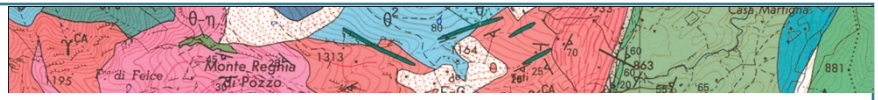

Evaluation of the CO_2 leakage risk along the abandoned wells in the French context

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Objectives of the study

- **Establish a classification adapted to the French context**
  - Criteria to be retained
  - Are data available for verification?
  - Risk levels derivation and mapping
- **Incorporation of environmental criteria from a case study:**
  - Reservoir fluid chemistry
  - Mechanical behaviour of rocks surrounding abandoned well
  - *In situ* stress, pressure and temperature

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Part I : Adaptation of Watson and Bachu (2007) classification to the French context

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Retained criteria for the classification

- **Wellbore type (cased or uncased):**
  - → A well is considered as “cased” if it has a cased interval intercepting the reservoir where CO_2 may be stored (here, the Dogger or Keuper reservoirs in the Paris Basin)
- **Date of abandonment:**
  - → To be compared to year 2000, which corresponds to a significant improvement in the French wellbore abandonment regulation
- **Cemented up to the surface (or not)**
- **Deviated well (or not):**
  - → A wellbore is deviated if its total depth (TD) exceeds its total vertical depth (TVD)
- **Spud date:**
  - → To be compared to year 1980

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Data source

- **We essentially used the database “Forages profonds”**
  - Carried out under an agreement between BRGM and the French water agency (Vernoux *et al.,* (2003))
- **A total of 3482 wells, among them 3144 were analysed to perform this study**
- **Available information in the main table:**
  - Well identification code
  - Dates (end of drilling, abandonment, …)
  - Well type
  - State (operating or abandoned)
  - Depth
  - Cementing and casing
  - Plugging (for abandoned wells)
  - ...and other tables that complete wells description

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Verification of availability of data relative to the considered criteria

> **Only the Dogger aquifer is considered**

> **But the database allows to access only to geologic strata that have been crossed by the wells**

→ **So we make the following assumptions :**

- The Dogger aquifer is present anywhere in the Middle Jurassic
- Depth of its roof between 800 and 1600 m

→ **216 wells are concerned**

> **Results from verification:**

	Retained criteria for the classification				
	Wellbore Type	**Abandonm-ent Date**	**Cementing**	**Deviation**	**Spud date**
Avalaibility in the database	**85.6%**	**57.87%**	**100%**	**100% or 23%**	**100%**

Availability of data in the 216 abandoned wells likely to intercept the Dogger aquifer

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Shallow leakage risk calculation

- **Shallow leakage factors (Watson & Bachu 2008)**
- **Lack of information for 2 criteria**

→ **4 values for each well : min-min, min-max, max-min and max-max**

- Min: the minimum value is attributed to the criteria when information is lacking
- Max: : the maximum value is attributed to the criteria when information is lacking

Criterion	Value
Cased well Uncased well Lack of information	8 1 8 or 1
Abandoned before 2000 Abandoned after 2000 Lack of information	5 1 5 or 1
No cement to surface Cementing intervals unknown Other cases	5 4 1
Deviated well Non deviated well	1.5 1
Spud date before 1980 Spud date after 1980	3 1

