UANL
UNIVERSIDAD AUTÓNOMA DE NUEVO LEÓN

FCT
FACULTAD DE CIENCIAS DE LA TIERRA

Stochastic Modeling of Particle Transport in Micrographs of Porous Shale Media Using Cellular Automata: Validation with Carman-Kozeny

Presented by:

Escobar-Hernández Leonel

Table of contents

Kozeny-Carman Equation

Kozeny's law relates permeability (***k***) to the geometric properties of the porous medium, such as porosity (***ϕ***), specific pore surface area (***S***), and an empirical parameter (***c***), which in most cases is close to 0.2 (Kozeny, 1927; Carman, 1938).

$$k = \frac{\phi^3}{c\tau^2 S^2} \quad (1)$$

$$\tau = \frac{\lambda}{L} \quad (2)$$

Kozeny-Carman equation for shale

$$K = \frac{1}{2\tau^2 S_{Vgr}^2}\left(\frac{{\phi_e}^3}{(1-\phi_e)^2}\right) \quad (3)$$

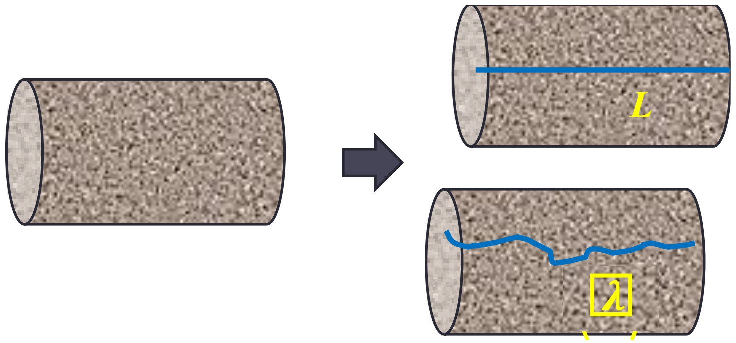


Figure 1. Representation of a tortuous system

Objectives

i. Numerical estimation of the *Porosity* (ϕ)

ii. Design random trajectories for the Cellular Automata

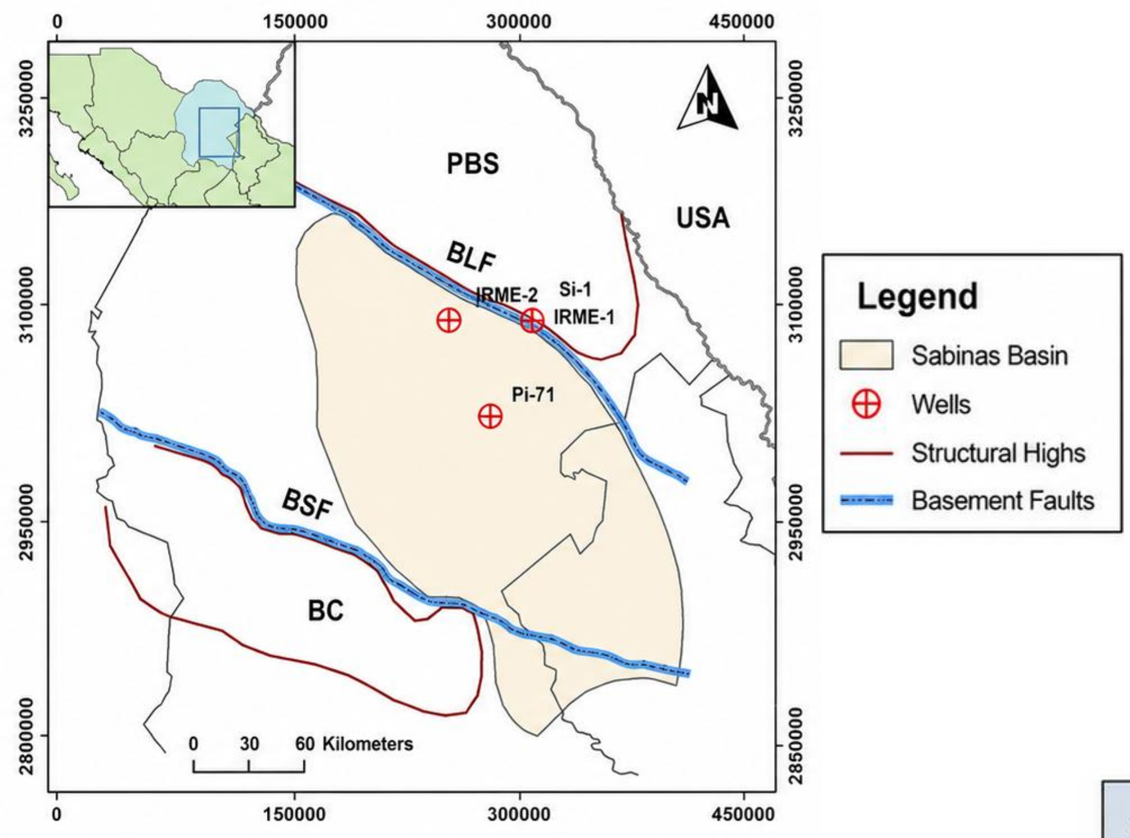
iii. Estimate *Tortuosity* ($\boldsymbol{\tau}$)

