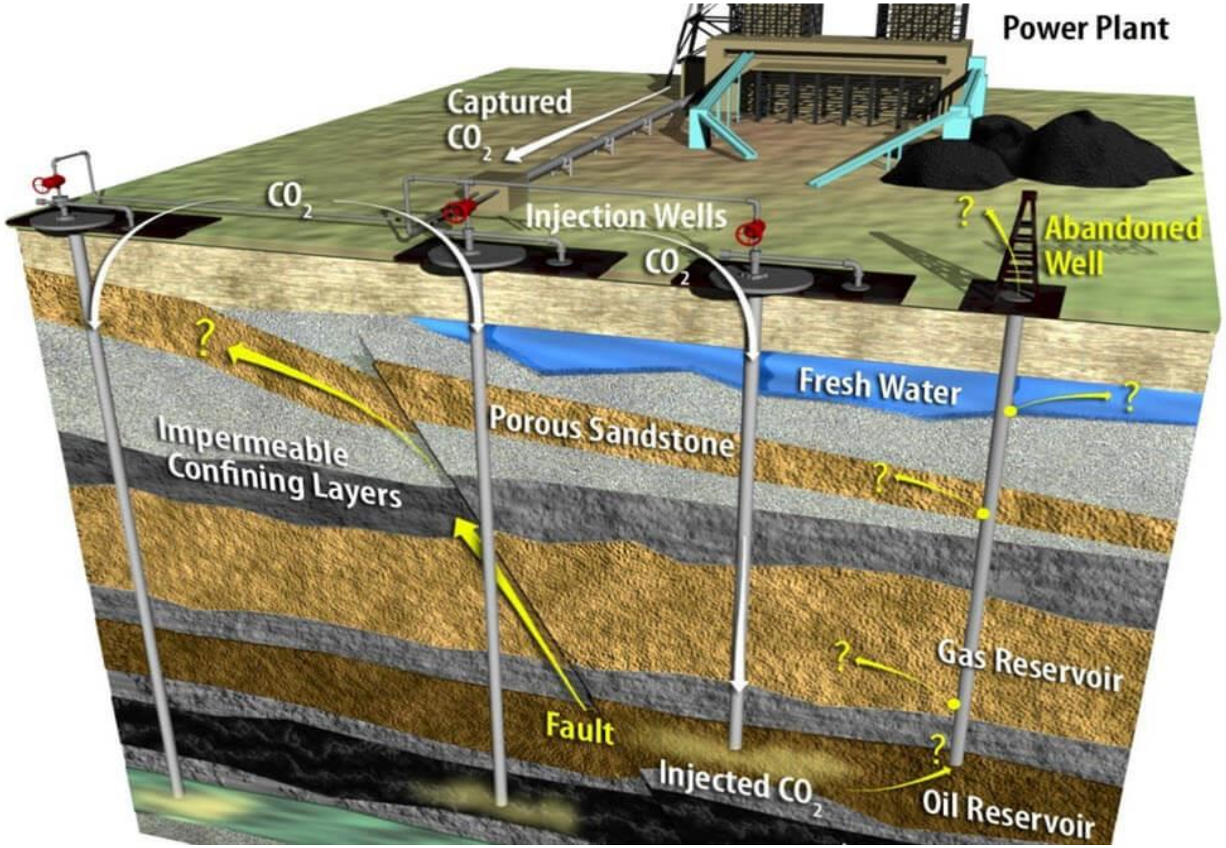


(Javadpour, 2015)

Diffusion in natural rocks

Applications

- Oil and gas recovery
- CO_2 sequestration
- Contaminant remediation
- Geologic disposal of radioactive waste



(GoldSim)

Sample properties

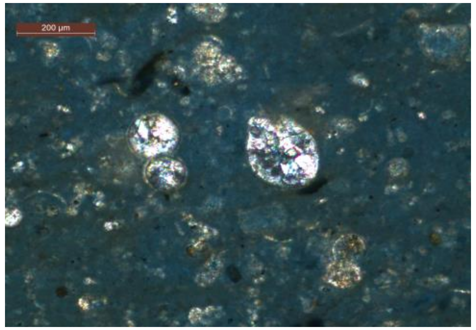
Series	Stage	Formation	
Upper Cretaceous	Santonian	Austin Chalk	
	Coniacian	Atco Chalk	
	Turonian	Eagle Ford Fm. Boquillas Fm.	E
			D
			C
	Cenomanian		B
			A
		Buda Limestone	
		Del Rio Formation	
Lower Cretaceous	Albian	Salmon Peak Limestone	

Outcrop in Midlothian, Ellis County, TX

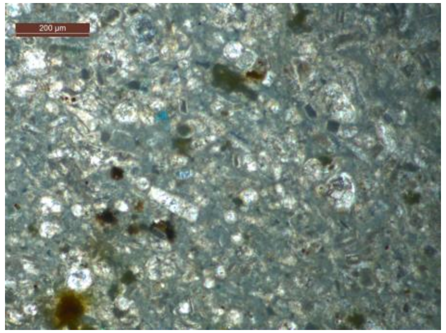
Del Rio, Val Verde County, TX

Sample properties

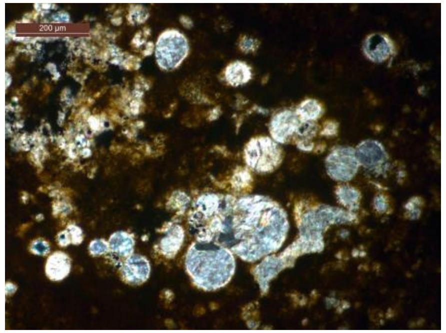
Sample ID	Mineral composition (wt.%)								
	Quartz	Calcite	Ankerite	Kutnohorite	Pyrite	Magnetite	Goethite	Kaolinite	Illite
Austin Chalk	1.2	96.3		0.5					2.0
Atco Chalk	1.0	99.0							
Eagle Ford B Calcareous Shale	15.5	79.6	1.2		0.8			1.3	1.6
Eagle Ford A Dolomitic Ash Bed	9.8	0.7	44.9	36.5		0.2	2.0	2.8	3.2
Buda Limestone	1.3	98.7							
Salmon Peak Limestone	0.2	99.8							



