Insights on Shale as a Barrier Towards Plug and Abandonment (P&A) of Brazilian Wells

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Extended abstract

Introduction

Well plug and abandonment (P&A) represents a challenge in ensuring long-term environment protection, and a big non-return expense for operators. This topic has been very important for the Brazilian oil and gas (O&G) industry since massive investments have been directed towards decommissioning, and a large part of which towards well P&A [1]. Decarbonization actions also encourage P&A since repurposed reservoirs for carbon dioxide (CO_2) storage may be crossed by abandoned wells, whose barriers need to be verified in order to forecast fluid leakage.

Cement plugs degrade over time, especially when exposed to CO_2. Autochthonous materials, such as salt and some shales, are alternatives to restore the nature to its condition before well drilling. “Shale” is often a generic term to refer to clayey rocks [2], [3]. P&A standards worldwide (including Brazilian guidelines [4]) often accept rock barriers if they meet strength and tightness criteria required from cement plugs. The rock has to hold deformation capacity over time and ductility so that uncemented casing is embraced, requiring only its inner section to be plugged, Figure 1.

Cases of barrier formation within the well lifespan have been reported in the literature, mainly in the North Sea [5]–[7]. Besides that, drilling issues, such as stuck pipes, may be positively seen as deformation capacity. There are also track records of tight hole and hole closure in clayey intervals in Campos basin, Brazil [8]. Salt and shale have been qualified as hosts of toxic nuclear waste, application that requires very strict standards, encouraging their use as barriers for P&A.

The project SABAR (Figure 2) studies the formation of shale barriers in well engineering and the barrier effectiveness in terms of holding tightness and integrity. Knowledge production and methodologies are strategic for the O&G industry considering the upcoming P&A demand in Brazil since:

- P&A is recent in the Brazilian industry specially regarding cement-alternative approaches.
- Consolidated experience on Brazilian O&G shales should be directed to well P&A.

Geology and geomechanics

About 70% of world's sedimentary basins hold fine-grained sedimentary formations [9]. Among them, shales exhibit a great mineralogical diversity, impacting geomechanical and geochemical behaviors. In well geomechanics, it is worthy distinguishing between ductile and brittle shales, which exhibit compacted and cemented matrices, respectively [10]. Ductile shales are often normally consolidated rocks [11] with a high content of clayey minerals – particularly expansive minerals such as smectite and illite –, and also a low content of quartz [12]–[14]. The expansivity capacity is often recognized *sensu lato* as "creep" and represented by constitutive models that capture the macroscopic time-dependent deformation. Microscopically, water accumulates between the clay platelets causing shrinkage, besides enhancing rock mobility [2]. Ductile "creeping" shales are generally the ideal shale candidates to form barriers during the well lifespan [11], simplifying P&A. Qualitative criteria to indicate shale candidates from data available in well log files have been compiled from the literature, Table 1.

Main contributions

- Application to well data (SABAR Web)

The web application SABAR Web [16] has been developed to support well engineers in identifying the formation of shale barriers. SABAR Web imports information from a well log file and calculates relevant missing data using correlations to define a set of geophysical, mineralogical and mechanical data.

The application follows a smart workflow (Figure 3) to indicate the shale intervals and, among them, those that are candidates for barrier formation. The properties of the shale formation are presented along the logged interval. Mineralogical data is shown over depth and in a ternary diagram to check if the shale falls into a promising domain for barrier formation. The values are then evaluated based on the criteria listed in Table 1 to refine the identification of candidate intervals. Next, an analytical solution for creep is applied to estimate the time required for shale barrier formation.

- Mathematical solutions

The analysis of the formation of a rock barrier demands the consideration of many aspects related to the host rock and well components, i.e. borehole, cement sheaths and casings. Numerical modeling and simulation provide high geometric flexibility and enable the representation of sophisticated material behavior. However, the computational cost can be significant, depending on the modeling decisions.