Shallow leakage factors

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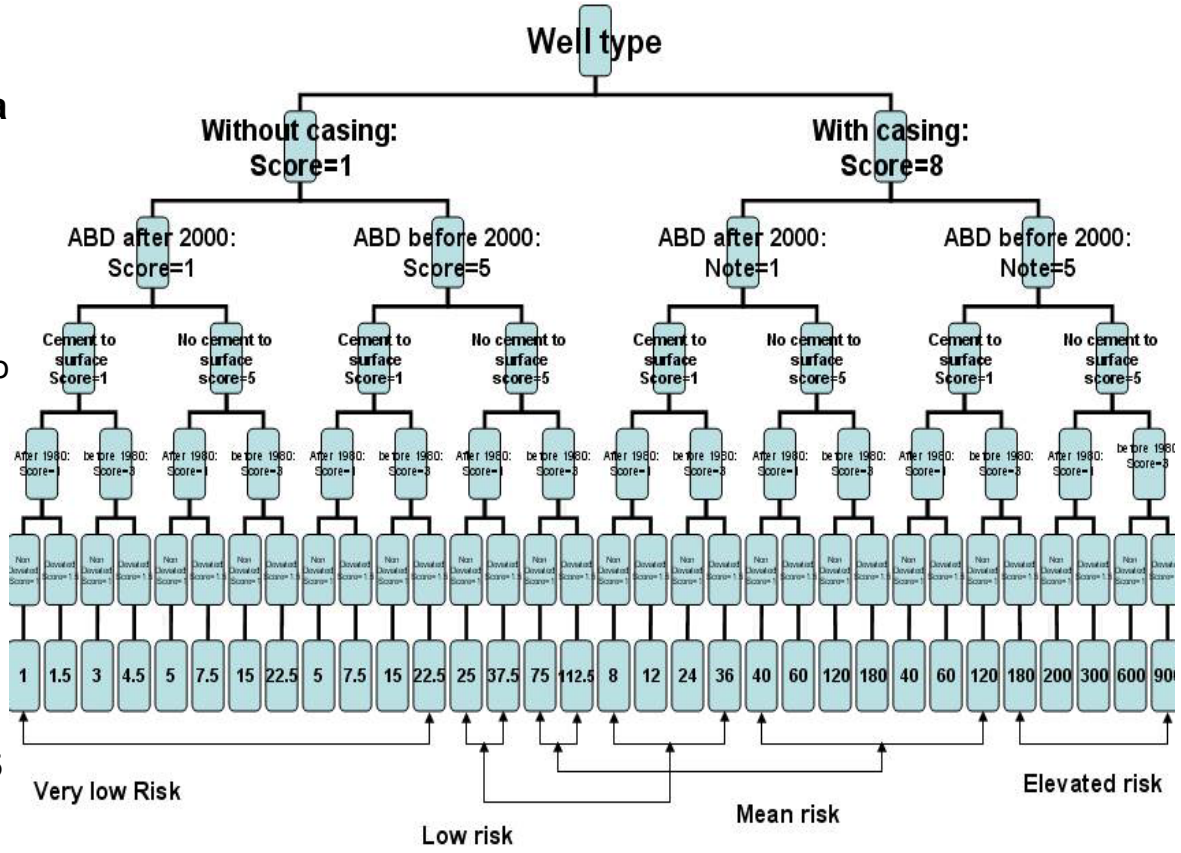
Risk levels

> **Using the values of table 2, a tree risk of 32 branches has been determined. The tree risk shows four risk levels:**

- **Elevated risk**: the CO_2 surface leakage risk of the well is greater than or equal to 200 and less than or equal to 900
- **Mean risk**: the CO_2 surface leakage risk of the well is greater than or equal to 40 and less than or equal to 180
- **Low risk**: the CO_2 surface leakage risk of the well is greater than or equal to 24 and less than or equal to 37.5
- **Very low risk**: CO_2 surface leakage risk of the well must be greater than or equal to 1 and less than or equal to 22.5.