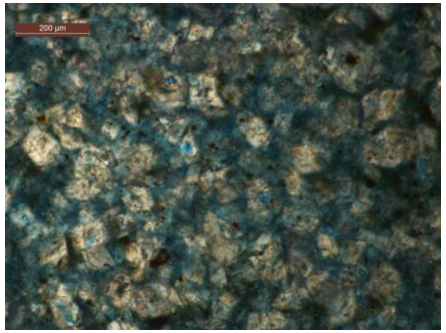
Austin Chalk



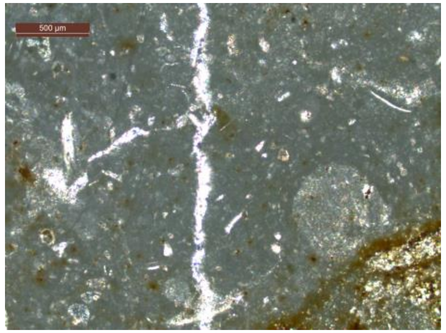
Atco Chalk



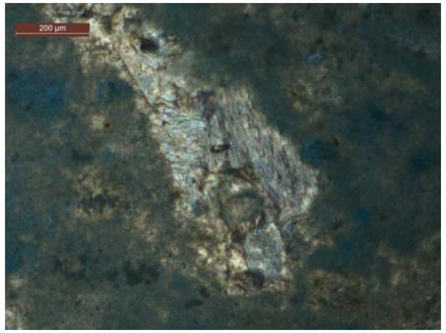
Eagle Ford B Calcareous Shale



Eagle Ford A Dolomitic Ash Bed



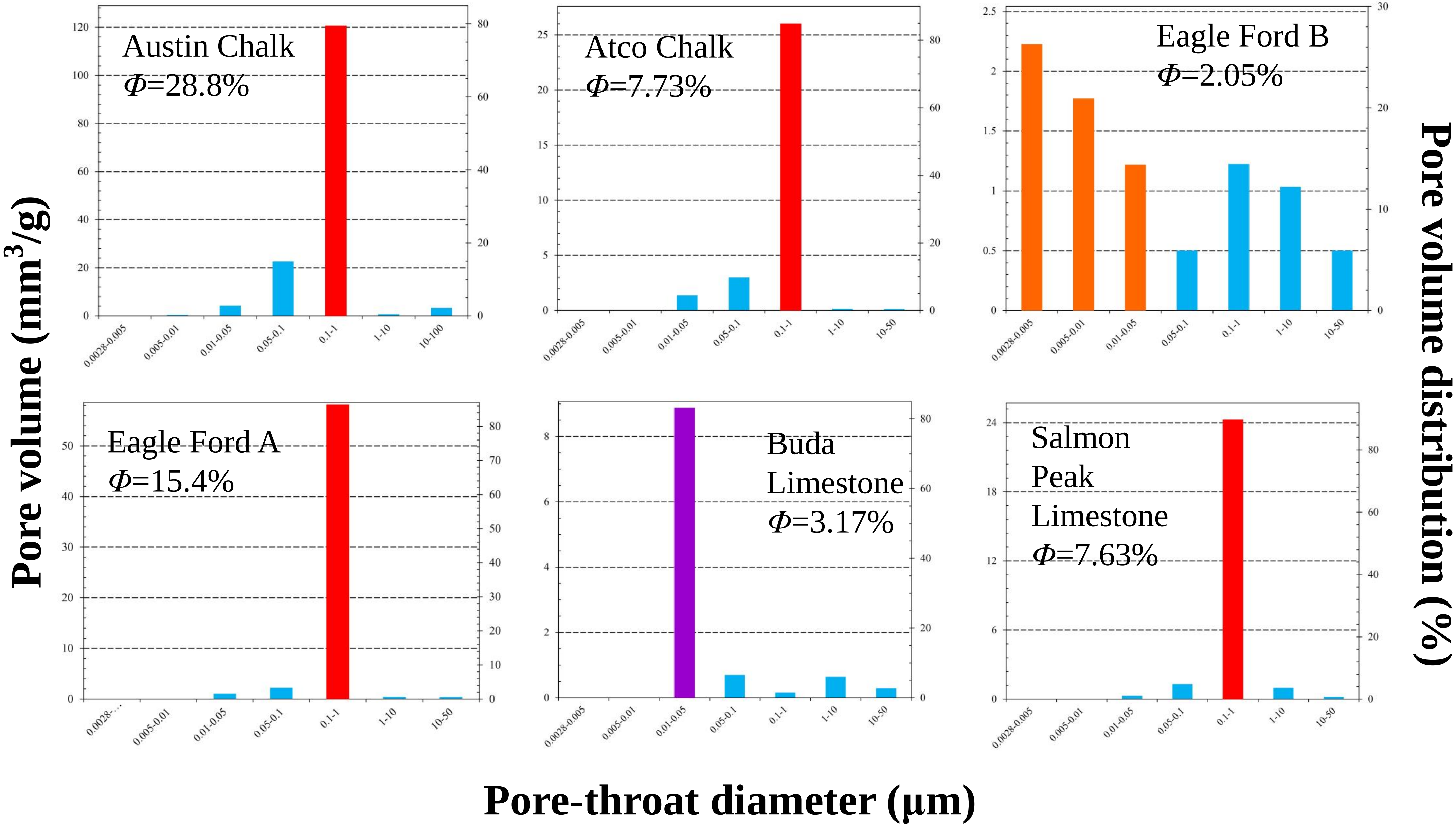
Buda Limestone



Salmon Peak Limestone

Sample properties

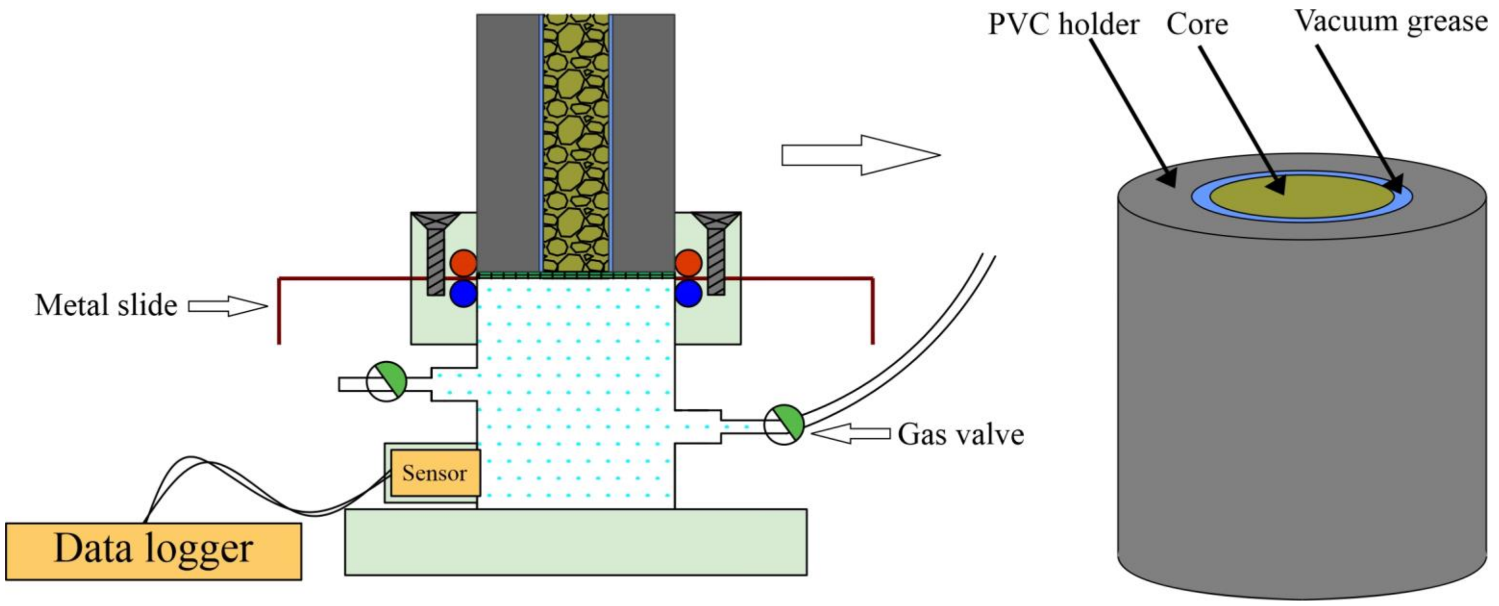
Mercury intrusion porosimetry



Tracer gas diffusion method

