NubiaStore: A multidisciplinary investigation for implementing CPG in the Gulf of Suez (Egypt)

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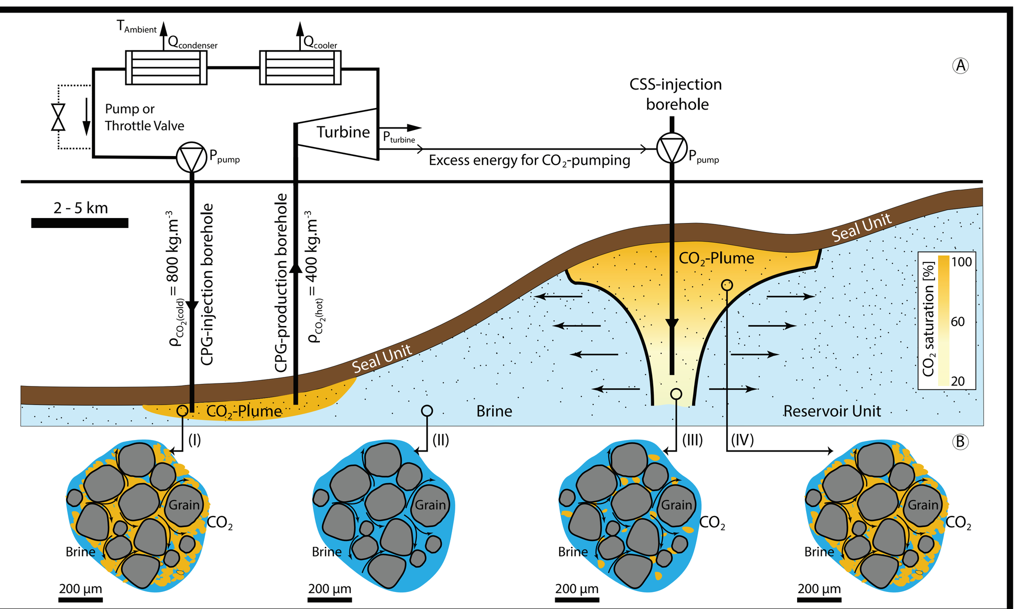
1. Introduction

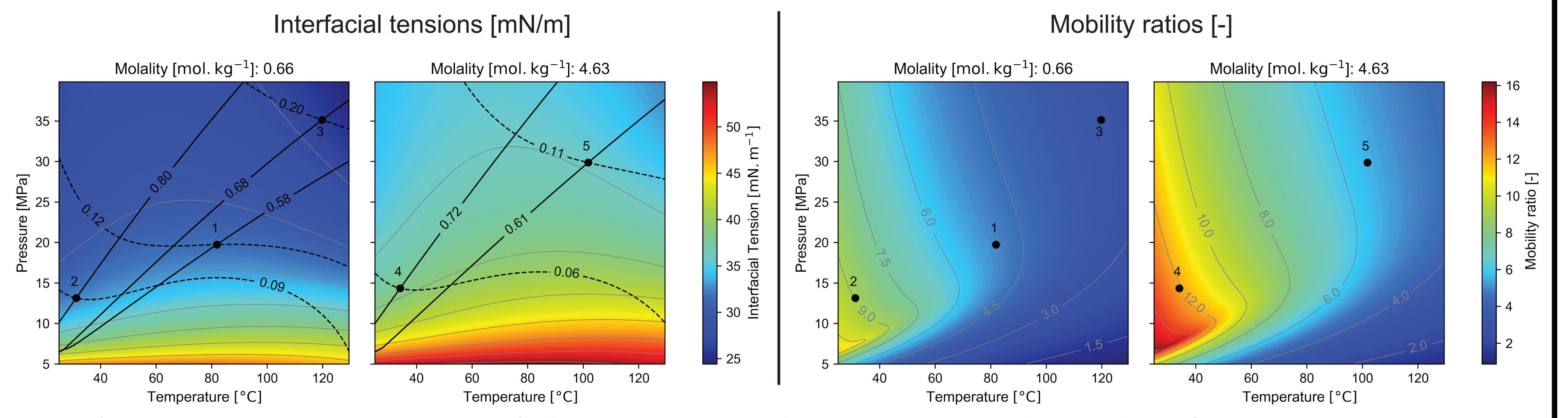
The injection of CO_2 into the highly permeable Nubian Sandstone of a depleted oilfield in the central Gulf of Suez basin (Egypt) can be an effective way to extract geothermal energy from deep sedimentary basins while geologically sequestering a substantial amount of CO_2 (main green-house gas driver), forming a so-called CO_2-Plume Geothermal (CPG) system (Adams et al., 2015, Randolph and Saar (2011) and Garapati et al. (2015)). A CO_2 thermosiphon make CO_2 a favorable subsurface working fluid as will be shown next.