Typical numerical approaches to analyze shale barrier formation consider a creeping or a thermally consolidated rock [17], [18]. These approaches allow predicting the time-dependent well closure around casing. Barrier effectiveness is often evaluated through the evolution of permeability and the microannuli closure over time. Moreover, an existing creep analytical solution [19], [20] for the circular well closure also provides a good prediction at lower computational cost. This solution has been applied to shales using parameters calibrated by the authors for numerical simulations. A comparison between numerical and analytical solutions for compatible models is shown in Figure 4, based on [21].

Final remarks

This work presented highlights of the project SABAR, which is dedicated to applying the state-of-the-art knowledge on ductile "creeping" shales to well P&A. Notably, such shales are ideal formations for many strategic engineering projects. The formation of barriers around uncemented casing intervals (Figure 1) during the well lifespan represents a promising alternative to simplify permanent well P&A or, at least, to act as an informal and additional barrier. If the barrier proves to be effective, a geoengineering and environmentally ideal solution is reached.

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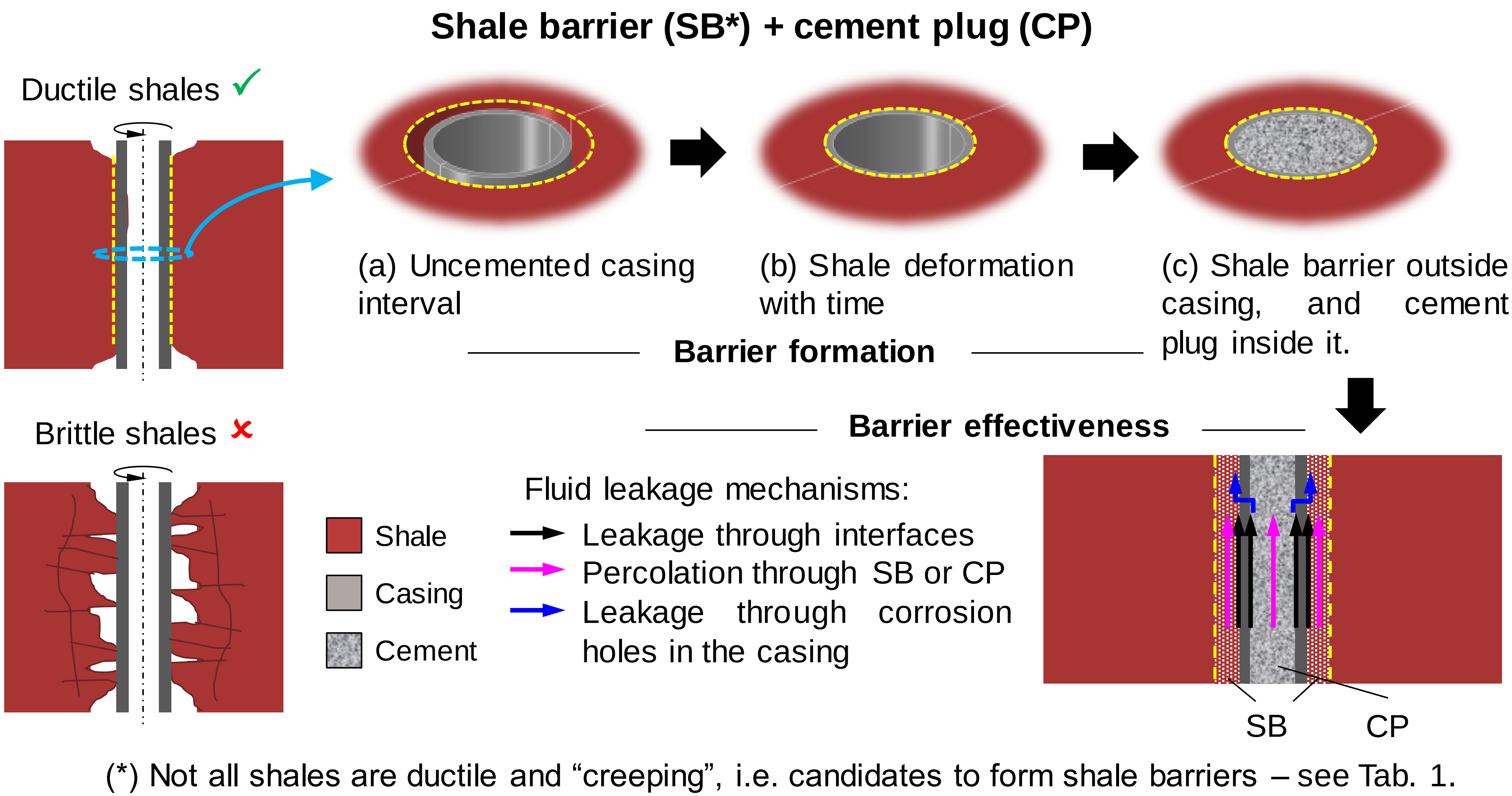

