# Coupled Hydromechanical Model For Assessing Land Subsidence Due To Salt Layers Dissolution

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**Abstract**

Long term evolution of salt mine depends on elasto-viscoplastic behavior of the material but also on specific conditions like the intrusion of water into working areas. Such phenomenon has been observed in the Nancy Basin where brine percolates through access shafts accompanied by significant subsidence at the surface level, bringing about growing societal concerns.

In order to understand the mechanisms and kinetics of dissolution of salt inducing the phenomenon of subsidence, a numerical model is implemented. The model simulates the circulation of water between the salt layer and the impervious layer and the creation of dissolution channels. In active dissolution zones, the channel network constantly evolves: new channels appear with new dissolution zones while others collapse because of their too important dimensions.

Initial porosity and hydraulic conductivity fields, related to each other by a cubic law, are assumed to follow a Weibull distribution. From this initial state, the transient model calculates the evolution of porosity with time, taking into account Darcy's velocity as it was formulated by Yao et al. (2012). Progress in dissolution and transport gives rise to the creation of dissolution channels.

Channels mechanical behavior is investigated through geometrical evolution based on porosity threshold: when porosity exceeds a given value, the channel collapses and the salt layer thickness decreases. Influence of the cumulative salt layer dissolutions on the surface is determined by empirical propagation models.

Key words: Salt mine, Subsidence, Dissolution, Model

## Introduction

Salt dissolution induced by freshwater percolation into salt formations (through natural aquifer or mine works) may lead to significant subsidence at the surface level, as it is the case in the area of Dombasle in the Nancy Basin (France). Large salt mining exploitations started there in the mid-19th century and significant subsidence has been noticed and recorded since.

In this on-going study, we aim to numerically model patterns of salt dissolution leading to slow or brutal vertical displacements, using Matlab and Comsol Multiphysics.

### Nancy Basin: a 150-year old case study

Dombasle area is heavily constrained in terms of urban development because of past salt mining activities on its territory which are responsible for subsidence and structure damages.

Lorraine subsurface consists in an important Lower Keuper saliferous deposit which is approximately 200 km long, 50 km wide and 100 to 150 meters thick with a dip of a few degrees (Saunier and Courrioux 2008). Under river beds, the saliferous formation roof is only 50 meters deep. The lithostratigraphic section of the Lower Keuper formation is presented on fig. 1. The salt deposit has been industrially mined for 150 years in Nancy Basin (Art-sur-Meurthe in 1861 and Dombasle in 1877), at the confluence of Meurthe and Sânon rivers, 12 km South-East of Nancy City.