A schematic diagram shows the key processes on how CO_2 sequestration in a saline aquifer while simulatineously producing power as in a typical CPG system.

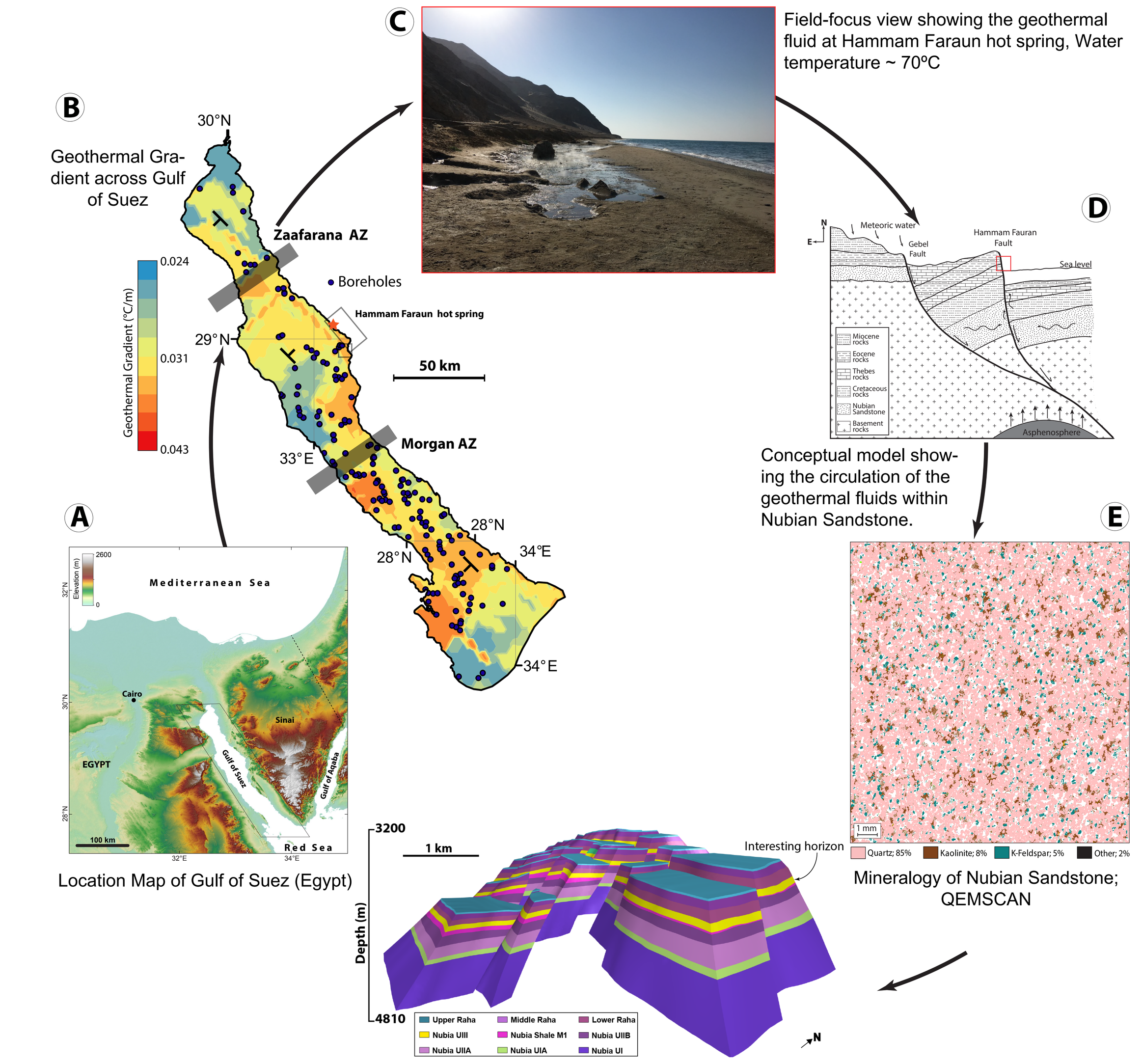
1a. A CO_2 Thermosiphon Phenomena

Since CO_2 density is much sensitive for pressure and temperature compared to water, the density gradients between injection-production wellbores is the main physical driver of CO_2 to circulate without the necessity of a mechanical pump in a so-called CO_2 Thermosiphoning phenomena.



The insitu thermophysics properties of CO_2-brine prevail over different reservoir situations (pressure, temperature, and salinity). Their respective isoline are shown as solid grey lines. Solid black lines represent constant density ratios (0.22 - 0.85) while the dashed black lines represent constant viscosity contrasts (0.04 - 0.12). Numbered dots correspond to the investigated conditions for the current reservoir simulations.

