Study on the Distribution Patterns and Resistivity Characteristics of THF Hydrates in Sandstone Sediments

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Research Significance

- X-CT and resistivity joint measurements indicate that while the distribution of Tetrahydrofuran (THF) hydrates in sandstone sediments is similar to that in conventional oil and gas reservoirs, the resistivity measurements do not fully conform to the Archie model.
- This discrepancy arises because the formation of THF hydrates is a dynamic process which involves fluctuations in hydrate saturation, formation water salinity, temperature, and spatial distribution, making it challenging to accurately characterize these variables using traditional resistivity measurements.

Method

- Three-dimensional grayscale sediment images are segmented to create a digital rock core.
- The spatial distribution of hydrates in sediment pores is simulated using the Diffusion Limited Cluster Aggregation (DLCA) model.
- The finite element method calculates resistivity for both fully saturated formation water (R_0) and at varying water saturations (R_t), revealing the correlation between resistivity increase and water saturation.

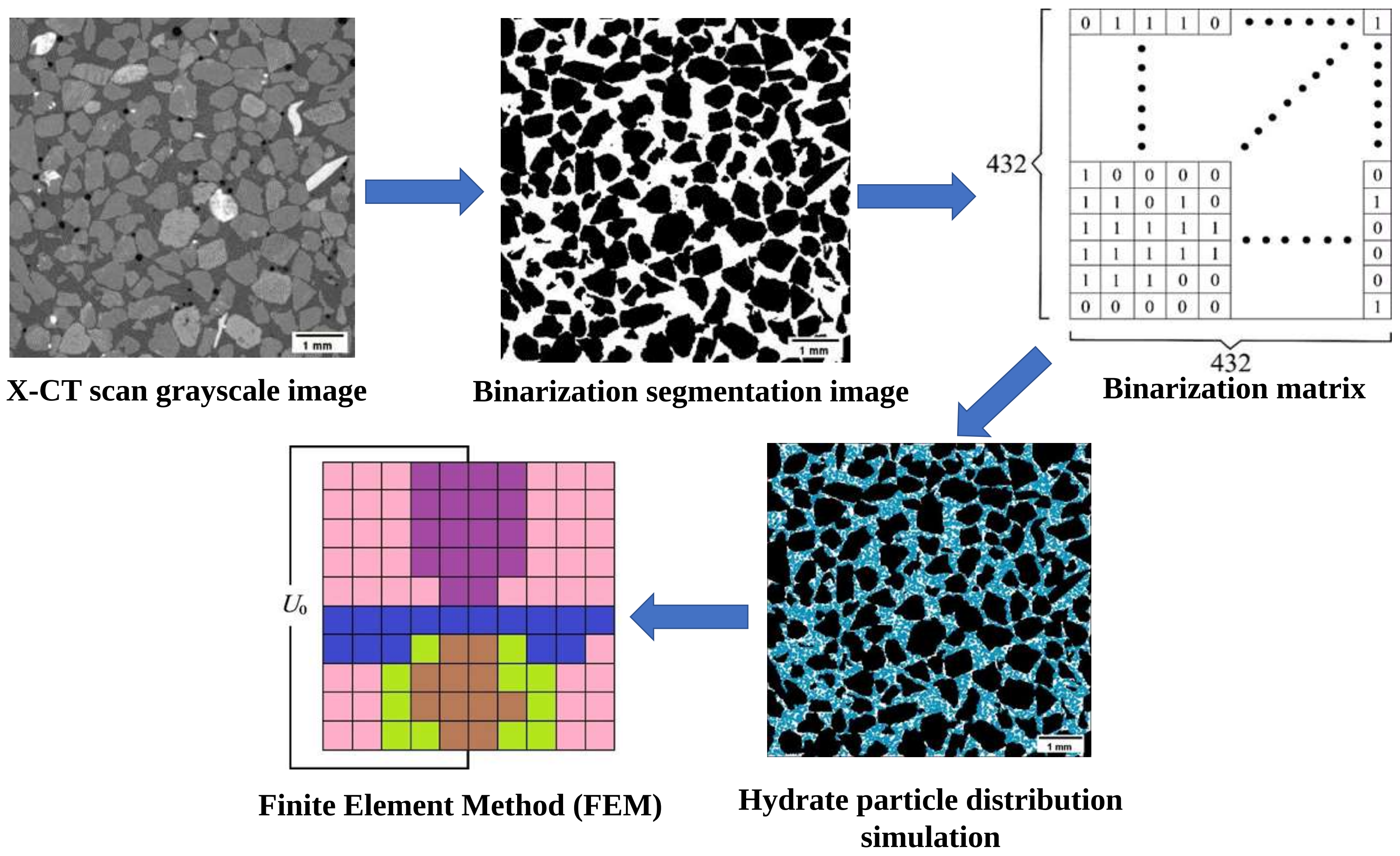


Fig.1 Flow Diagram of the Employed Methodology

Numerical Simulation Results of Hydrate Formation Distribution

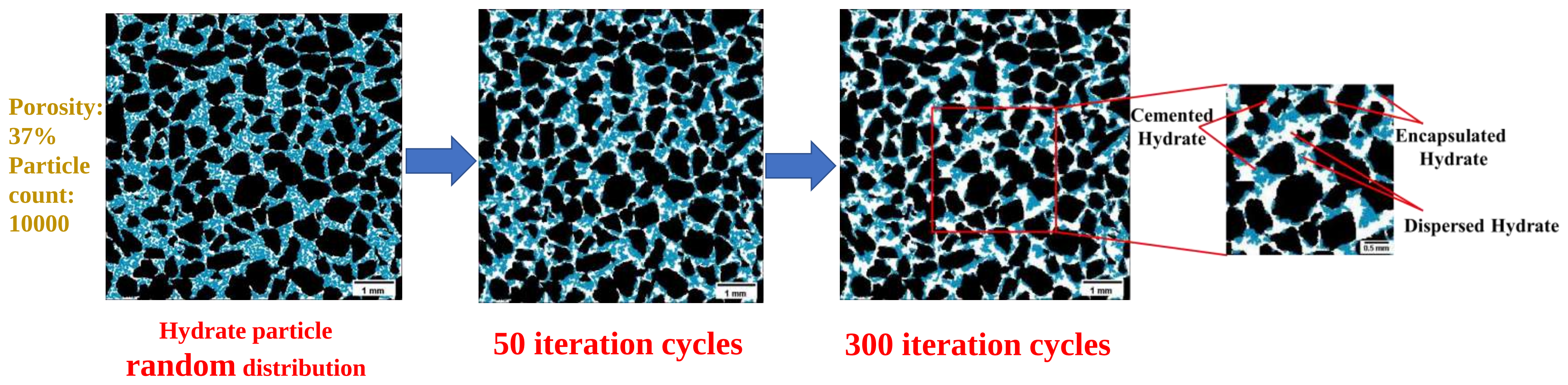
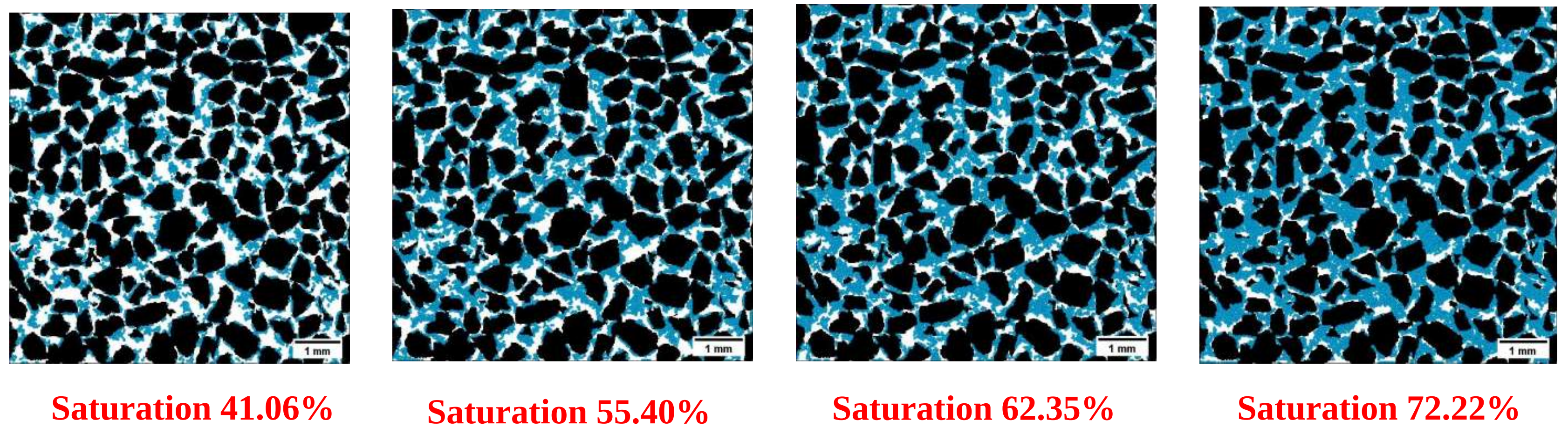