Currie method:

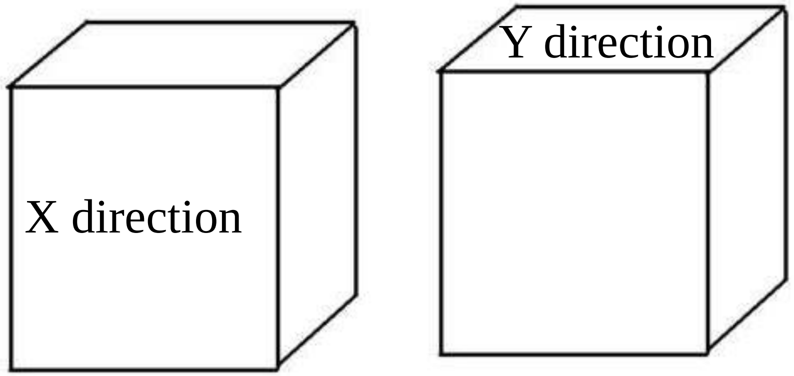
- First reported by Currie (1960).
- Commonly used in soil science
- Tracer gas: O_2



Advantages:

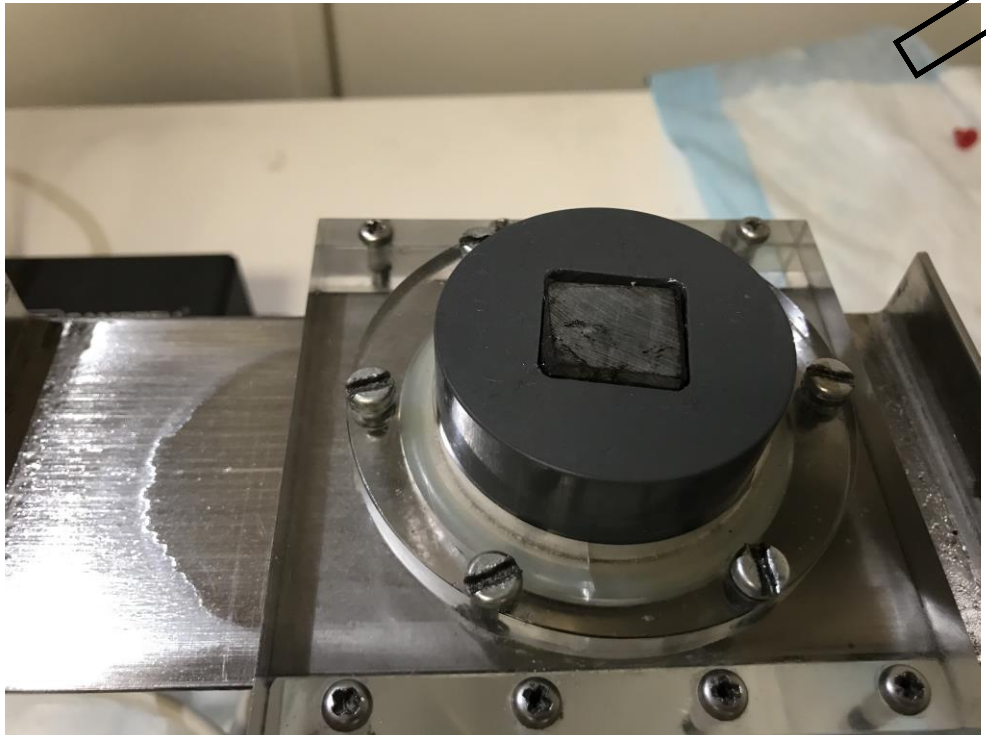
- Various sample shapes (irregulars; regulars: **cylindrical**, **cubic**, and granular)
- Applicable to various initial sample conditions (oven-dry, air-dry, partially saturated, fully saturated)