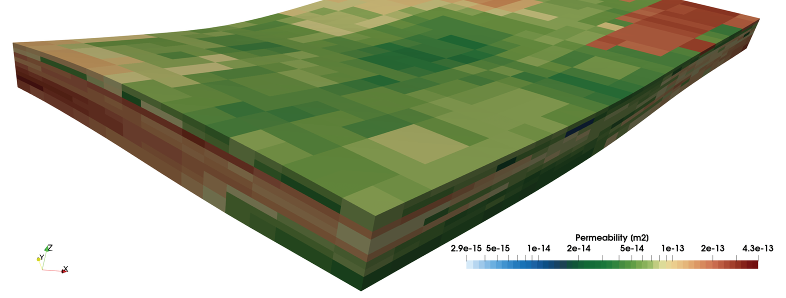
2. Geological Characterization



In Gulf of Suez, where most of the Egyptian oil/gas-producing provinces are located, suitable CPG sedimentary formations cover much of the area.

Finding I:
The pattern of the modeled geothermal gradient map shows a higher thermal nomaly at Hammam Faraun location with 35.7 C/km geothermal gradient. The pattern is due to changes in the listric faults polarity.

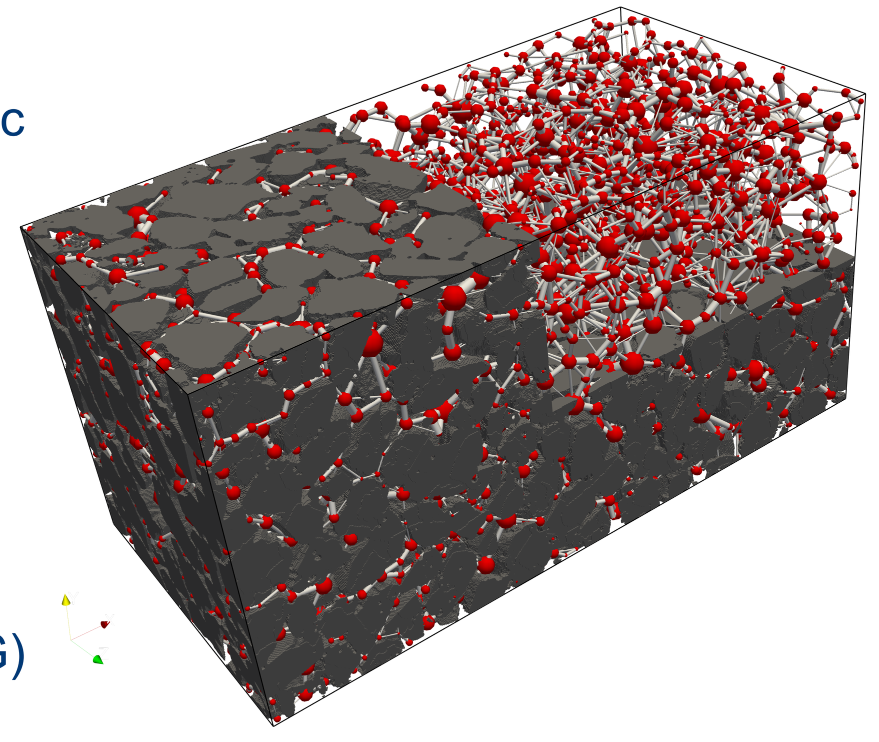
Finding II:
Nubian Sandstone (a common rock type found in the Gulf of Suez's reservoirs at depths of 2.5-4.4 km) can serve as a potential CPG subsurface convection cell. Theoretically, the CO_2 thermosiphon in Nubian Sandstone will increase mass flow rate, pumping-efficiency required for subsurface fluid circulation compared to water, and power production.