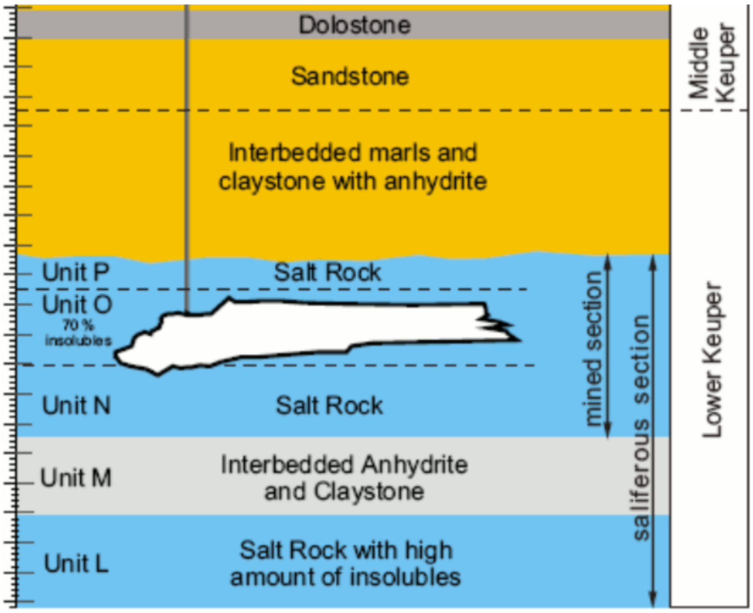
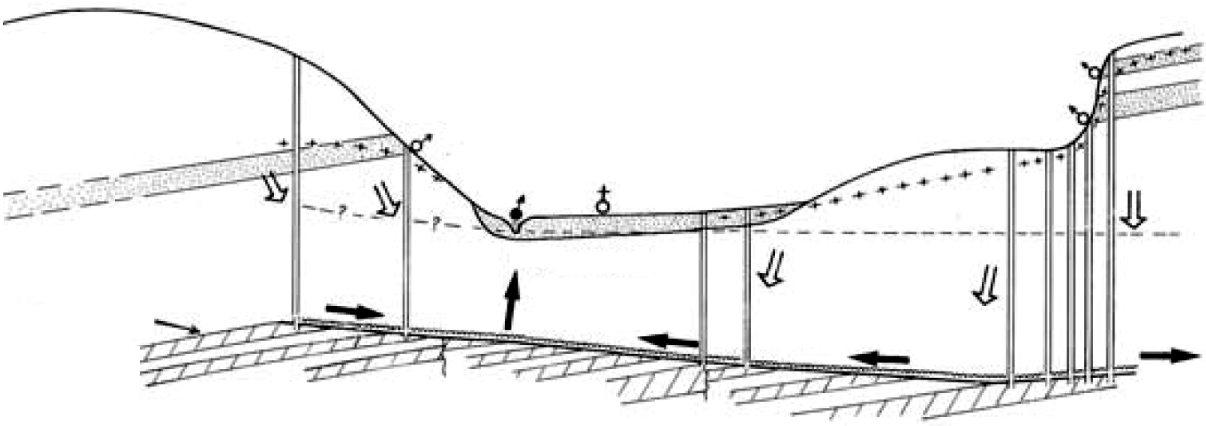



***Figure 1*** *Nancy Basin lithostratigraphic section.*

The mechanism of dissolution is likely related to rainwater percolation through the overburden towards the salt deposit roof. The latter is impervious to water, therefore groundwater flows towards its outlets (springs or rivers) while leaching the saliferous layers top (fig. 2). It is estimated that 30,000 tons of salt are rejected in the surface water system each year (Lebon 1987).

This mechanism existed prior to mining operations and explains the presence of Dombasle saline aquifer which is actually a network of anastomotic dissolution channels, separated by contact zones between the saliferous deposit and its overburden. During mining activities, the equilibrium of the system has been probably disturbed, allowing the reactivation or the acceleration of the dissolution processes.



Freshwater
Former extraction borehole
Dombasle water table (approximated)
Freshwater table (very approximated)
Freshwater circulation
Former freshwater source
Salted water circulation
Current salted water source
Salt formation
Salted water table

***Figure 2*** *Dombasle saline aquifer circulations.*

Salt dissolution creates voids which lead to subsidence at the surface. Due to social constraints, the region has been the object of regular and diverse monitoring for a century.

