Doctoral project proposal, 39th Cycle, by Sandro Longo

Gravity currents in geologic media with application to CO2 injection and trapping

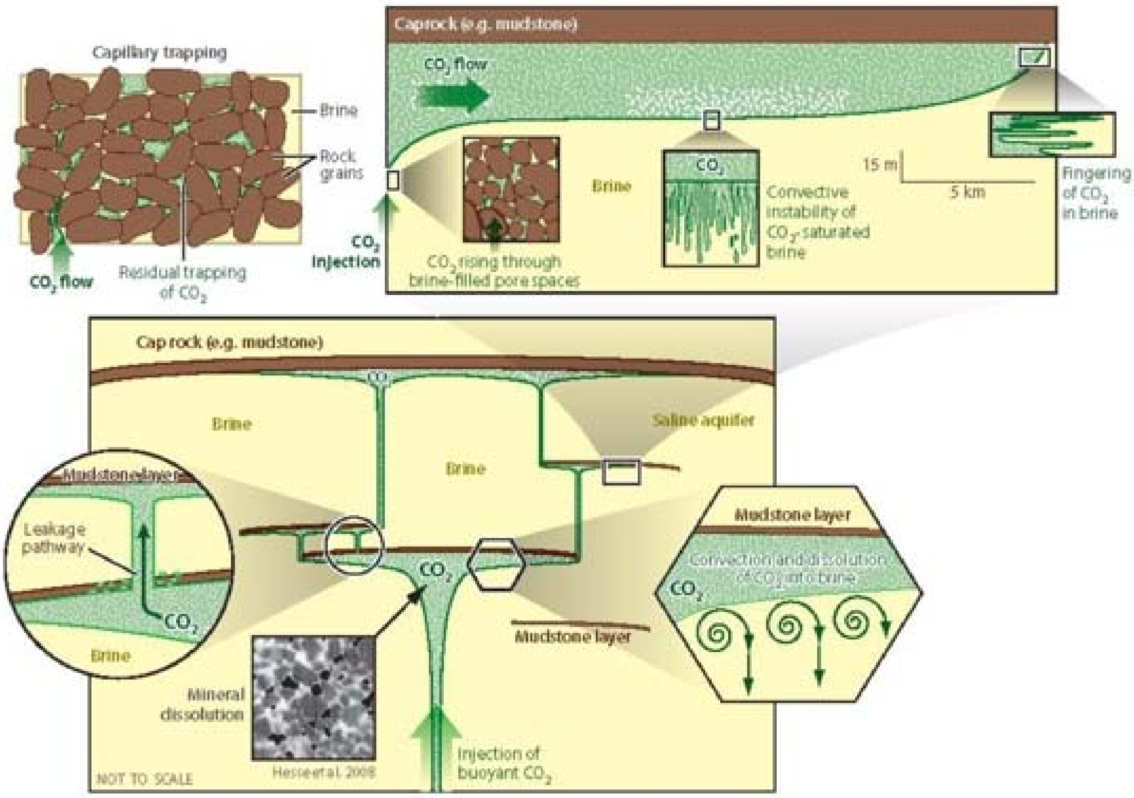

Figure 1. Trapping mechanism for CO2

Buoyancy-driven flows are ubiquitous in natural and engineered systems, such as the subsurface environment. The study of gravity currents (GCs) dynamics in geologic media is motivated by CO2 sequestration, CO2-enhanced geothermal systems, hydrogen storage, contaminant migration, seawater intrusion, and mud invasion from drilling.

GCs develop in both fractured and porous media; in existing formulations, one or more complicating factors that add realism to the domain description (topography, heterogeneity, bottom and/or edge drainage, leakage via faults or fissures) are added to the basic scheme, plane/radial geometry with Newtonian fluid flow. However, the effect of macro-heterogeneities on the propagation of the gravity current is far from clarified and is a first knowledge gap to be addressed. In addition, many fluids in subsurface applications exhibit a strongly non-Newtonian rheology; this poses further challenges to effective modeling. See Figure 1 for a schematic review of the possible scenarios.