Nubian III reservoir	Value
Petrophysics parameters [a]:	
Porosity, $\overline{\phi}_{\text{eff}}^{\log}$ [−]	$0.08 < \phi_{\text{eff}}^{\log} < 0.30$ $\overline{\phi}_{\text{eff}}^{\log} : 0.12,\ \sigma_\phi : 0.04$
Permeability, $\overline{k}_{\text{eff}}^{\log}$ [$\times 10^{-15}$ m^2]	$0.01 < k_{\text{eff}}^{\log} < 689.73$ $\overline{k}_{\text{eff}}^{\log} : 95.97,\ \sigma_k : 78.80$

3. Pore-Scale Perspective

Using Synchrotron Radiation X-ray Tomographic Microscopy (SRXTM), 3D images with a voxel size of 650 nm³ for Nubian Sandstone were obtained and pore network model (PNM) was constrcuted.



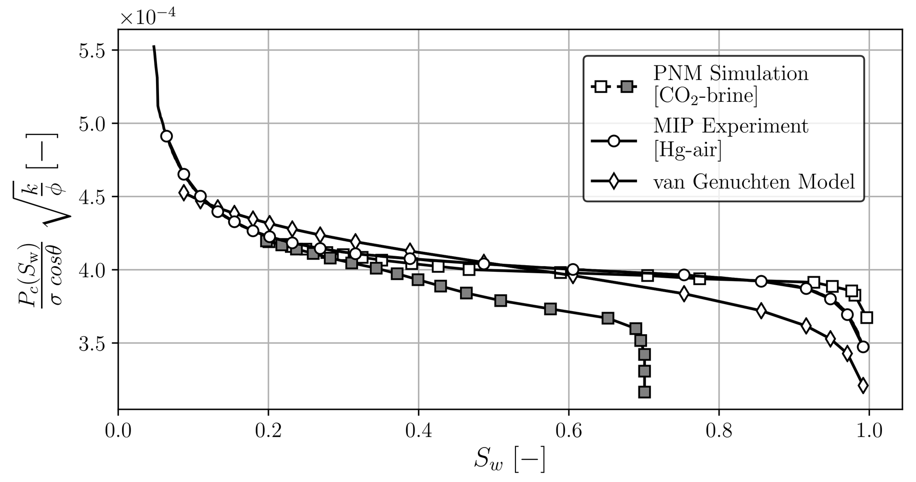
3D view of the Nubian Sandstone pore-network (domain size: 1.4x1.4x2.8 mm3). The voxel SRXTM image shows the solid phase in gray, while the extracted pore elements are overlain.