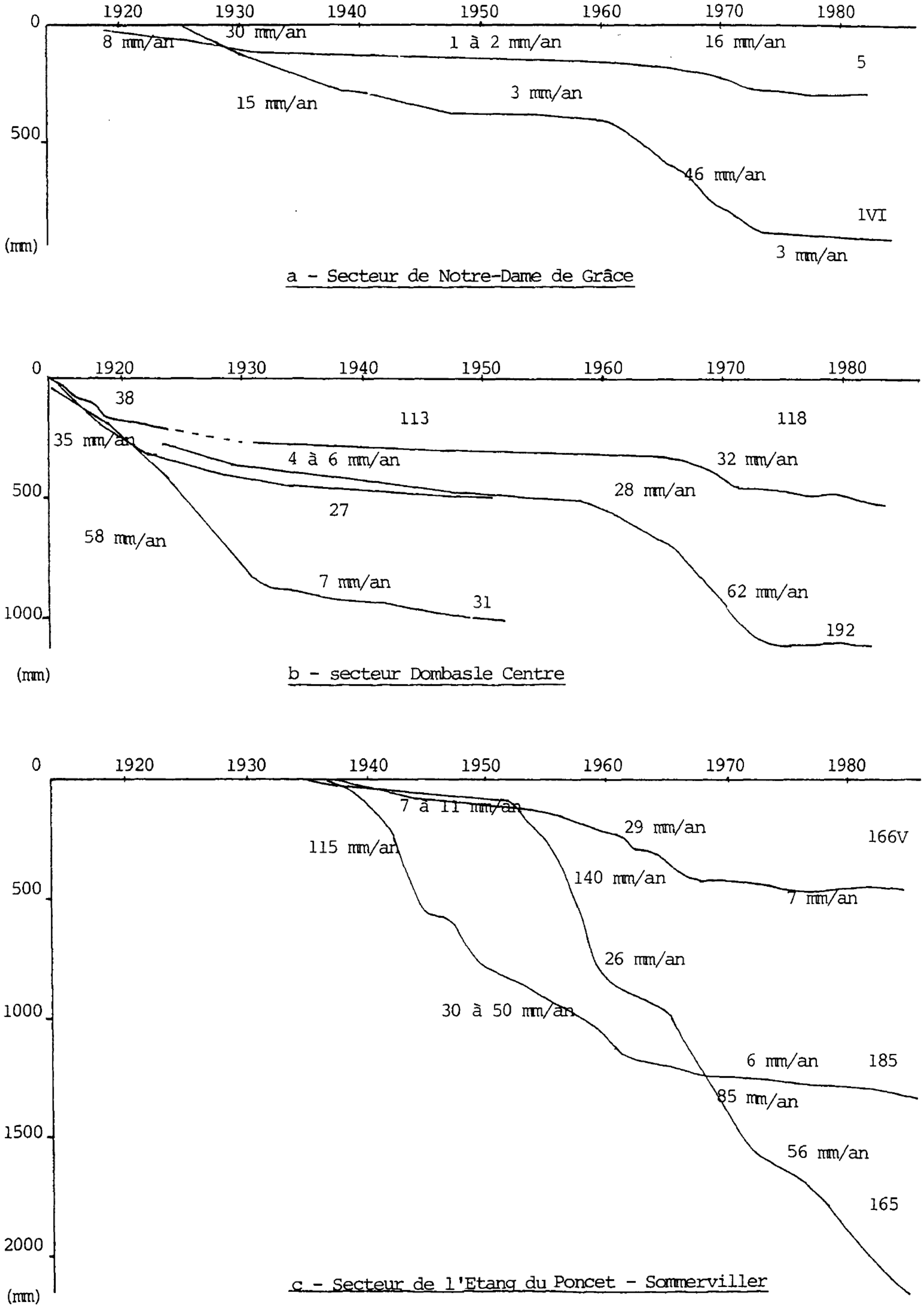



***Figure 3*** *Subsidence monitoring since 1914 in Dombasle area.*

Subsidence rates have been measured between 30 and 60 mm/year during active dissolution periods (fig. 3), it can reach 140 mm/year in particular sectors. During low dissolution period, the subsidence rate is around 5 mm/year. It has been shown that active/low dissolution periods are correlated to rainfall cycles. Cumulated subsidence after 70 years (fig. 3) is approximately one meter on several sectors and has exceeded two meters on particular points.

Dissolved salt thickness can be locally very important. The intensity of dissolution occurring at the contact between salt deposit and overburden varies according to the location: dissolution is very active where a rich layer is in contact with groundwater.