iv. Estimate *Permeability* ($\boldsymbol{K}$)

Methodology

i. Sampling and retrieval of Eagle Ford shale cores
ii. Preparation of thin sections and SEM micrographs
iii. Digital processing of SEM micrographs
iv. Estimation of porosity, surface area and tortuosity
v. Permeability estimation
vi. Validation of estimates against established literature data

Study Area



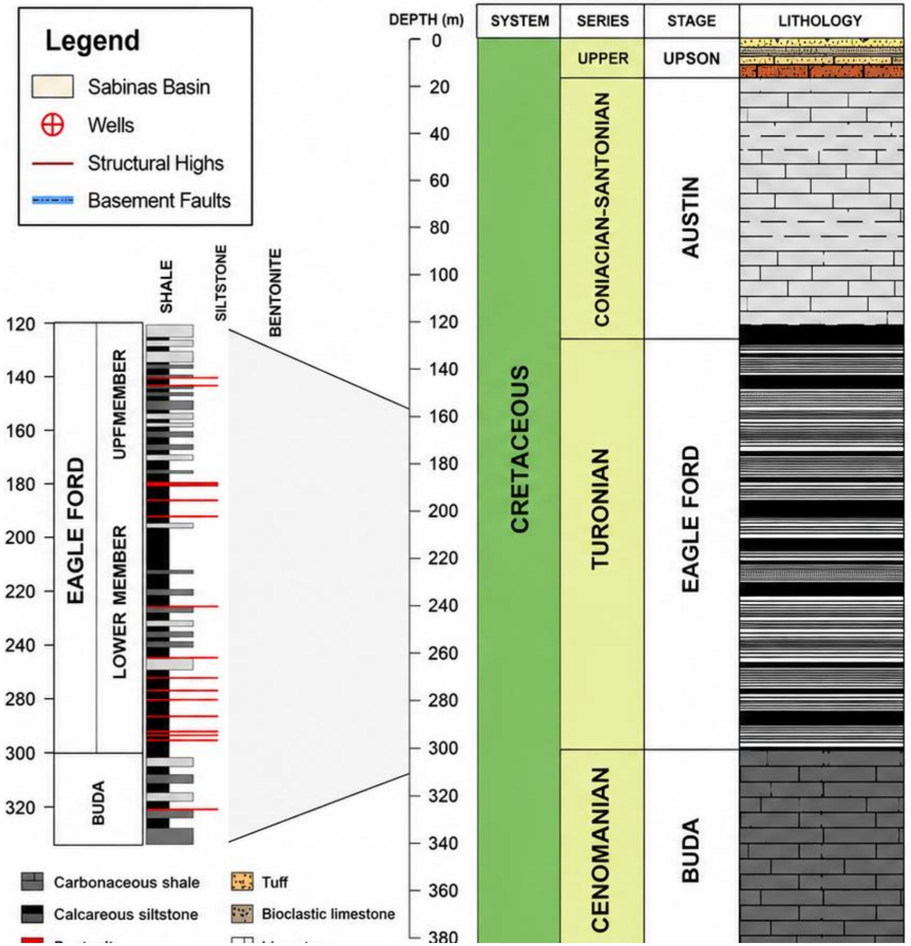
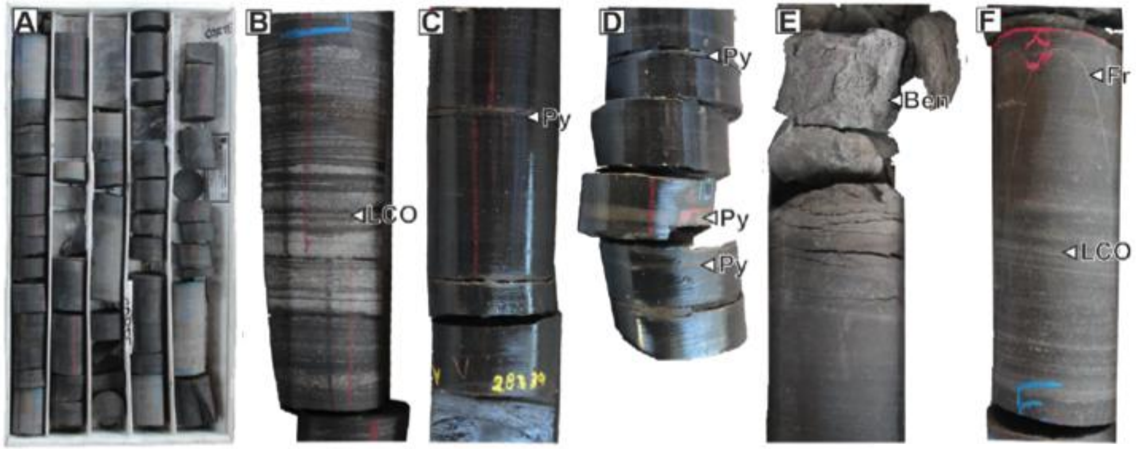