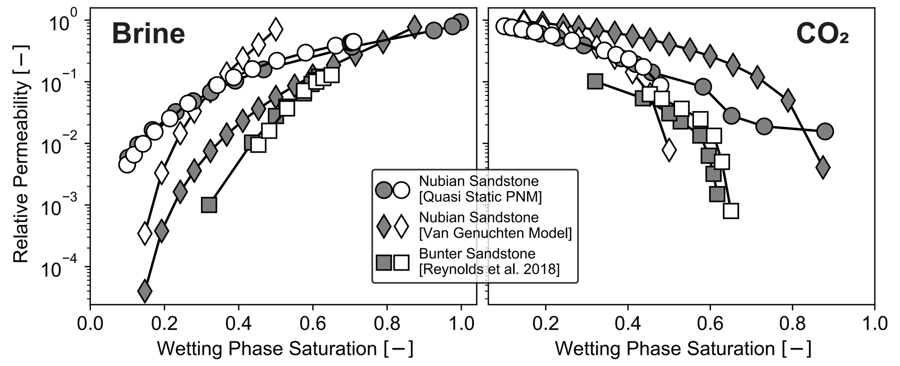
Finding I:
To capture the angularity of the PNM elements (where CO_2 will be trapped there), we found a new formulation to describe the shape factor (G) of the pore space from CT images.

$$G = \frac{R_{ins}^2}{4A_{ide}}$$

Finding II:

- A comparison between the experimental P_c-S_w curve, measured from the MIP experiment, and drainage-main imbibition of quasi-static invasion simulation show a good agreement.
- The non-wetting phase residual saturation was determined to be ~0.35. At the residual brine saturation, the end-point relative permeability for the $scCO_2$ curve is reached at ~0.7.
- The van Genuchten parameters are:
  - drainage: m=0.47[-], α=3.72e-3 [MPa]
  - imbibition: m=0.58[-], α=1.85e-3 [MPa]



