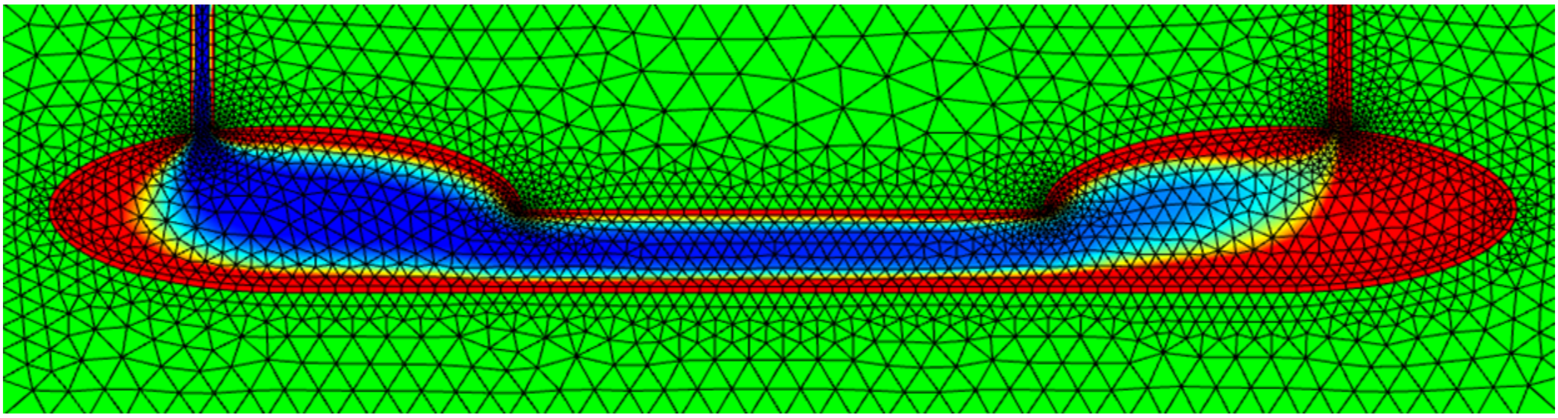
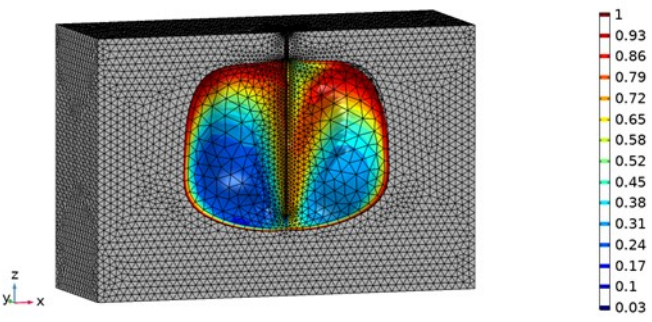


Numerical modelling of the dissolution of rocks

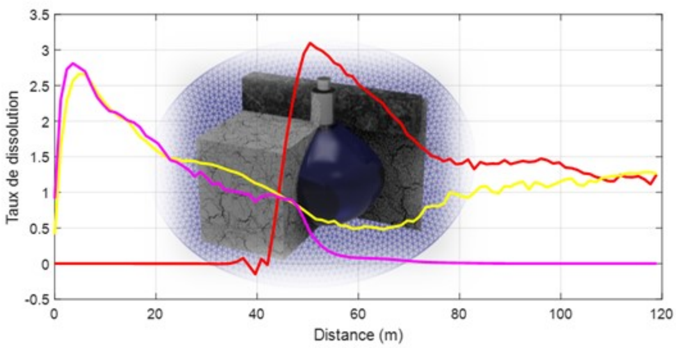
Local authorities, developers, works managers and mineral resource operators are faced with risks related to the underground dissolution of salt and gypsum, which leads to the formation of underground cavities. In order to study dissolution phenomenon, Ineris develops advanced numerical modelling tools that can describe the place and the space-time evolution of these cavities. These models provide access to information (volume, shape, development kinetics) about the cavities that is not accessible by means of observation or measurement. These developments are applied to the study and evaluation of hazards and risks of industrial or natural origin.

DEVELOPPED NUMERICAL APPROACH The numerical modelling of the evolution of anthropic or natural cavities formed by dissolution is complex because of the numerous and interacting physico-chemical processes involved. Ineris has formalised this multi-scale and multi-physical problem by relying on principles of balance within the framework of thermodynamics and chemical kinetics. The developed approaches are based on a change of scale and a homogenisation method (average theory). Given that dissolution is conditioned by the nature of the fluid in contact with the salt or gypsum, it is necessary to precisely describe the (two-phase or three-phase) flows and the transport of dissolved species within the framework of thermo-hydro-chemical coupling. These approaches make it possible to model the evolution of arbitrary morphologies with complex structures.

FIRST APPLICATION CASE: OPTIMISATION OF SALT MINING OPERATIONS. The implemented numerical approach was used on behalf of a salt operator as part of a salt deposit mining operation. The aim was to optimise the operation while minimising the impact on the surface. The tool made it possible to carry out a large number of injection simulations in vertical and horizontal boreholes (see banner and figures below). The impact of different scenarios and injection parameters on the dissolution kinetics and evolution of the cavity could be appreciated.