The tree risk used to derive the risk levels

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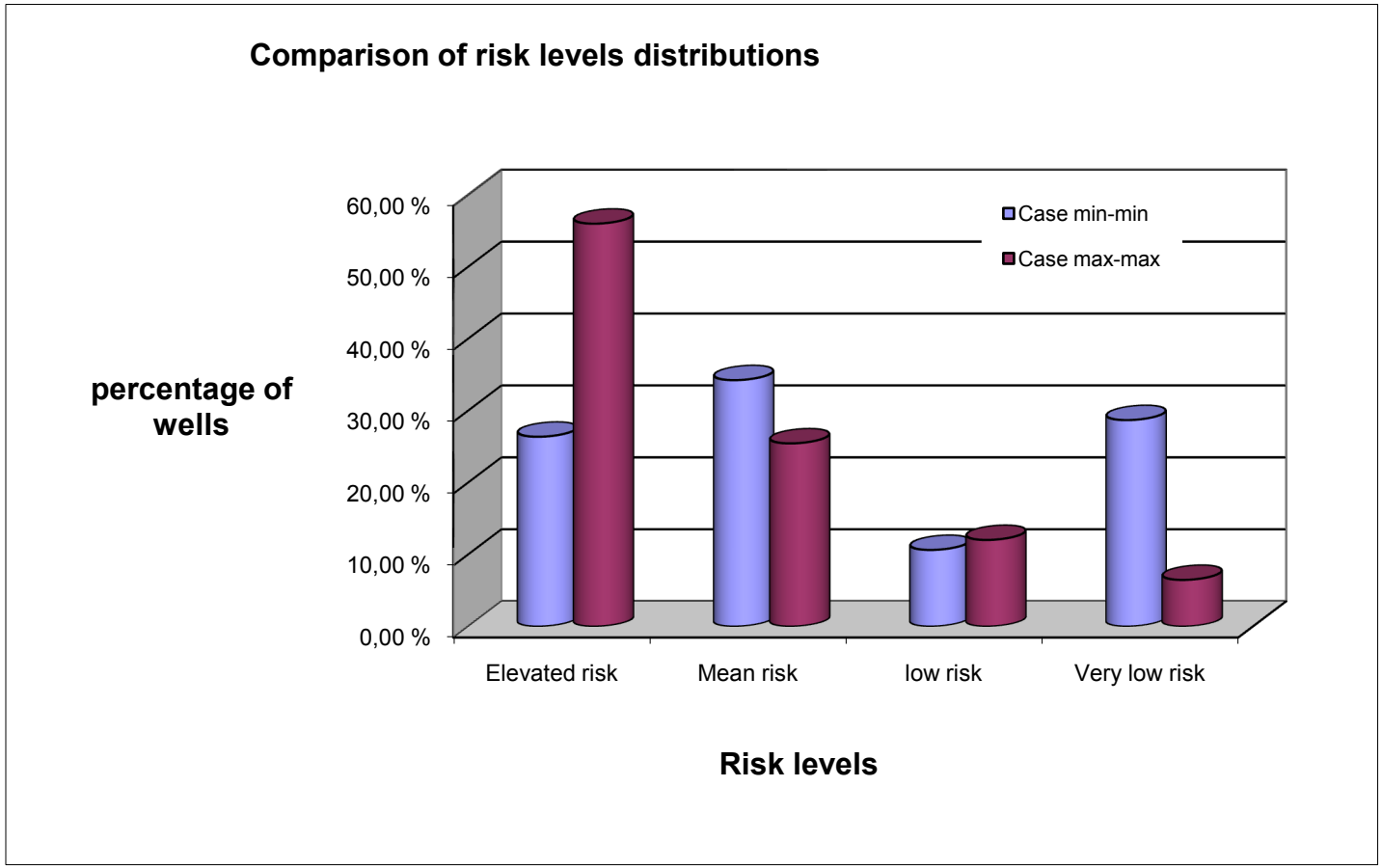
Risk levels comparison