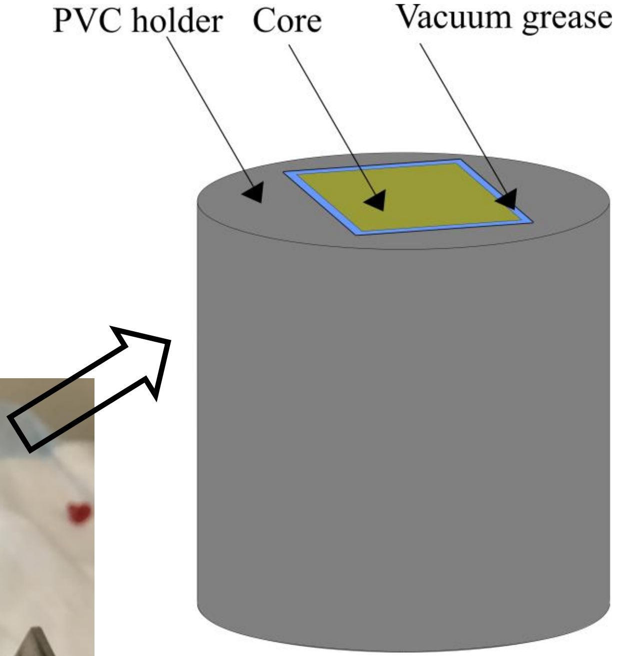
Tracer gas diffusion method



Diffusion coefficients analyzed in two directions perpendicular to each other

Sample and holder was sealed by vacuum grease to minimize leakage



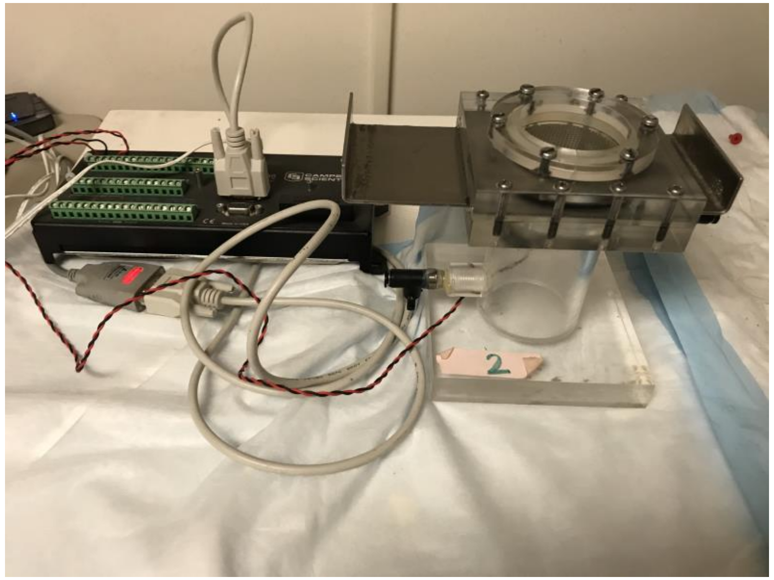


Tracer gas diffusion method

Fick's First law-based diffusion equation

$$C_r = \frac{C_t - C_s}{C_0 - C_s} = \sum_{n=1}^{\infty} \frac{2h \exp\left(-\frac{D_p \alpha_n^2 t}{\emptyset}\right)}{L(\alpha_n^2 + h^2) + h}$$

(Rolston and Moldrup, 2002)



At ln-ln scale,

$$lnC_r = -\frac{D_p \alpha_1^2 t}{\emptyset} ln\left(\frac{2h}{L(\alpha_1^2 + h^2) + h}\right)$$

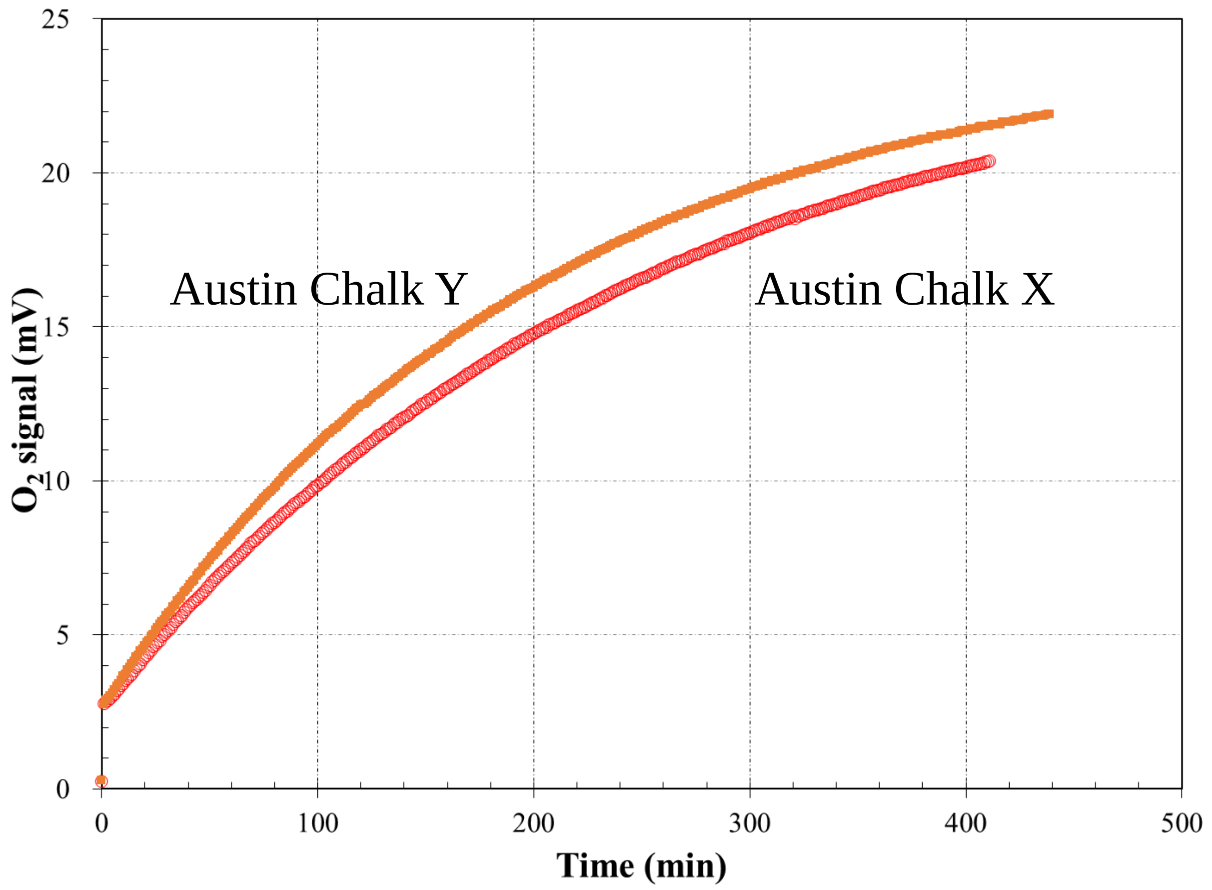
ln C_r is a linear function to t with a slope of $-\frac{D_p \alpha_1^2}{\emptyset}$