Figure 1. Big picture of the formation of shale barriers for well P&A.

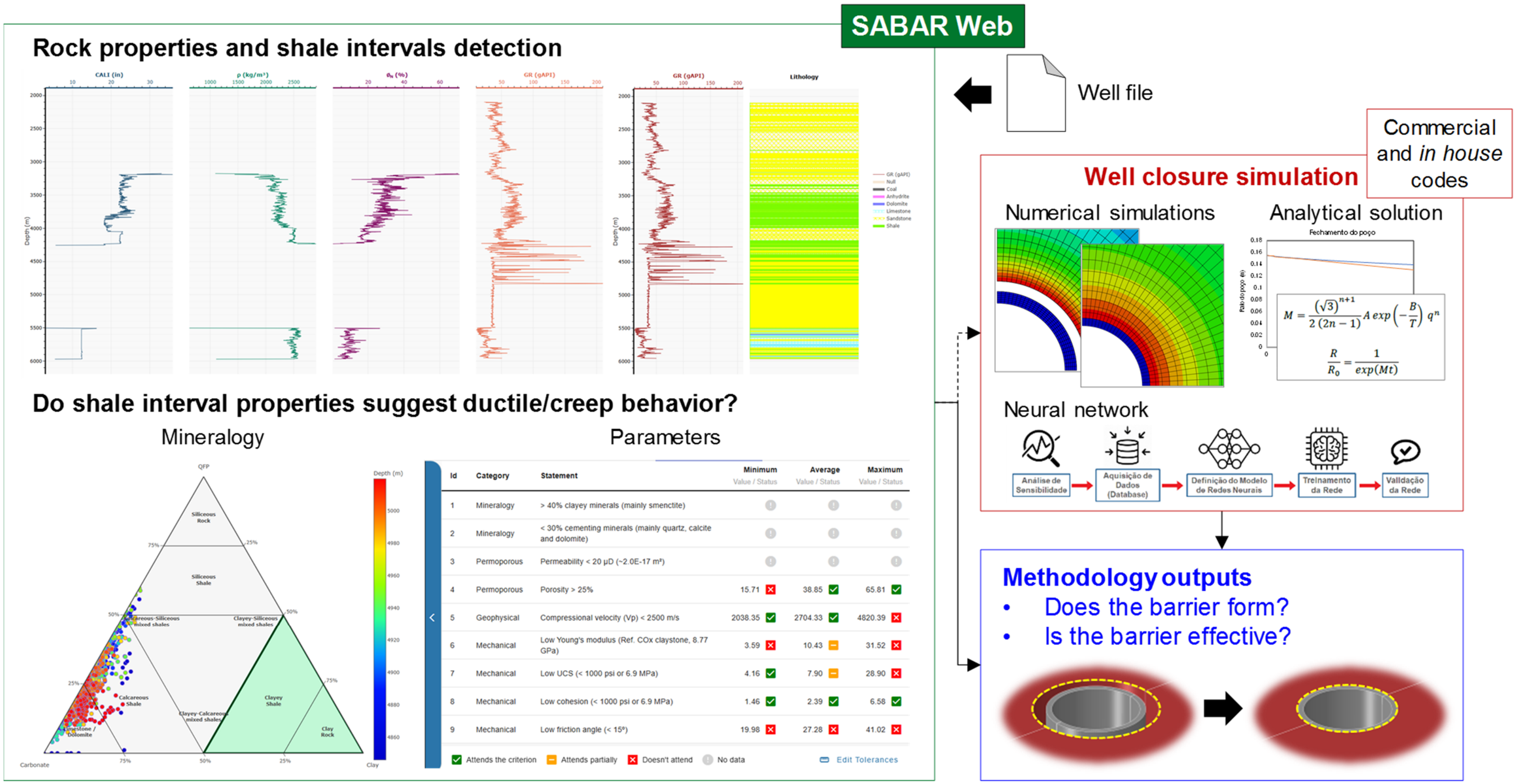

Figure 2. Graphical abstract of the project and big picture of SABAR Web application.