Comparison of risk levels distributions

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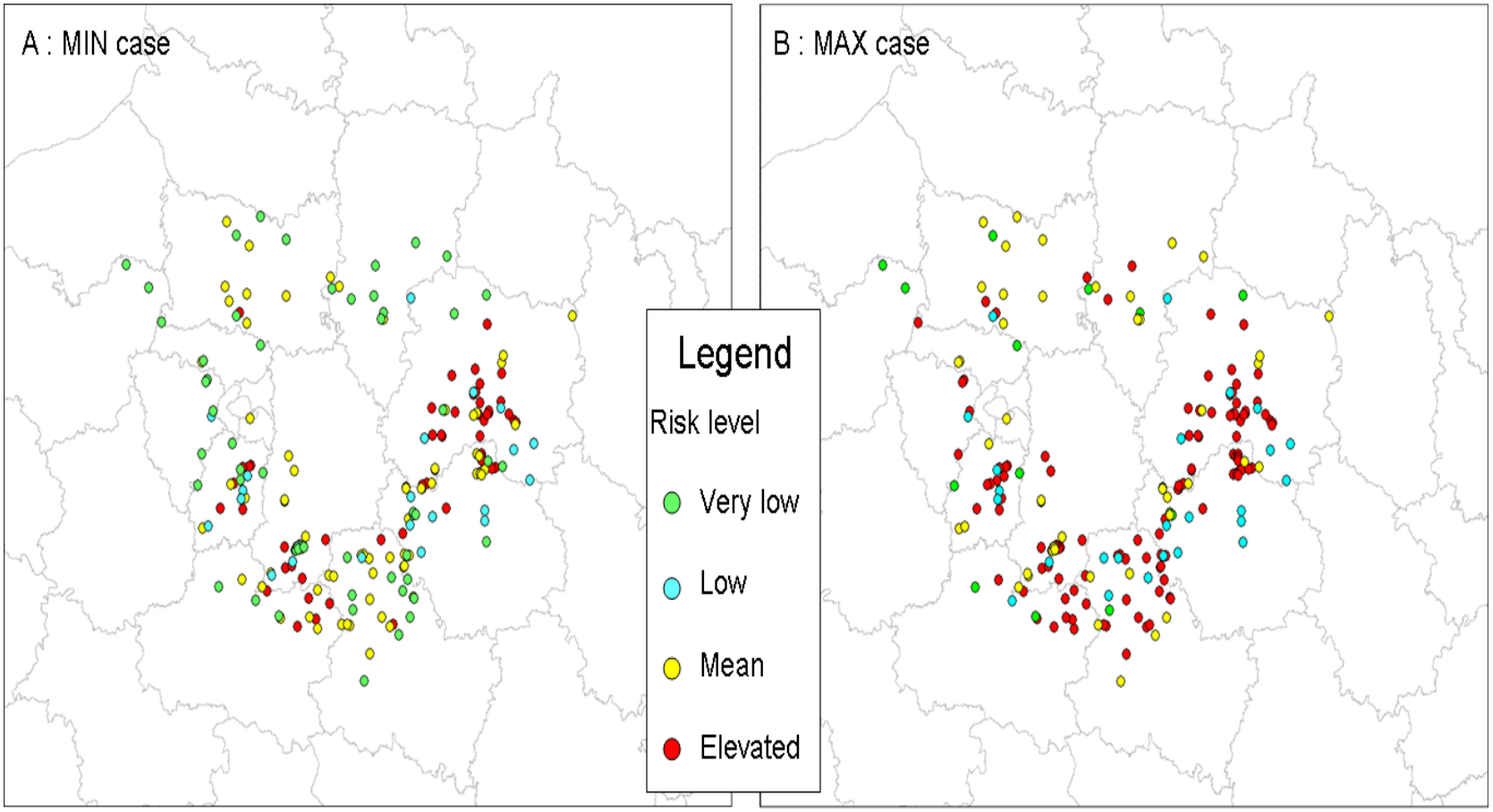
Mapping



The resulting maps emphasizing that the classification is strongly influenced by the way that the lack of information is managed

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Conclusions about the classification

- **The input data necessary to establish the classification are mostly available**
- **The management of the lack of data is of primary importance in this kind of study**
- **The methodology used here does not take into account any changes in the integrity of the well in the long run.**

→ **This is the goal of the next step of this study**

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Part II: Towards mechanical and environmental criteria