Figure 2. Study area location and stratigraphic column.

Sample ID	Well	Formation	Depth (m)	Easting (m)	Northing (m)
MC-25	IRME-2	Eagle Ford	291.54	249393	3093765

Fieldwork

Lower member of the Eagle Ford Formation



$Ø_{core} = 5.08\ cm$

Figure 3. Photographs of the main sedimentological features of the lower member of the Eagle Ford Formation.

(A)-Interbedding of limestone and shale
(B)-Plane-parallel lamination, note the alternation of light and dark laminae
(C)-Carbonaceous shale with pyrite laminae
(D)-Pyrite laminae
(E)-Bentonite horizon
(F)-Calcite-filled fracture

LOC: light and dark laminae
Py: pyrite
Ben: bentonite
Fr: calcite-filled fracture.

Image Processing

spyder The Scientific Python Development Environment

ImageJ Image Processing and Analysis in Java

RStudio

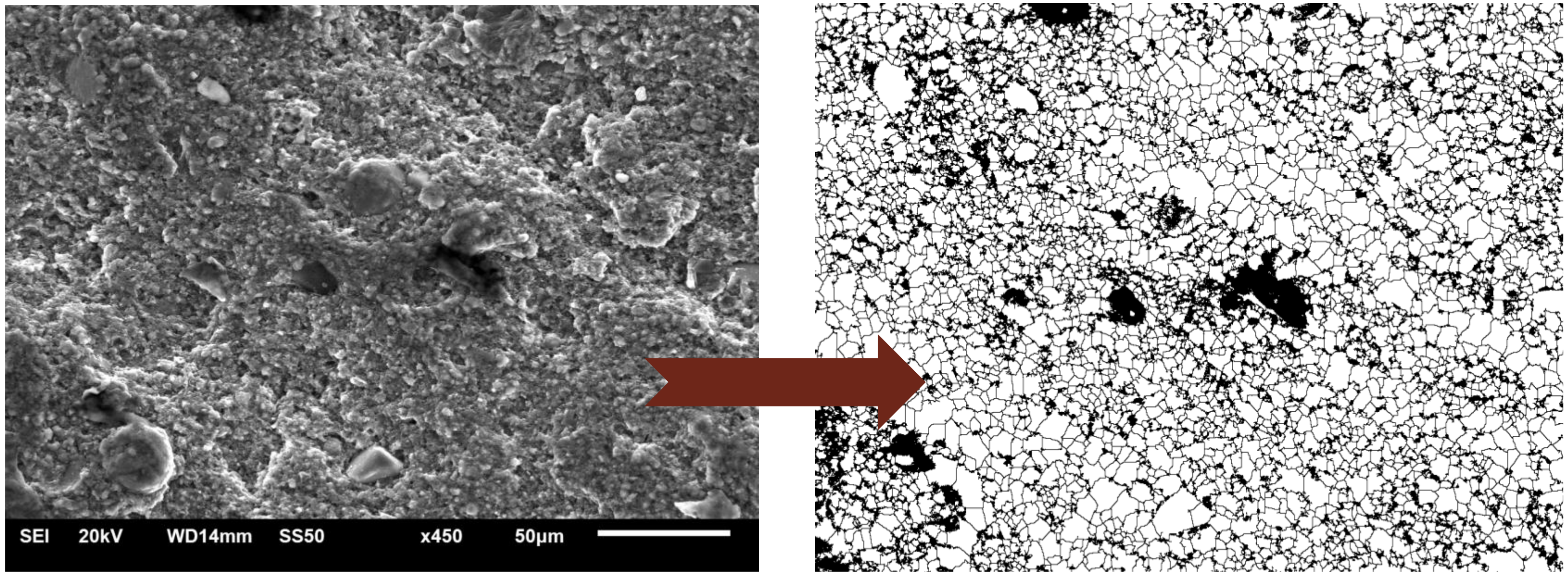


Figure 4. ***SEM image processing in ImageJ***

Image Processing

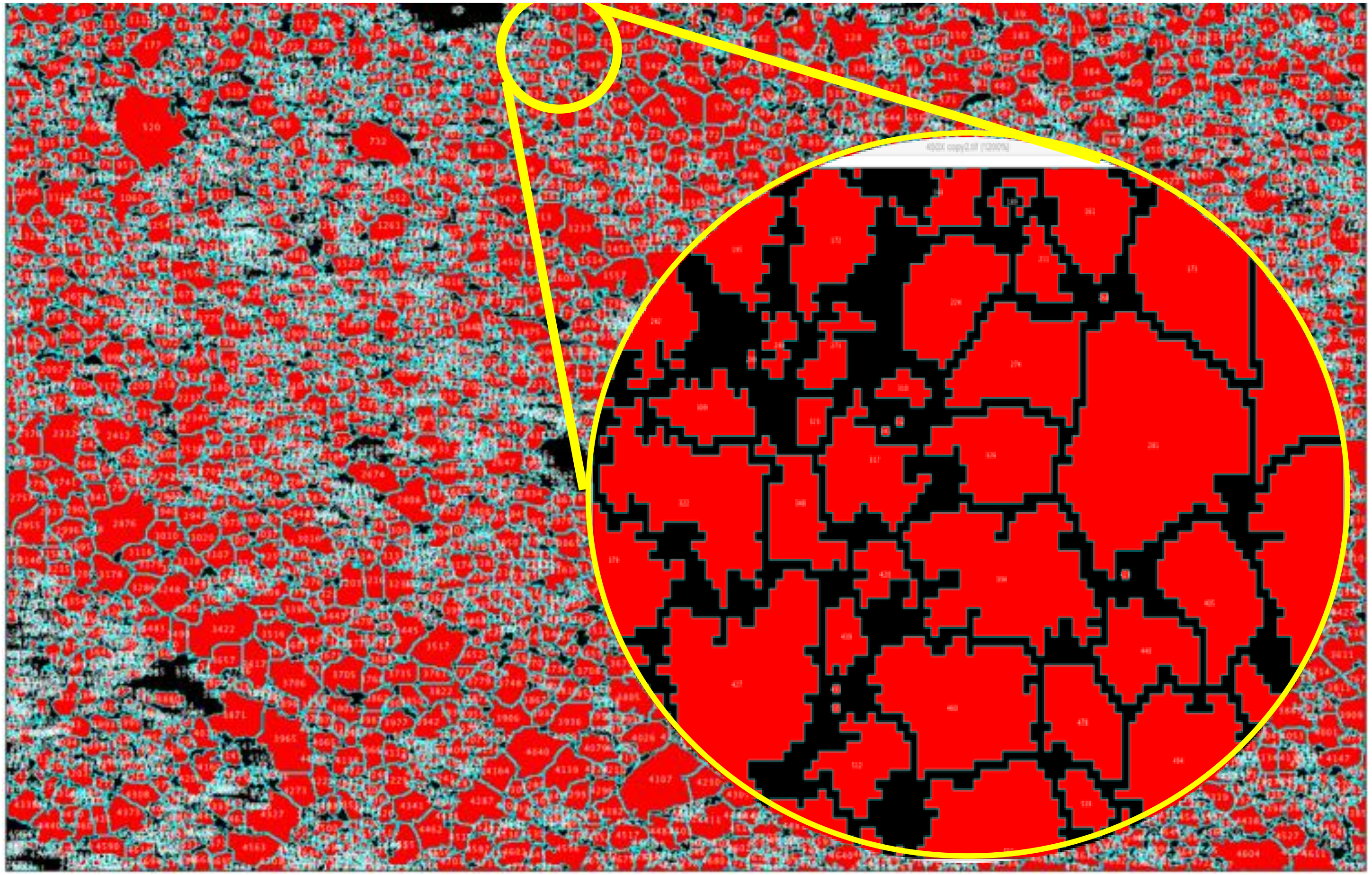