In active dissolution zones, the channel network constantly evolves: new channels appear with new dissolution zones while others collapse because of their too important dimensions. Several boreholes have been drilled to observe the structure of the dissolution channels: they do not exceed 20 cm in thickness.

*In situ* experimentations show that this groundwater system presents a high transmissivity. Isotopic dating of groundwater shows that these saline waters are "young": 1 to 4 years old. They come from natural infiltration of rainwater which percolates later through mineshafts.

**Salt channel modelling**

Initial porosity field is assumed to follow a Weibull distribution (eq. 1) to take into account the heterogeneity of the salt layer. A random correlated porosity field is initially set in the domain, using the following values of Weibull distribution parameters: λ = 0.15 (scale factor) and k = 5 (shape factor). Initial porosity values (fig. 4a) range from 3% to 25%.

$$f(x) = \left[\frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^{k}} \; if\; x \geq 0 \right. \atop 0\; if\; x < 0 \tag{1}$$

Porosity (ϕ) and hydraulic conductivity (k) fields are related to each other by a cubic law (eq. 2).

$$k = k_0\left(\frac{\phi}{\Phi_0}\right)^3 \tag{2}$$

In a regular cartesian mesh, Darcy's law and an Ordinary Differential Equation (ODE) linking porosity and flow, as it was formulated by Yao et al. (2012), are solved with Comsol Multiphysics (ϕ: porosity; c: salt concentration; v: Darcy's velocity; K: coefficient). The transient model calculates the evolution of porosity with time, simulating dissolution and transport, giving rise to the creation of dissolution channels (fig. 4b).

$$\frac{\partial \phi}{\partial t} = K(1-\phi)c\|\vec{v}\| \tag{3}$$

This is a simplification of the geochemical phenomena which occur and which could require more comprehensive (but also time-consuming) investigations by reactive transport modelling means (e.g. with codes such as Phast, Toughreact, Crunch, etc.)

**Vertical displacements and collapses**

Several mechanisms of vertical displacements occur in the Dombasle area, the prominent one being slow subsidence. We also observe sudden collapse, piping or chimneying. For now in this study, we primarily focus on slow subsidence.

Considering that geochemistry and geomechanics coupling is a highly delicate field of investigation (Liu et al. 2009 and Malvoisin et al. 2015), we make strong assumptions and take a straightforward empirical approach based on porosity and geometry evolution.

Model geometry is regularly updated with Matlab, according to porosity and pressure conditions, in order to simulate fast collapses within the salt formation (fig. 5). Poroelastic strains are considered small and slow compared to collapse mechanisms.

Influence on the surface is determined by propagation empirical models (fig. 6). The conical effect (influence and rupture angles) is expected to be not significant as the salt formation is relatively shallow and topped with significant amounts of clay.

The results of these investigations seem to be consistent with the in situ measurements, notably with the estimation of the subsidence rate, once determined the right parameters values.