Theoretical results available for the edge/diffusion/localised drainage scenarios indicate a good degree of characterisation of the loss mechanisms affecting subsurface GCs, but experimental validations are lacking. Therefore, the project aims to provide experimental validation of existing theoretical schemes for advancing Newtonian GCs when different loss mechanisms are present. A second objective is to develop theoretical and experimental studies on Newtonian GCs by coupling the effect of macro-heterogeneities with different loss mechanisms. The third objective is to develop theoretical and experimental studies on non-Newtonian GCs by combining macro-heterogeneities (aperture variation and stratification) and leakage. A fourth objective is to apply a time-independent rheological model other than the power law to assess the impact of a more realistic non-Newtonian rheology.

The project aims to investigate two possible configurations for GCs in porous or fractured media:
1) Scenario I: GC subject to leakage from the substrate and edges;
2) Scenario II: GC produced by localised injection and subject to localised leakage (see Figure 2).
These main scenarios incorporate several variants connected to macro-heterogeneity and fluid rheology.
To achieve these goals, the project activities will be articulated in:
a) Experimental modelling and rheometry, centered on two prototype laboratory experiments and related rheometric measurements;
b) Theoretical modelling, based on the synergy between numerical and analytical methods and with emphasis on the prediction of time scales associated with CO2 trapping.

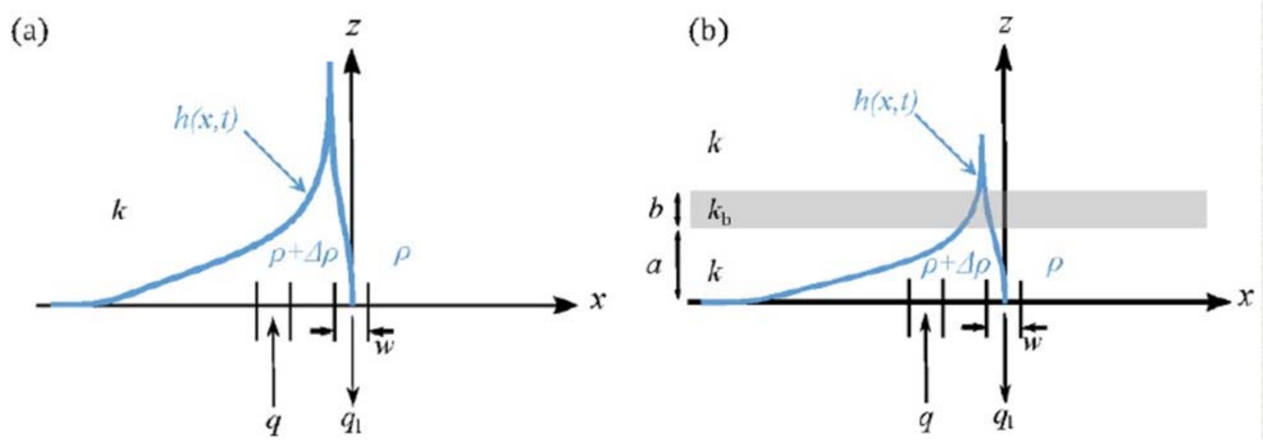

Figure 2. 2D schematics of a GC injected into a (a) homogeneous and (b) heterogeneous porous domain with a low-permeability inclusion and drained by vertical fracture.

Given its multiple benefits – for environmental protection, groundwater management, energy production, climate mitigation, climate adaptation services – the project contributes to several Sustainable Development Goals (SDGs) of the UN, including good health and well-being (SDG3), clean water (SDG6), affordable and clean energy (SDG7), work and economic growth (SDG8), climate change (SDG13) and life on land (SDG15).

Relevant publications on this topic by the proposer

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