Figure 4.1 *SEM image processing in ImageJ*

Particle Simulation

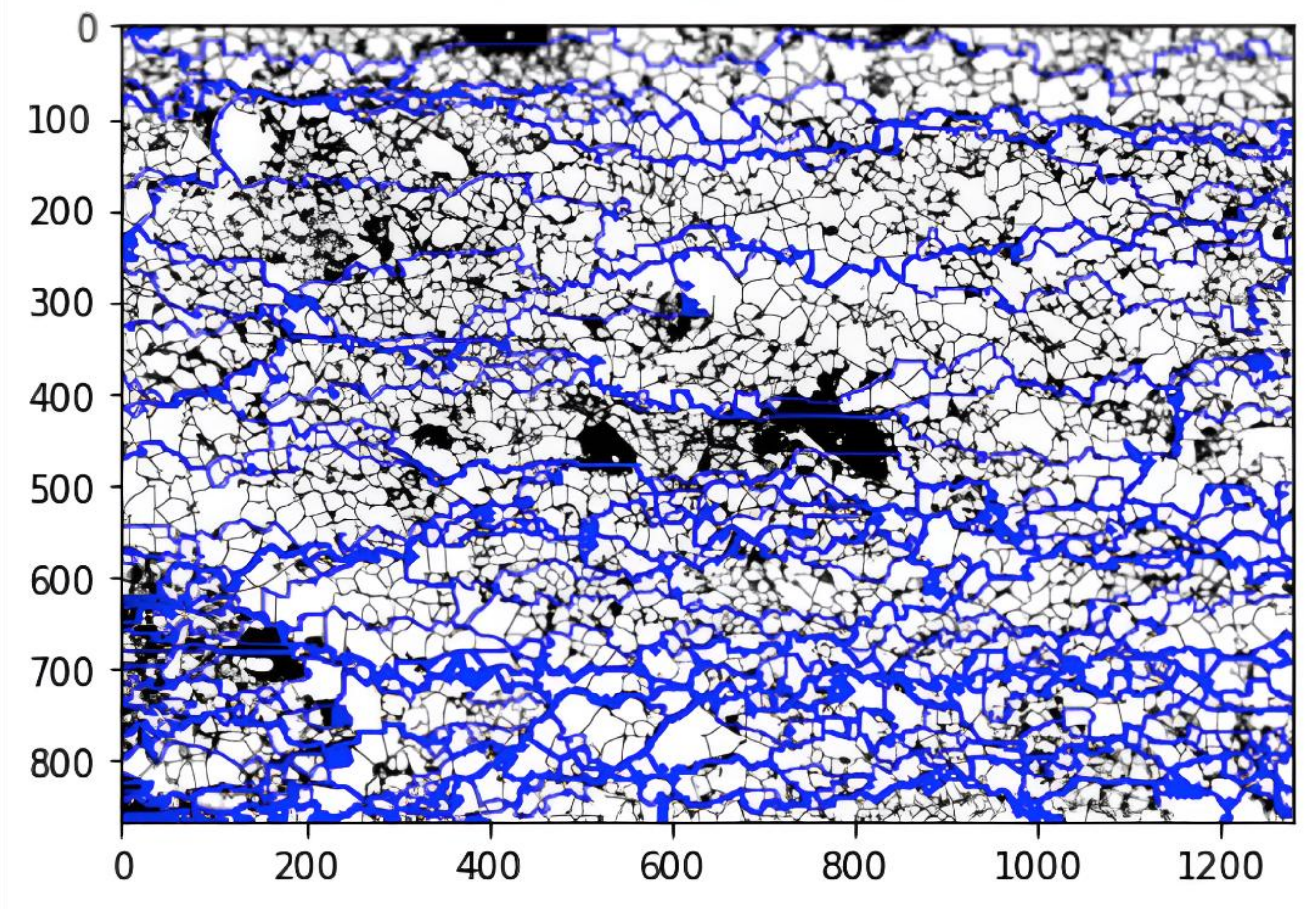


Figure 5. ***Representation of particle trajectories; 50 particles were used for this example.***

Calculations and Results

(4) $\phi_b = \frac{A_p}{A_T} \times 100$ $\phi_e = 7\%$

$\phi_b = 25.68\%$

(3) $K = \frac{1}{2\tau^2 S_{Vgr}^2}\left(\frac{{\phi_e}^3}{(1-\phi_e)^2}\right) = \frac{1}{(2)(1.971)^2(3.869)^2}\left(\frac{(0.07)^3}{(1-0.07)^2}\right)$