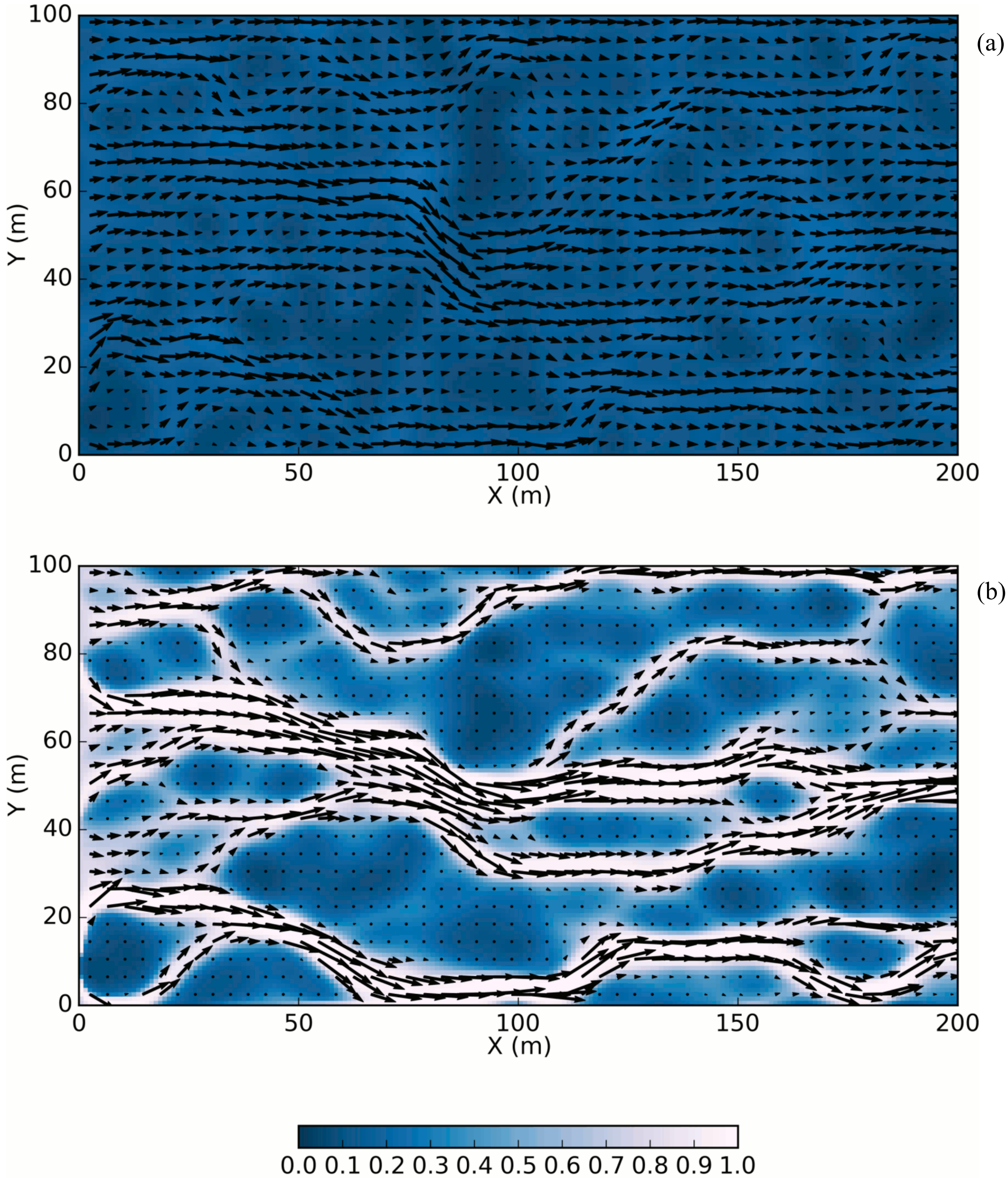



***Figure 4*** *Example of channels formation modelling in a 2D XY (200 x 100 m) Cartesian mesh (1 m discretization). c is taken approximately constant at salt saturation concentration such as K*c = 0.001. Initial Weibull distribution convoluted with a 5 m radius Gaussian filter. Porosity fields (range from 0% to 100%, color scale dark blue to white) and Darcy's velocity fields (arrows) for T = 0 year (a) and T = 40 years (b). Computed norms of Darcy's velocities range from* $10^{-9}$ *to* $10^{-5}$ *m.s*$^{-1}$.