Fig.2 Progressive Evolution in the Simulation of Hydrate Distribution

- Hydrate distributions are categorized into three fundamental types:

1. Cementing Hydrates: Predominantly involving hydrate particles cemented within pore spaces, with a substantial concentration at the pore throats;
2. Encapsulating Hydrates: Characterized by hydrate particles in contact with and adhering to the surfaces of marine sand grains;
3. Dispersed Hydrates: Principally featuring small clusters of cohesive particles scattered throughout the pore spaces.



Saturation 41.06% Saturation 55.40% Saturation 62.35% Saturation 72.22%

Fig.3 Simulation image of hydrate formation spatial distribution with different particle number

Numerical Simulation Results of Hydrate Formation Distribution

- Spatial distribution patterns at various hydrate saturation levels, as deduced from numerical simulations, align with those observed in hydrate formation through in-situ CT scanning experiments, characterized by the following attributes:

1. At lower hydrate saturation levels, hydrates predominantly manifest in a dispersed pattern interspersed among marine sand grains;
2. Conversely, at higher hydrate saturation levels, hydrates are chiefly present in cementing or encapsulating forms between the marine sand grains, thereby reinforcing their collective cohesion and structural integrity.

Hydrate Resistivity Numerical Simulation Results

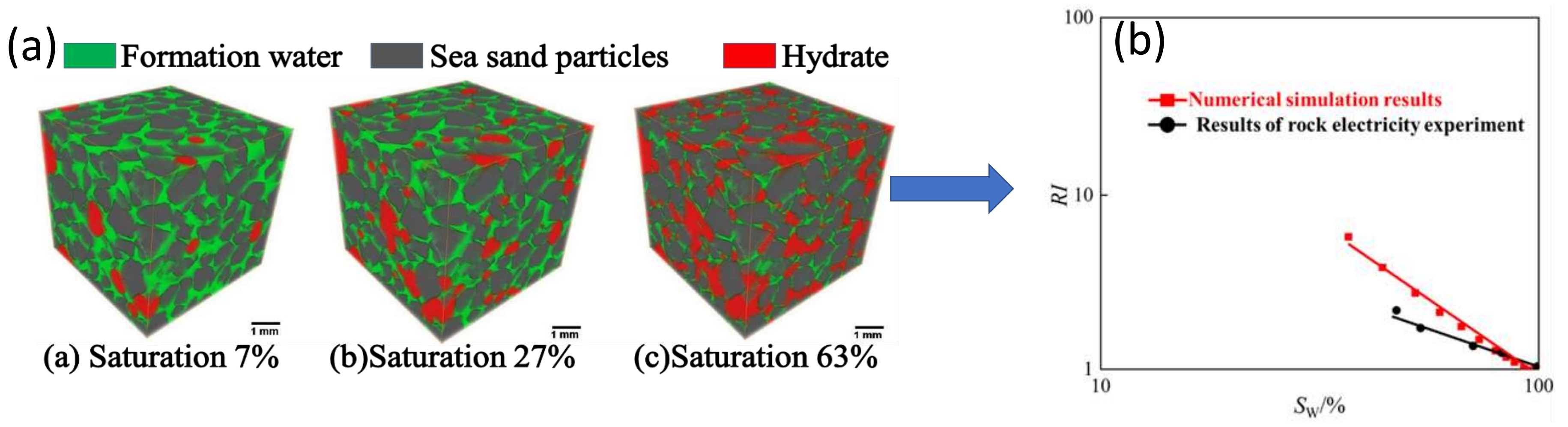


Fig.4 (a)Simulation results of pore distribution under different THF hydrate saturation (b)RI~Sw curves of simulation and experimental results.

- Upon defining the pore fluid distribution, a three-dimensional digital rock core is constructed. Utilizing the finite element method, we establish the relation between resistivity increase and water saturation, deriving a saturation index of n=1.751 through curve fitting. This aligns with typical sandstone reservoir petrophysical results **but diverges from hydrate petrophysical experiment findings**.