$K = 3.409789109X10^{-6}\mu m^2$

$K = 0.0000034097\ D$

$K = 0.003409\ mD$

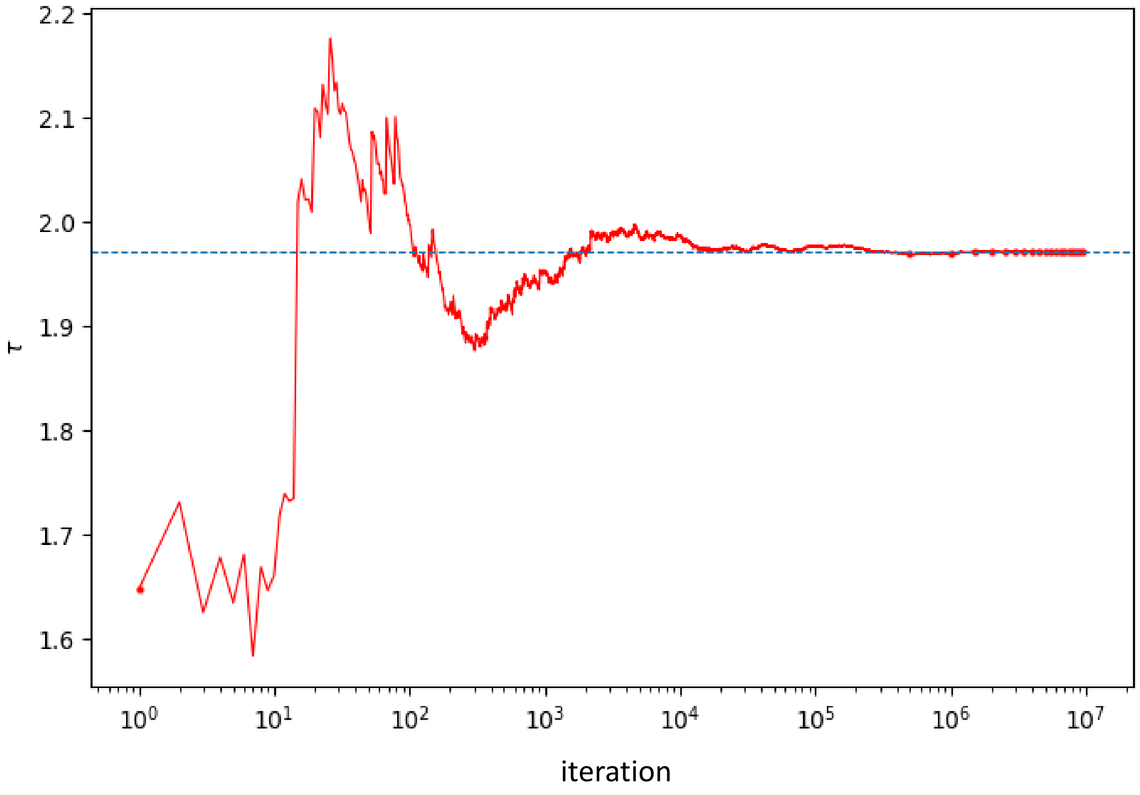


Figure 6. ***Calculation of tortuosity as a function of the number of particles. A value of τ = 1.971 was obtained from 10,000,000 iterations.***

Literature Data

Name of the Rock Cores	Length of the Core	Cutting Direction	Porosity (%)	Permeability (mD)
Sample 1-Chicontepec	5 cm	Parallel	10.7	*undefined*
Sample 2-Chicontepec	5 cm	Perpendicular	8.0	0.001
Sample 1-Amaxac	6 cm	Parallel	7.0	0.002
Sample 2-Amaxac	5 cm	Perpendicular	8.1	0.041

Table 1. *Petrophysical values of rock samples from Chicontepec and Amaxac outcrops*

Conclusions

i. This work represents a low-cost alternative for estimating petrophysical parameters compared to laboratory experiments.
ii. The results are consistent with those found in the literature.
iii. Particle simulation within the porous medium allows us to measure their trajectories to estimate tortuosity, a crucial parameter in petrophysics.
iv. Since permeability is a parameter that is highly difficult to measure, these types of experiments allow us to calculate more realistic values, as approximations can be numerically controlled.

References

- ✓ *Djebbar Tiab, E. C. (2012). Petrophysics Theory and Practice of Measuring Reservoir Rock and Fluid Transport Properties (Third Edition ed.). (G. P. Publishing, Ed.) Oxford, Uk.*