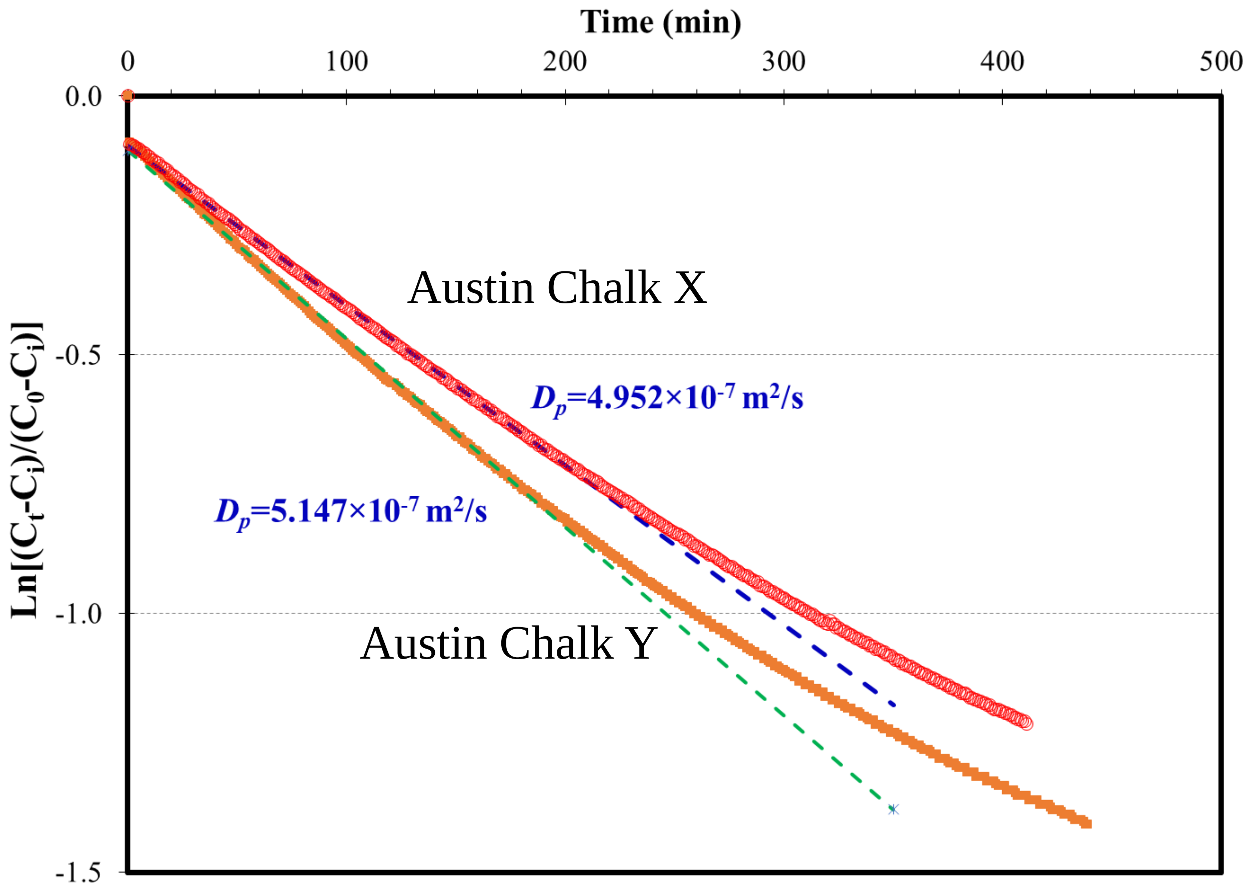
Diffusion coefficient D_p could be determined when α and Ø is known.

- C_r: tracer gas concentration
- Ct: tracer gas concentration in the chamber when t=t
- C0: tracer gas concentration in the chamber when t=0
- Cs: tracer gas (O_2) concentration in atmosphere
- h=Ø/a
- A: the length or volume of the diffusion chamber or volume of chamber per area of the sample
- Dp: diffusion coefficient of sample to tracer gas
- α_n: the positive roots of $\alpha_n \tan(\alpha_n L)=h$, with n=1,2,…. When t >0, the terms for n ≥ 2 are negligible due to the very small influence on the result when compared to n=1