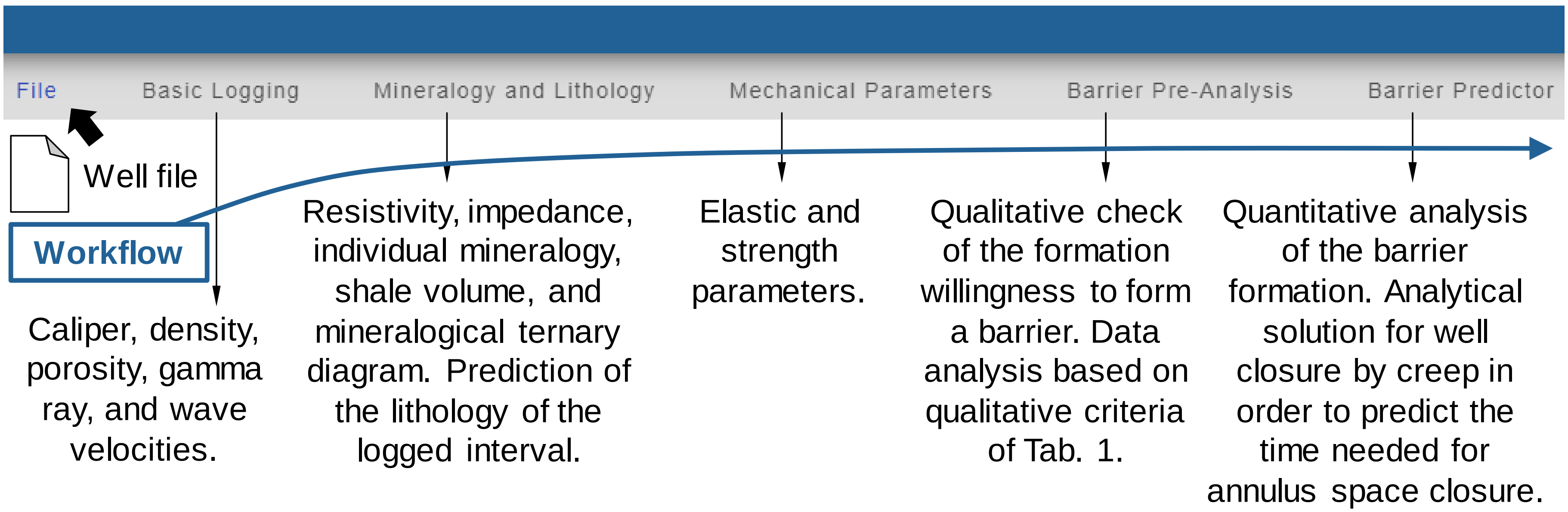

Figure 3. SABAR Web analysis workflow.