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Objectives

> **The objective is to assess the failure risk of the cement plug of an abandoned well after injecting CO_2 :**
  - For different CO_2 injection scenarios (**injection rate**)
  - Different distances between injection well and the abandoned well (**d**)
  - In a compressive stress regime or an extensive one (**K**)
  - For different type of the rock surrounding the abandoned well

> **For now only the mechanical aspects are investigated**

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Method

> The calculation is in two parts:

1. Large-scale hydro-mechanical simulation of the CO_2 injection using the “Superviseur”
   - In a 150 km radius axisymmetric model
   - For each stress regime and each injection rate
   - Variation of the effective stresses induced by the injection was extracted at different distances (from injection point) where the abandoned well could be located
2. 3D simulation of the well cement plug and its immediate environment by superimposing:
   - The loading history of the abandoned well
   - And the variation of effective stresses induced by the injection of CO_2

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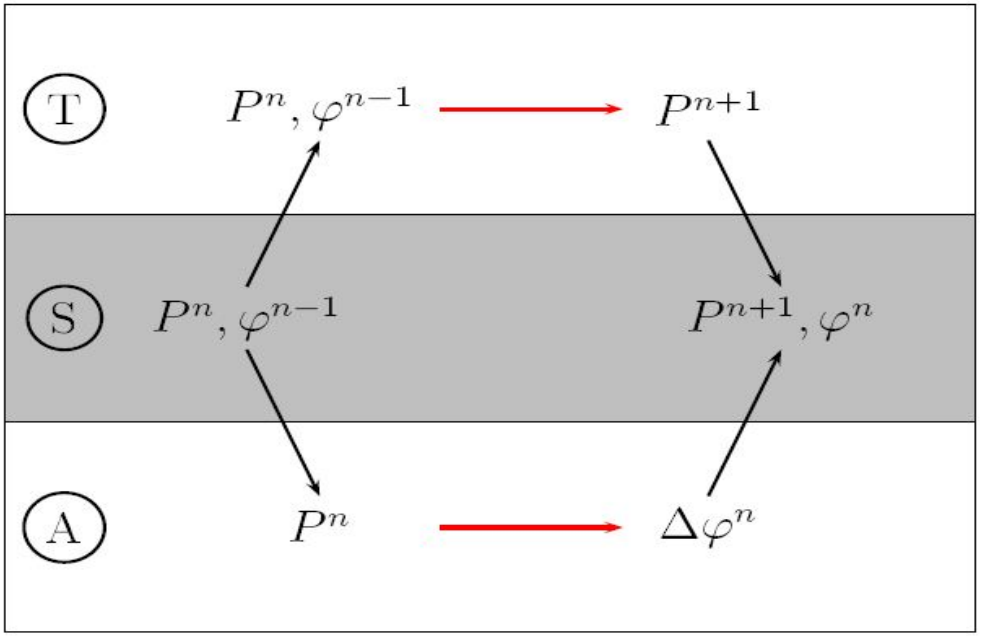
The “Superviseur”

- **Provides a coupling between Code_Aster and TOUGH2/ECO2N (for its ability to take into account the supercritical property of the injected CO_2)**
  - Pre-processing, launching, synchronisation of the two codes
  - Communication between the two codes
  - Storage of the data for post-processing



Parallel algorithm. At time n, TOUGH2 calculates the total pressure for the time n + 1 while Code_Aster is calculating the change in porosity that allows to update the permeability for time n + 1 (**Sochala et al., 2010**)

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3D simulation of the well cement plug

> **To illustrate the proposed methodology, the results from Mainguy et al. 2007 are used to reproduce the well state during production and abandonment. We summarize this study as follows:**

- A large scale reservoir simulation is carried out to simulate production and abandonment

→P and T are then calculated

- These P and T are used to derive effective stresses in a geomechanical model, in two cases:
  - Maximum compressive load
  - Maximum tensile load