Tracer gas diffusion method

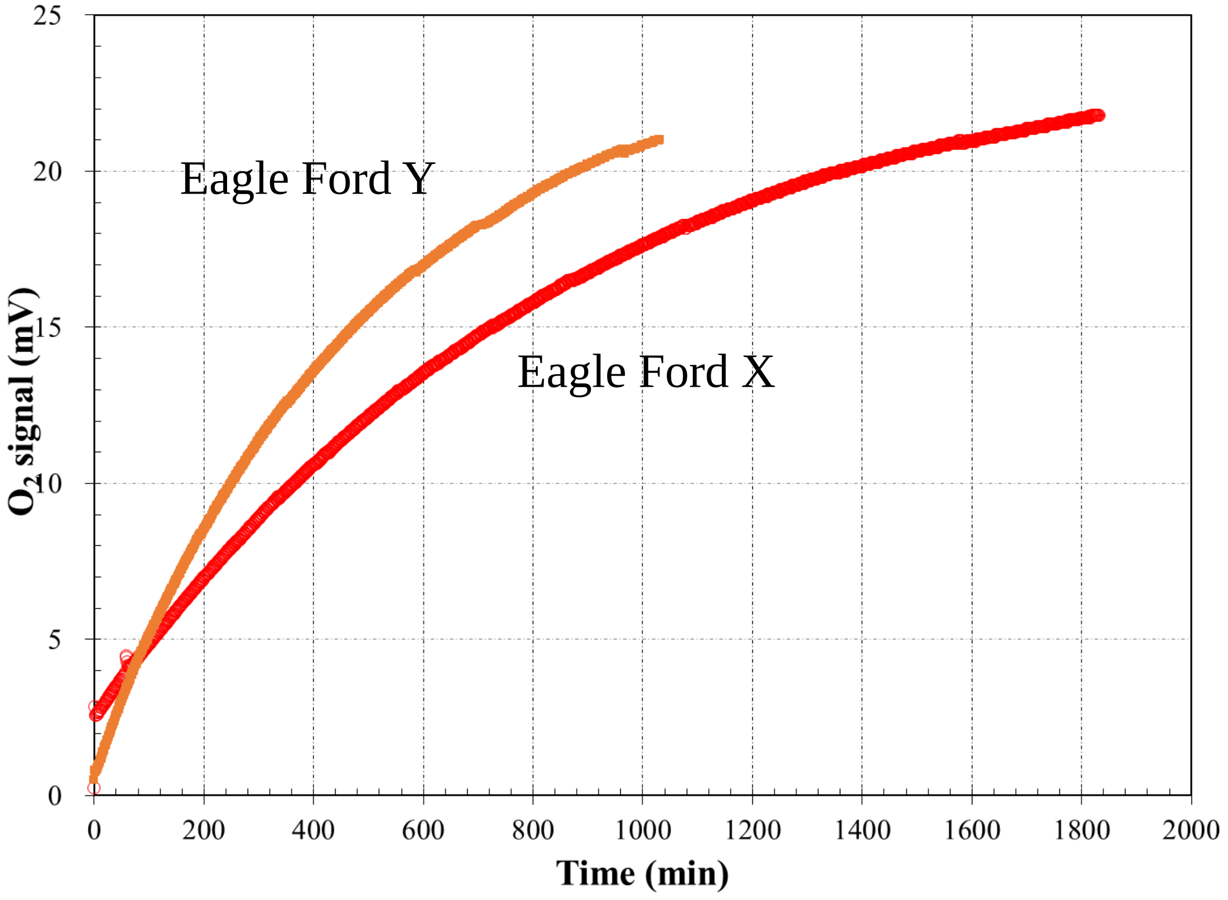
Austin Chalk Φ=28.8% Dominate pore diameter: 0.1-1μm