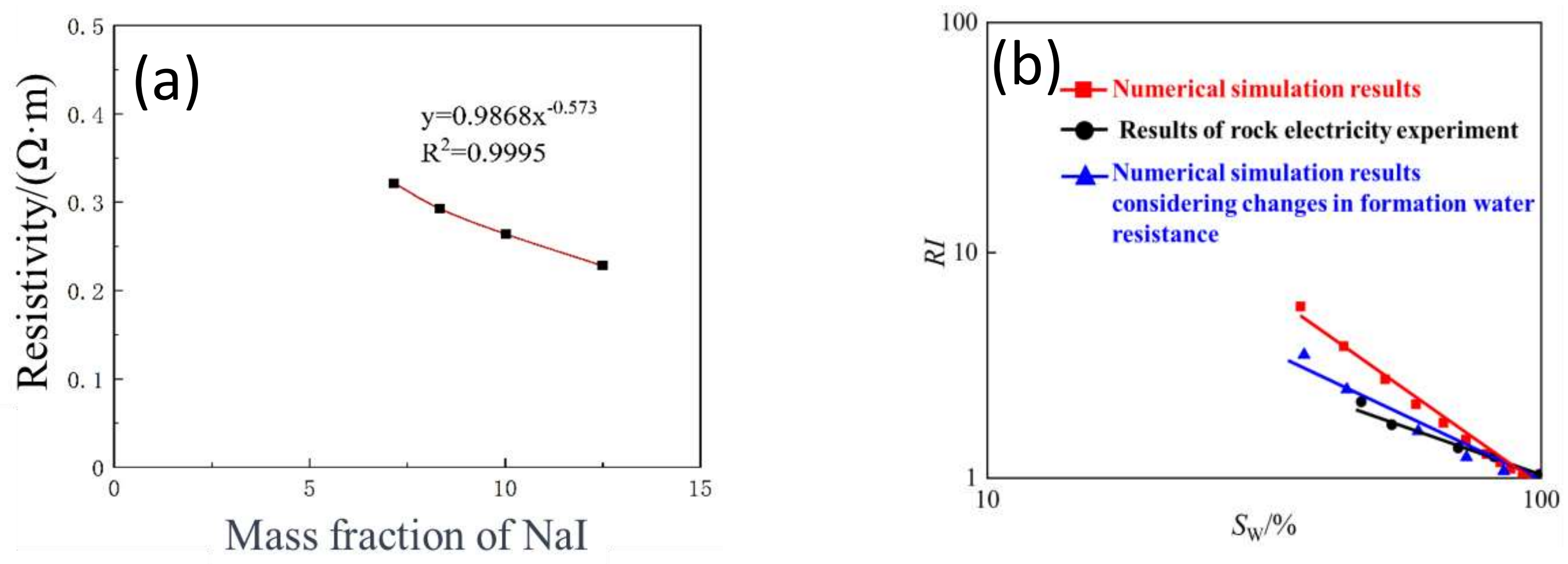


Fig.5 (a) Relationship between NaI mass fraction and solution resistivity, (b) Comparing resistivity simulation results with and without considering changes in the mass fraction of NaI in formation water solutions to experimental data.

- In the realm of computational modeling, the paradigm assumes a static electrical resistivity for formation waters, invariant across a spectrum of saturation degrees.
- In petro-electrical experiments, hydrate formation depletes and mineralizes formation water, altering its electrical resistivity.

Archie's formula: $RI = \frac{R_t}{R_0} = \frac{b}{S_W{}^n}$

- By considering the changes in the resistivity of formation water, the resistivity numerical simulation results were obtained. Fitting led to a saturation index of n=1.2, which is basically consistent with the results of rock-electric experiments.

Conclusion

- The results show that at low hydrate saturations, hydrates exist in a dispersed form within the pores, while at high saturations, they are distributed in cementing or encapsulating forms, enhancing the structural integrity of the sediments.
- Furthermore, analysis of the aggregate morphology, including changes in gyration radius and fractal dimension, effectively reflects the evolution of the structure.
- The combined results from experimentation and simulation demonstrate that varying hydrate saturations significantly influence the distribution forms and their impact on resistivity: at low saturations, hydrates have a minor effect on resistivity, whereas at high saturations, extensive hydrate formation and distribution patterns lead to a rapid increase in resistivity.