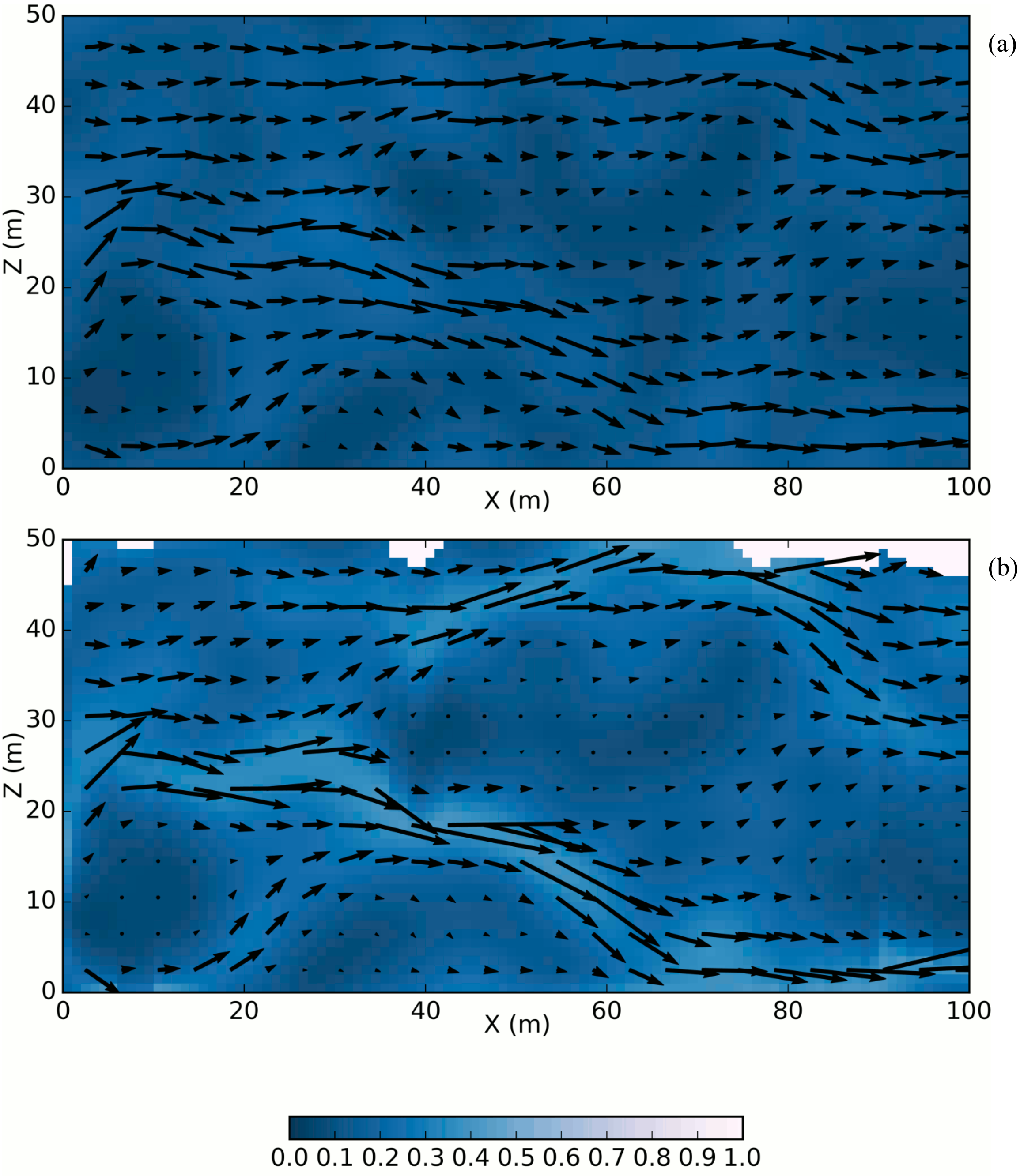



***Figure 5** Example of very fast collapse modelling in a 2D XZ (100 x 50 m) Cartesian mesh. Same flow and initial porosity settings, and same porosity scale, as in figure 4. After each transient flow calculation (0.1 year), geometry and porosity are updated by collapsing columns above a cell where porosity exceeds a threshold of $\phi$ = 0.4. Results shown at T = 0 year (a) and T = 3 years (b).*