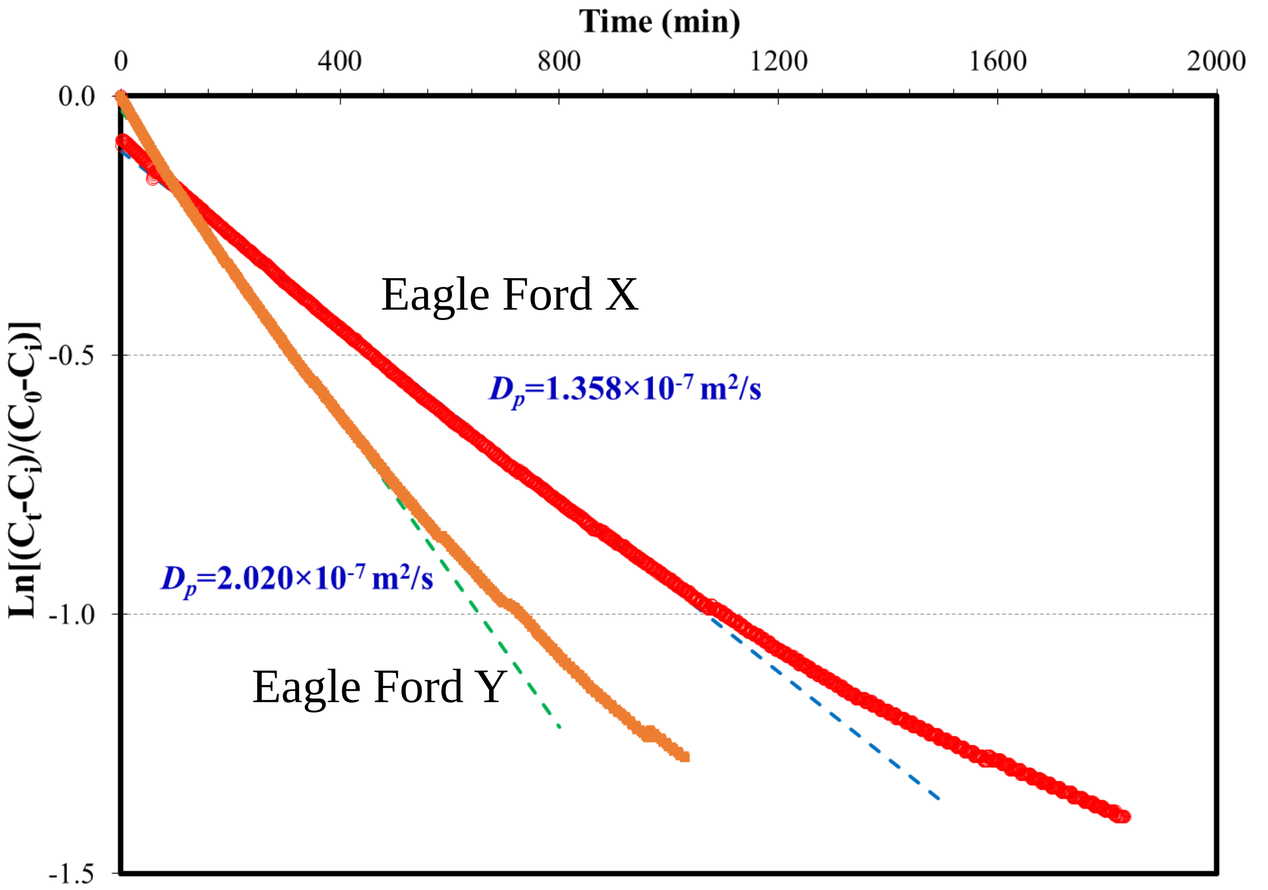




Tracer gas diffusion method

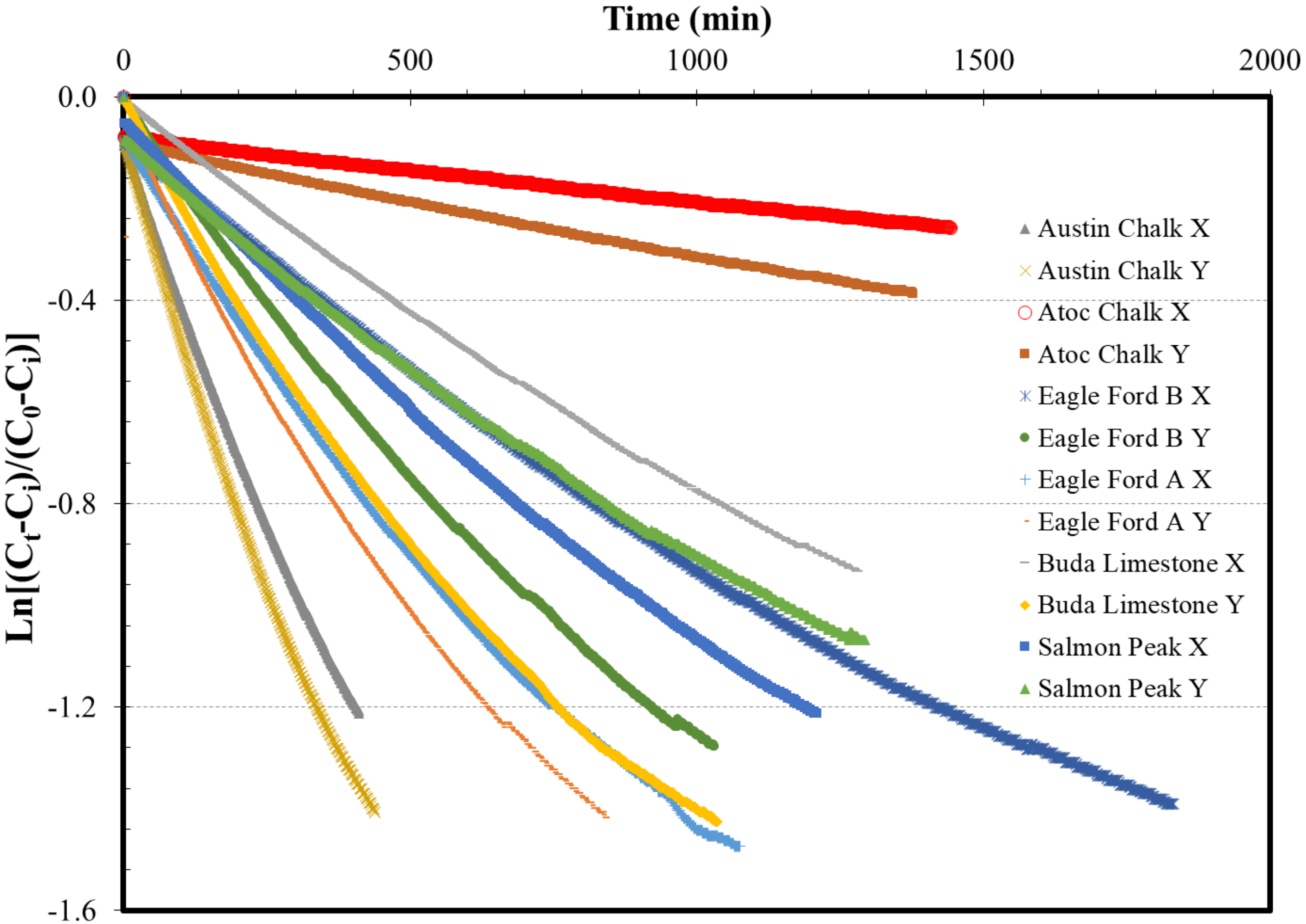
Eagle Ford B Calcareous Shale Φ=2.05%





Tracer gas diffusion method

The results show directional heterogeneity



Sample ID	Direction X D_p (m^2/s)	DirectionY D_p (m^2/s)
Austin Chalk	4.952E-07	5.147E-07
Atco Chalk	4.895E-08	3.427E-08
Eagle Ford A Dolomatic Ash Bed	2.417E-07	3.110E-07
Eagle Ford B Calcareous Shale	1.345E-07	2.020E-07
Buda Limestone	1.217E-07	3.012E-07
Salmon Peak Limestone	1.968E-07	1.137E-07