→The loading history of the abandoned well is then derived

- Finally a wellbore mechanical model is carried out using effective stresses extracted from the cell where the wellbore is located

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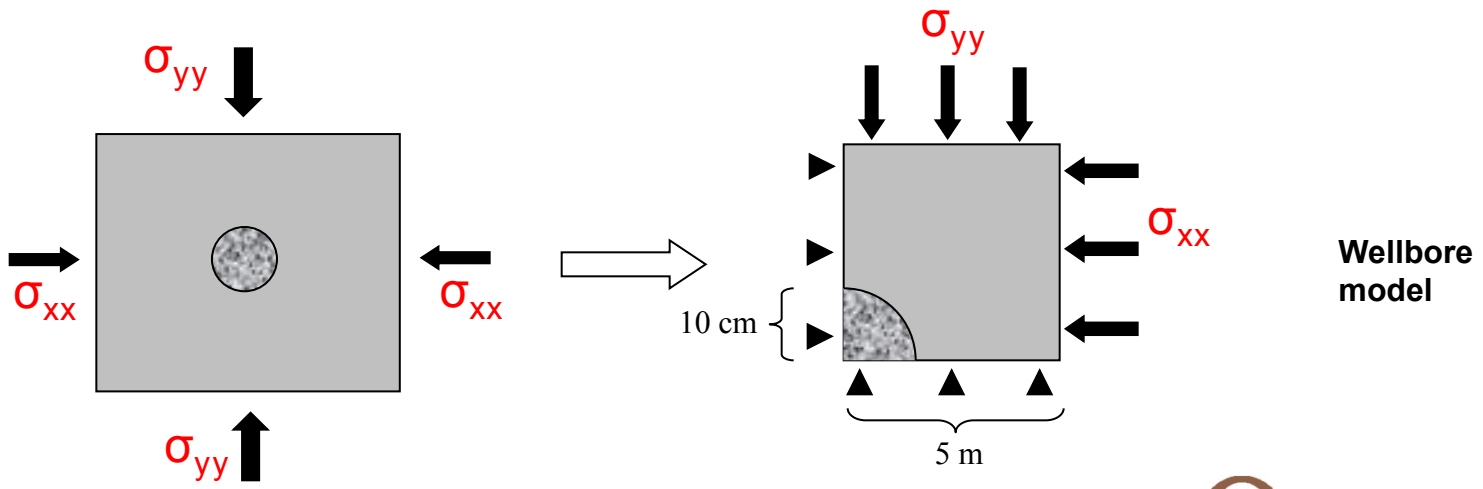
Wellbore mechanical model

- **Rock zone of 10m x 10m x 1m around the wellbore of 10cm radius.**
- **Stresses are applied to the boundaries of the model and in its upper face (not seen on the figure below)**
  - Loads history from the large scale geomechanical model of Mainguy et al. 2007, in the case of maximum tensile load
  - And loads representing effective stresses changes due to CO_2 injection (Rohmer & Seyedi, 2010 for material properties)
- **Zero displacements in the inner edge of the model due to symmetry and in the lower edge**