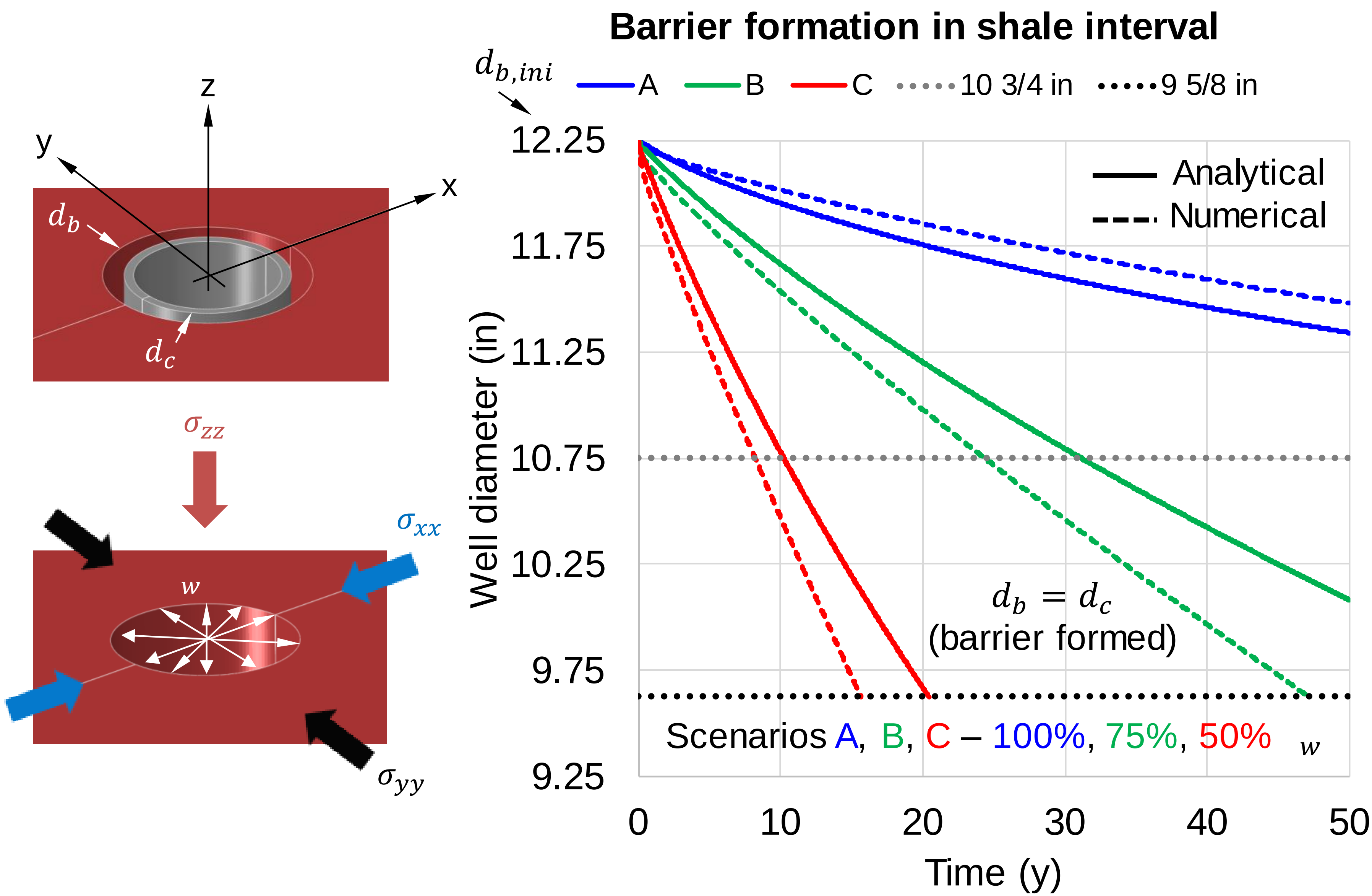

Figure 4. Well mathematical simulation.

Category		Statement
1	Mineralogy	> 40% clayey minerals (mainly Smectite)
2	Mineralogy	< 30% cementing minerals (mainly Quartz, Calcite, and Dolomite)
3	Permoporous	Permeability < 20 µD (~2.0E-17 m^2)
4	Permoporous	Porosity > 25%
5	Geophysical	Compressional wave velocity < 2500 m/s
6	Mechanical	Low Young's modulus
7	Mechanical	Low Unconfined Compressive Strength (UCS < 1000 psi or 6.9 MPa)
8	Mechanical	Low cohesion (< 1000 psi or 6.9 MPa)
9	Mechanical	Low friction angle (< 15°)
10	Chemical	Cation Exchange Capacity (CEC) > 50 meq/100g

Table 1. Qualitative criteria for shale barrier candidates [13], [15].