Tracer gas diffusion method

Issues in determining D_p

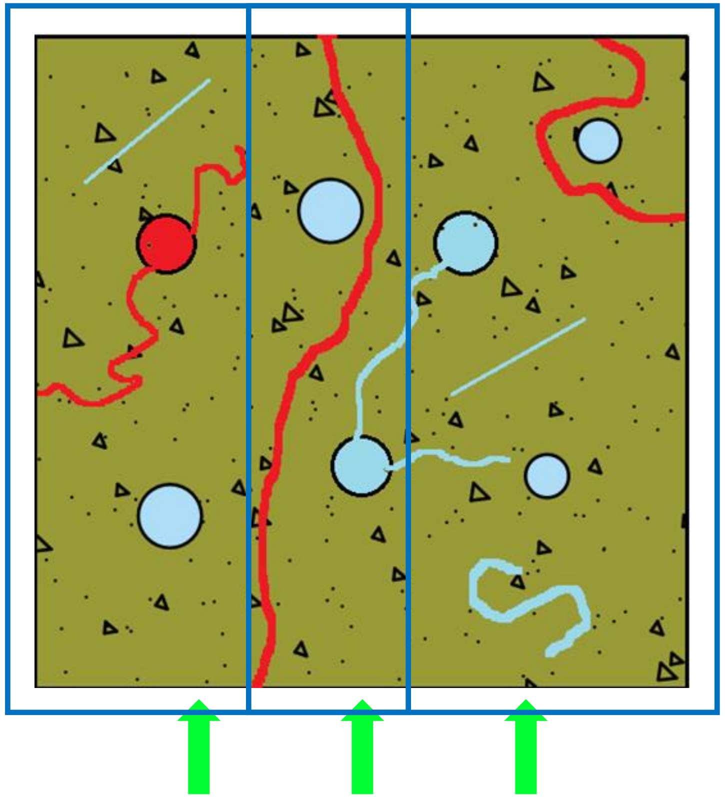
At ln-ln scale,

$$lnC_r = -\frac{D_p \alpha_1^2 t}{\emptyset} ln\left(\frac{2h}{L(\alpha_1^2 + h^2) + h}\right)$$

What is the porosity used in the D_p calculation?

- For monolithic samples: with different pore connectivity
- For granular samples: with inter- and intra-granular pore space

Pores are not 100% interconnected in rock matrix



Gas flow

- Porosity Ø used is the porosity of the whole monolithic rock
- Porosity Ø should be using is the fluid flow porosity in a specific direction

Tracer gas diffusion method

Pore connectivity

- Well connected materials: soils, granular rock samples, loose sandstone, and porous carbonate rocks
- Poorly connected materials: tight sandstone, tight carbonate rocks, crystalline rocks, shales, and evaporites

$$lnC_r = -\frac{D_p \alpha_1^2 t}{\emptyset} ln\left(\frac{2h}{L(\alpha_1^2 + h^2) + h}\right)$$

Well connected:

$$\emptyset_{fluid\ flow} \approx \emptyset_{whole\ sample}$$

$$D_{p\ (true)} \approx D_{p(calculated)}$$

Poorly connected:

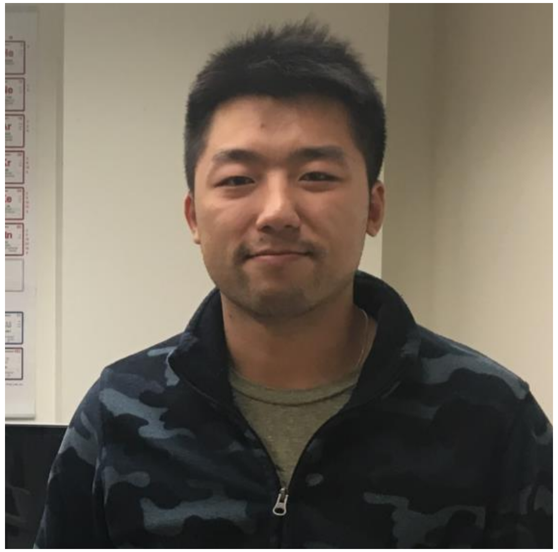
$$\emptyset_{fluid\ flow} < \emptyset_{whole\ sample}$$

$$D_{p\ (true)} < D_{p(calculated)}$$

Summary

- Tracer gas diffusion method to determine the diffusion coefficient is applicable to a wide range of rock lithologies, as demonstrated in a vertical profile in Texas.
- Porous Austin Chalk has a porosity of 28.8% and average diffusion coefficient of 5.050×10^{-7} m^2/s.
- Tight Eagle Ford B Calcareous Shale has a porosity of 2.05% and average diffusion coefficient of 1.683×10^{-7} m^2/s.
- Diffusion coefficient will be overestimated if an incorrect porosity, which is related to pore connectivity, is used in the calculation.

Acknowledgements



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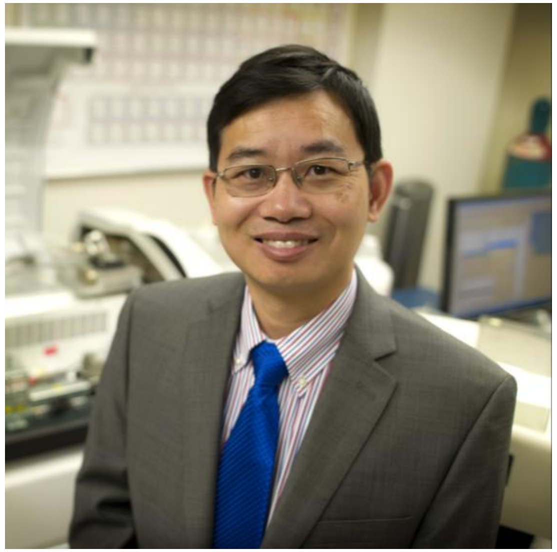

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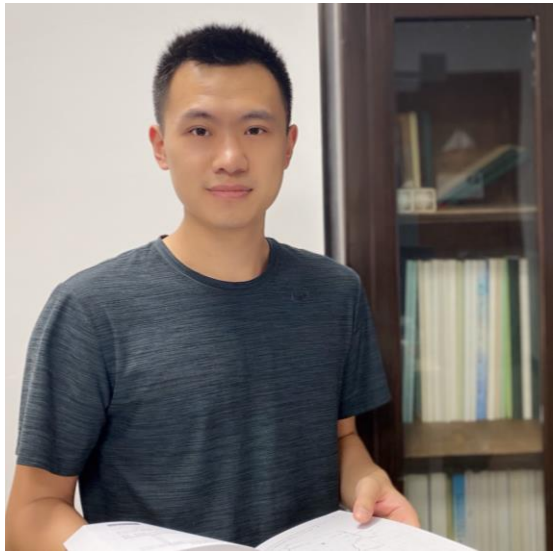

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