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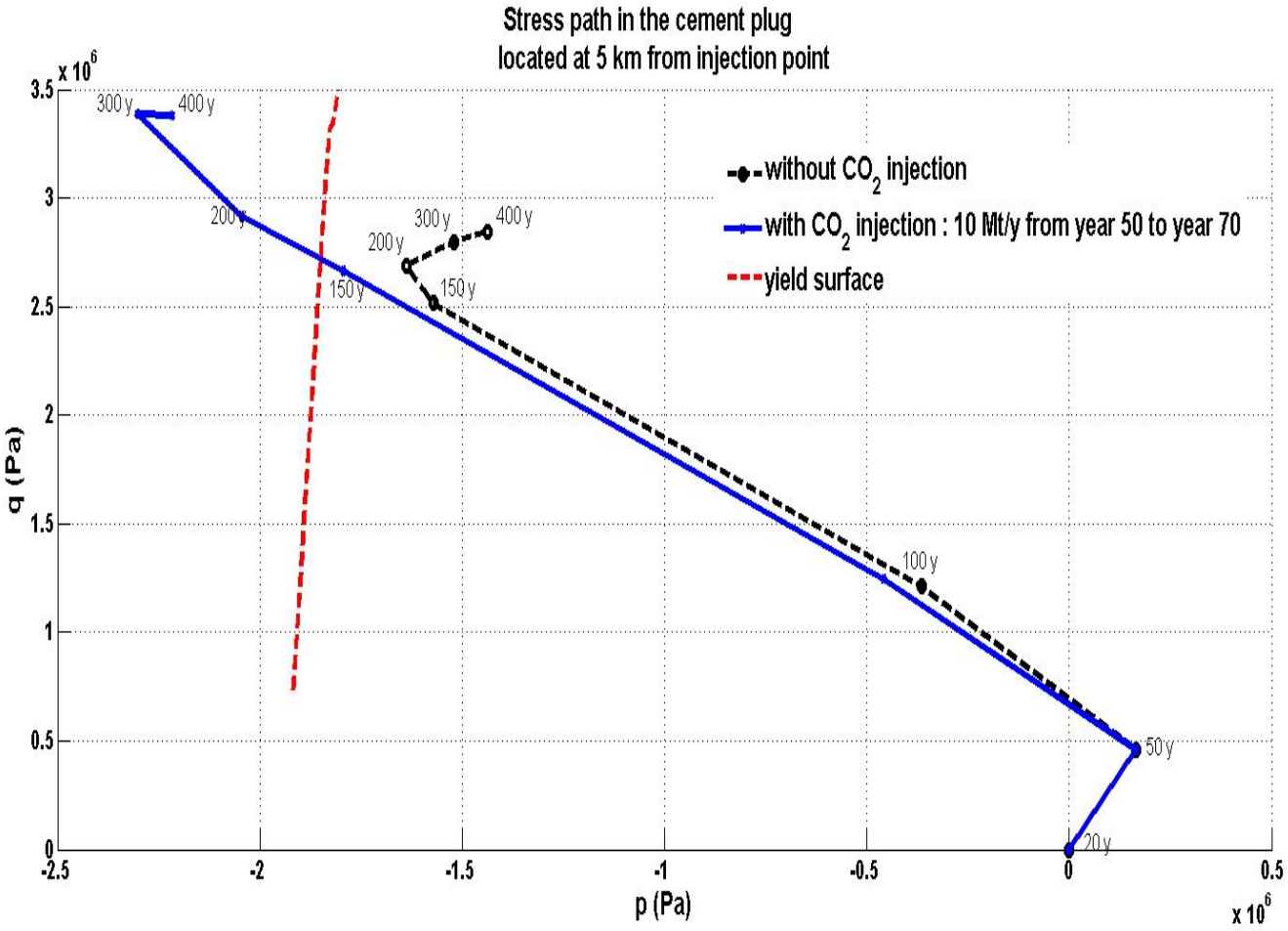
Results for 1 scenario



The injection of CO_2 may induce the abandoned well cement plug failure at approximately 150 years for the studied conditions

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Work in progress

- **Realization of the different scenarios**
- **Determining the parameters that influence the most the failure risk of the cement plug**
- **Proposing new environmental criteria related to:**
  - Stress regime
  - Mechanical properties of rock surrounding the abandoned well
  - CO_2 injection scenario (injection rate and distance of the injector well to the abandoned well)

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Conclusion

- **We have shown here a methodology for a mechanical study of an abandoned well**
- **The objectives are to draw general conclusions as the classification does**
- **And provide a complement to the classification for decision making**
- **The impact of the following parameters will be investigated**
  - Injection rate
  - Stress regime
  - Mechanical properties of rock surrounding the wellbore
  - Distance from the injector well

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