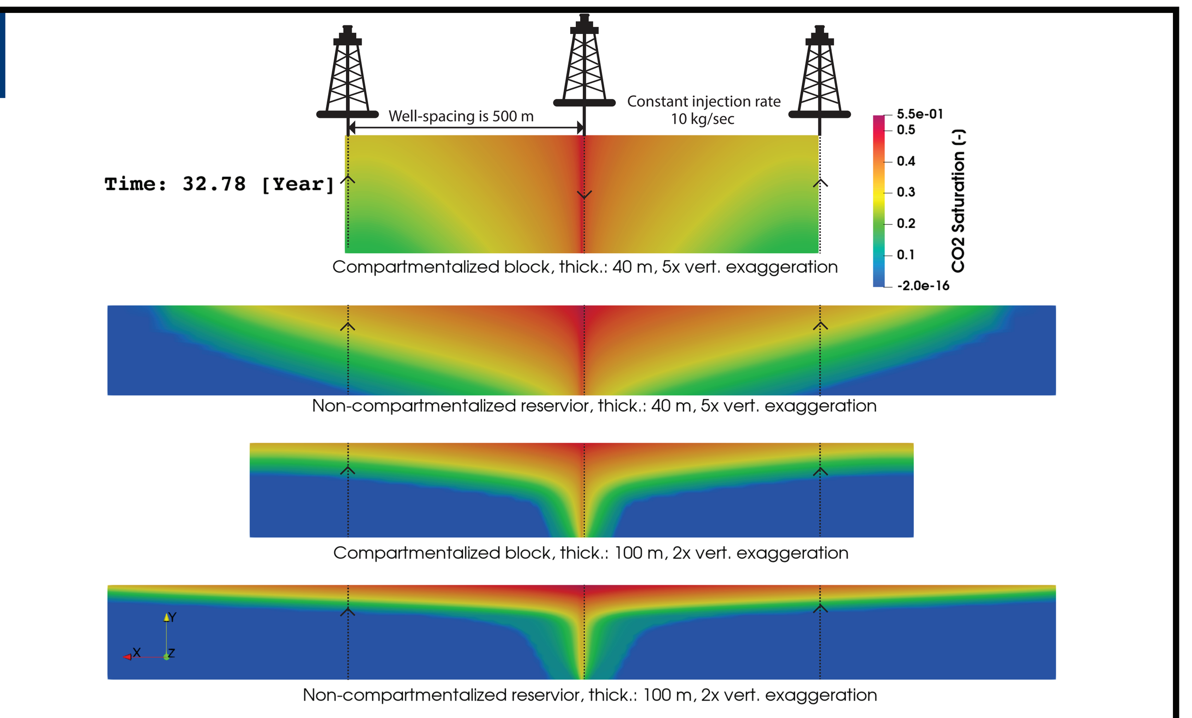


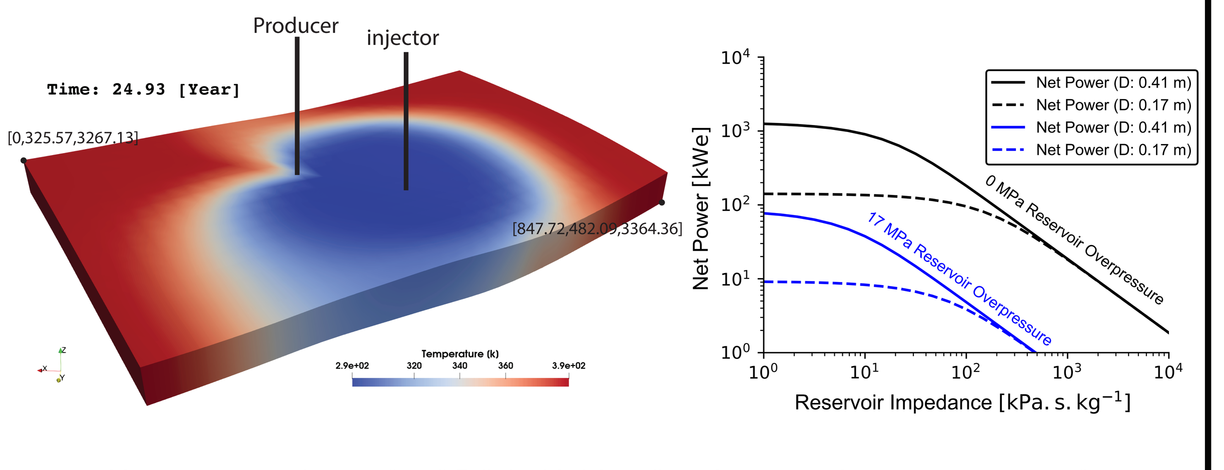
Experimental and modeled P_c-S_w curve [top] and k_r-S_w curve [bottom].

4. Reservoir Simulations

Finding:

- The behaviour of CO_2-plume spread in respond to the reservoir geometry (i.e. thickness, its compartmentalization) is shown to the right. The highest CO_2 concentration is found in a thin layer with a laterial confinment (from fault-seal analysis) in comparsion with non-compartmentalized formation. In the later and due to the buoyant force, CO_2 tends to spread radically over a wider surface area and the concentration be a minimal at the production well.
- For a Greenfield scenario, the potential net electric power generation capacity for the entire field (with a footprint of 15 km²) is 12 MWe and LCOE of <0.15 $/kWh.





Net-power estimate for CPG in Nubian Sandstone using one-quarter of a repeated 5-spot well pattern and for a single injection-production pair.

5. Conclusions

The high mobility of supercritical CO_2 results in roughly doubled geothermal heat energy extraction efficiencies, compared to water, all else being equal (such as reservoir depth and temperature). Such CO_2-Plume Geothermal (CPG) power plants are particularly well suited as add-ons to (partially) depleted oil or gas reservoirs that are (or will be) used as geologic CO_2 sequestration formations. The electricity such add-n CPG power plants generate can then be used for the CO_2 capture operation and/or the CO_2 injection pumps/compressors and/or to can be sold to the power grid. In any case, in this way, CPG would partially or fully recover the cost of CO_2 Capture and Sequestration (CCS), thereby increasing the economic viability of CCS projects. In some/many locations, where geothermal temperatures are particularly high at relatively shallow depths, both CCS cost recovery and additional power sale revenues may be expected.

References

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