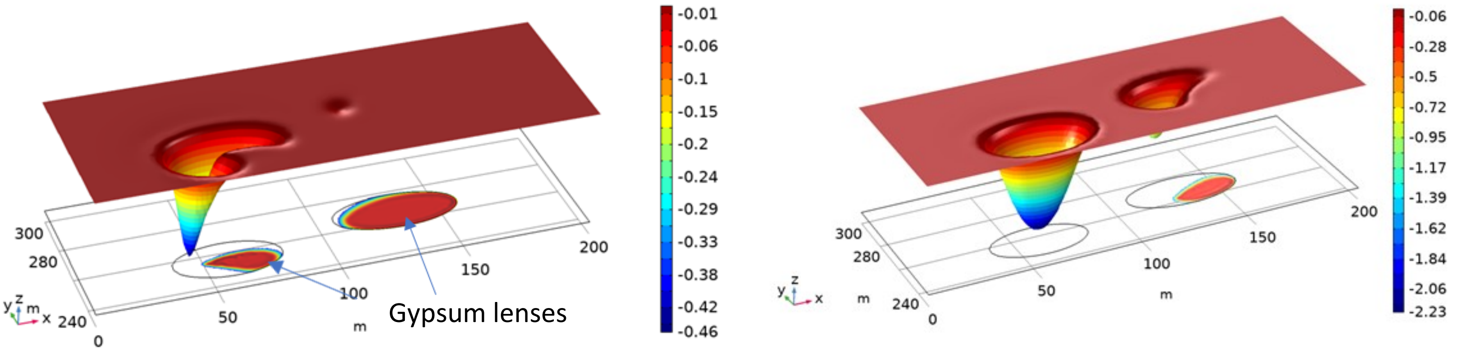
Cavity shape and normalised concentration field of the brine after a period of injection.



Evolution of the dissolution rate (g/m2/s) on the cavity wall. The rate of dissolution changes over time and according to spatial directions (different coloured curves).

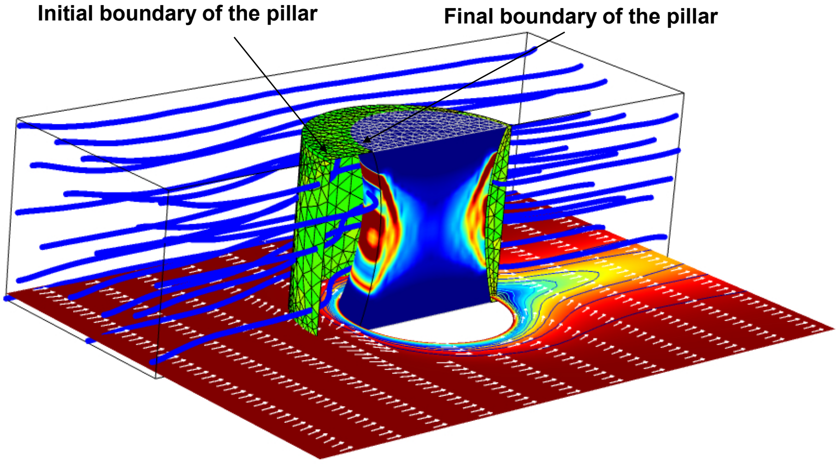
controlling risks
for sustainable development

SECOND APPLICATION CASE: GYPSUM LENS DISSOLUTION AND MECHANICAL CONSEQUENCES. In the aim to assist an underground works manager in characterising the mechanisms of instability linked to the dissolution of structures in gypsum formations, a case study has been modelled. This model involves the superposition of two gypsum lenses subjected to a flow of pure water. The simulation enabled to reproduce the formation and evolution of the cavities formed after several decades, to guide the works manager on the most influential parameters, and to propose suitable mitigation measures.

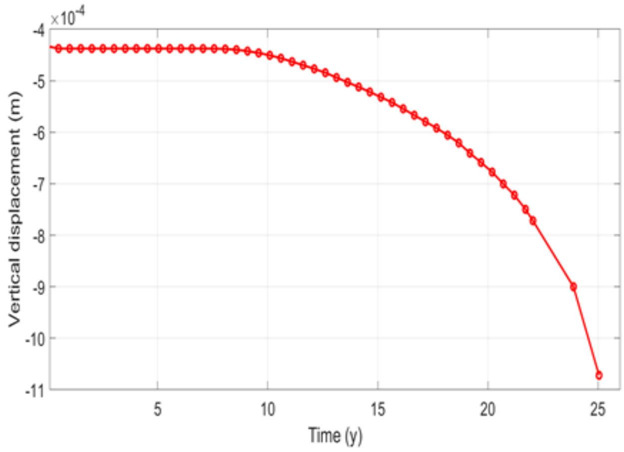


Evolution of the surface vertical displacement after 20 years (left) and 100 years (right), as function of the dissolution of the gypsum lenses. The units are in metres and the amplification of deformations is different for 20 and 100 years.

THIRD APPLICATION CASE: PILLAR FAILURE IN A FLOODED GYPSUM QUARRY. In order to assess the risks associated with the flooding of an ancient underground quarry, the dissolution of a pillar sustained by a flow of pure water was modelled. This simulation enabled to determine the time scale needed for the plastic deformation of the pillar to lead to its collapse.



Representation of plasticity induced by dissolution, flow paths, gypsum concentration isovalues, and vector field of flow velocities in the pillar.



Annual evolution of surface displacement induced by dissolution until the collapse of the pillar. The failure is characterised by a rapid increase in displacement as a function of time, which gives a predictive character to the method.

LESSONS LEARNED. The innovative approach developed by Ineris meets the increased needs of local authorities, operators, and works managers faced with the management of natural cavities. In the future, the impacts of climate change will modify underground hydraulic regimes (increase in rainfall, extreme weather, desaturation, flooding, renaturation of soils, etc.) and will exacerbate the risks linked to rock dissolution in urban areas. Within this context, numerical multi-physical modelling is unvoidable since it provides important spatial information on the evolution of cavities and the transport of dissolved species, information that is difficult to access and which remains usually point data through field subsurface investigations alone.