- ✓ *LIMARINO, L. I. (2000, Noviembre). Caracterización y origen de la porosidad en areniscas de la sección inferior del Grupo Paganzo (Carbonífero superior), Cuenca Paganzo, Argentina. (A. Revista, Ed.) Asociación Argentina de Sedimentología , 7, 72.*
- ✓ *Van Rossum, G., & Drake Jr, F. L. (1995). Python reference manual. Centrum voor Wiskunde en Informatica Amsterdam.*
- ✓ *Carrillo, J. A. B., Villalobos, R. S., Madera, C. G. A., & Ramos, A. (2016). Estimación de porosidad en areniscas a partir de micrografías digitales utilizando R-Studio.*
- ✓ *C.G. Aguilar-Madera, J.V. Flores-Cano, V. Matías-Pérez, J.A. Briones-Carrillo, F. Velasco-Tapia, Computing the permeability and Forchheimer tensor of porous rocks via closure problems and digital images,*
- ✓ *Advances in Water Resources, Volume 142, 2020,103616,ISSN 0309-1708, https://doi.org/10.1016/j.advwatres.2020.103616.*
- ✓ *Altawati, F. (2021). An experimental study to investigate the physical and dynamic elastic properties of Eagle Ford shale rock samples. Springer Nature. https://link.springer.com/article/10.1007/s13202-021-01243-w#auth-Faisal-Altawati-Aff1*
- ✓ *González, A. T. F. (2023). Estudio teórico y experimental de inyección de surfactantes como método de Recuperación Mejorada de aceite de la Formación Chicontepec.*

Collaborators

- *M.C. Briones-Carrillo Jorge Alberto*
- *Obregón-González Benny*
- *Ruíz-Ramos Roberto*
- *Farrera-Salazar Darío*
- *Romo-Castillo Sebastián*
- *Acevedo-González Juan Emiliano*
- *Valenzuela-Gutiérrez Valeria*

Linares, Nuevo León, México.

May 2026