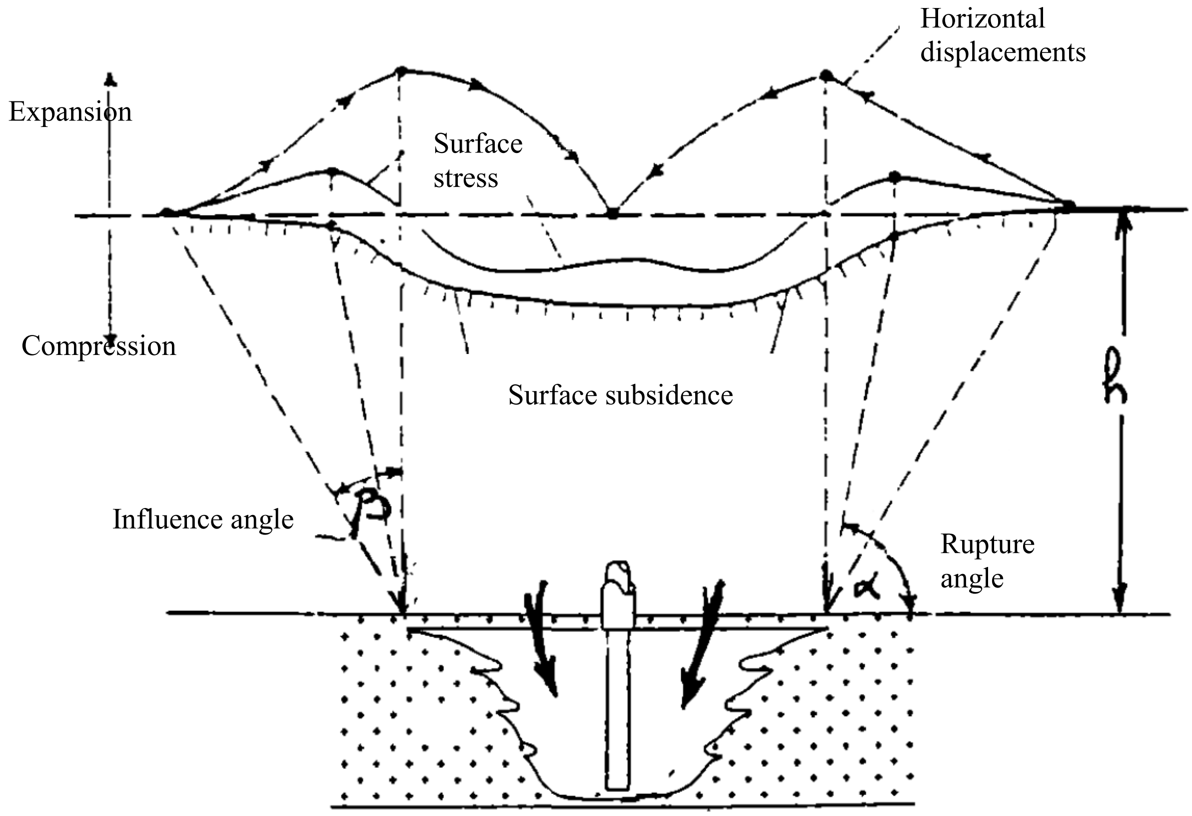



***Figure 6*** *Model of vertical displacements propagation inducing subsidence at the surface.*

## Conclusion and prospects

The loosely coupled hydro-mechanical model currently developed in the frame of this study allows realistic simulation of creation and collapse of dissolution channels.

Once enhanced in its capabilities of modelling several collapse shapes and kinetics, and with improvements on the solute transport representation, it can potentially be a powerful tool for assessing the ground stability around a salt mine. In particular, this model can be used to describe accurately the environmental consequences of salt mine closure on land stability and groundwater quality.

Global performance of the numerical models is expected to be improved in order to refine model geometry and, in the long run, be able to do 3D modelling.

## Acknowledgements

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