

Impact of uncertainties in rock mechanical properties on subsidence evaluation

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ABSTRACT: A methodology based on embedded stochastic simulations is proposed to propagate the large uncertainties usually attached to the rock mechanical properties down to the evaluation of the subsidence risk. First, the uncertainties on the lithology are accounted for through sequential indicator simulations. Second, the rock mechanical properties are simulated conditionally to the previously generated lithologies, after careful calibration of rock mechanical property distributions from log and core data. Finally, the mechanical computation is performed for each stochastic realization: it is based on a simplified 1D poro-elastic model under oedometric conditions, since it provides conservative results. The methodology is demonstrated on a specific field for which it is shown that the subsidence evaluation is mainly impacted by the uncertainties on the lithology within the reservoir.

KEYWORDS: *subsidence evaluation, rock mechanical properties, uncertainties, stochastic simulations.*

1. Introduction

The prediction of possible subsidence effects due to reservoir production over time is an important concern for oil companies, particularly when the depletion is strong and/or the reservoir corresponds to poorly consolidated or soft rocks. Indeed, the vertical displacements possibly induced by the pore pressure changes during production increase the risks of casing collapse, shear zones formation and could even lead to vertical displacements of the ground surface. A precise evaluation of the subsidence risk implies a fully coupled reservoir / geomechanical modelling based on a model of the reservoir and its overburden as realistic as possible. However, for a first-order evaluation, a 1-D poro-elastic geomechanical modelling approach under oedometric conditions is sufficient, since it returns upper bounds on the expected vertical displacements and therefore can contribute to the decision of undertaking or not a full 3-D modelling.

This simplified 1D approach is applied to a real case study: it is demonstrated how the large uncertainties on the rock poro-elastic properties, usual in such subsurface mechanical studies, impact the subsidence evaluation. Moreover, a methodology for handling those uncertainties and propagating them in the final estimation of vertical displacements and effective stress variations is proposed. The reservoir under study, at an approximate vertical depth from 3200 to 3450 m below sea level, belongs to the Brent group in North Sea and corresponds to fluvio-deltaic deposits of various sands and shale. A strong depressurisation is observed after 15 years of oil production (over 10 MPa). The reservoir is mainly characterized by well data (logs and cores) providing a lithological and petrophysical description (the reference well for this study is displayed on Fig. 1); but no direct mechanical measurements are available.

2. Estimation of the rock mechanical properties and their uncertainties

2.1. Methodology for estimating the rock mechanical properties

In the frame of poro-elasticity and under the simplified assumption of homogeneous isotropic media, bulk modulus K_d , shear modulus G , Biot's coefficient b and Biot's modulus M are the four parameters required in the mechanical computation. With a simplified 1D modelling under oedometric conditions, these mechanical parameters need to be described only for the reservoir interval (no overburden effect). Moreover, Biot's modulus M is not required in the simplified computation (see § 3.1.).

Since no laboratory measurements are available on the field under study and because of the large variability of rock-types within the Brent, the log data in conjunction with the core description are the most appropriate information for assessing the mechanical parameters and their uncertainties. The estimation is based on the matrix mineralogical composition, the porosity and the fluid content. For the matrix mineralogical composition, three sources of data are used: the standard log interpretation, the thin section description (petrographic analysis) and the X-Ray analysis. In a first step, the homogenization scheme proposed by Berryman (Berryman, 1995) is applied to get lower and upper bounds on the values of the matrix bulk modulus (K_s) and of the shear modulus (G_s). Then, in a second step, the same homogenization scheme is applied to the matrix and the pores to estimate upper and lower bounds on the undrained moduli. Last, a drainage correction based on Gassmann equation is applied to derive the drained bulk moduli K_d from their undrained values. The corrections from dynamic to static moduli were neglected, since they appear small by comparison with the impact on the moduli of the rock matrix composition uncertainty.

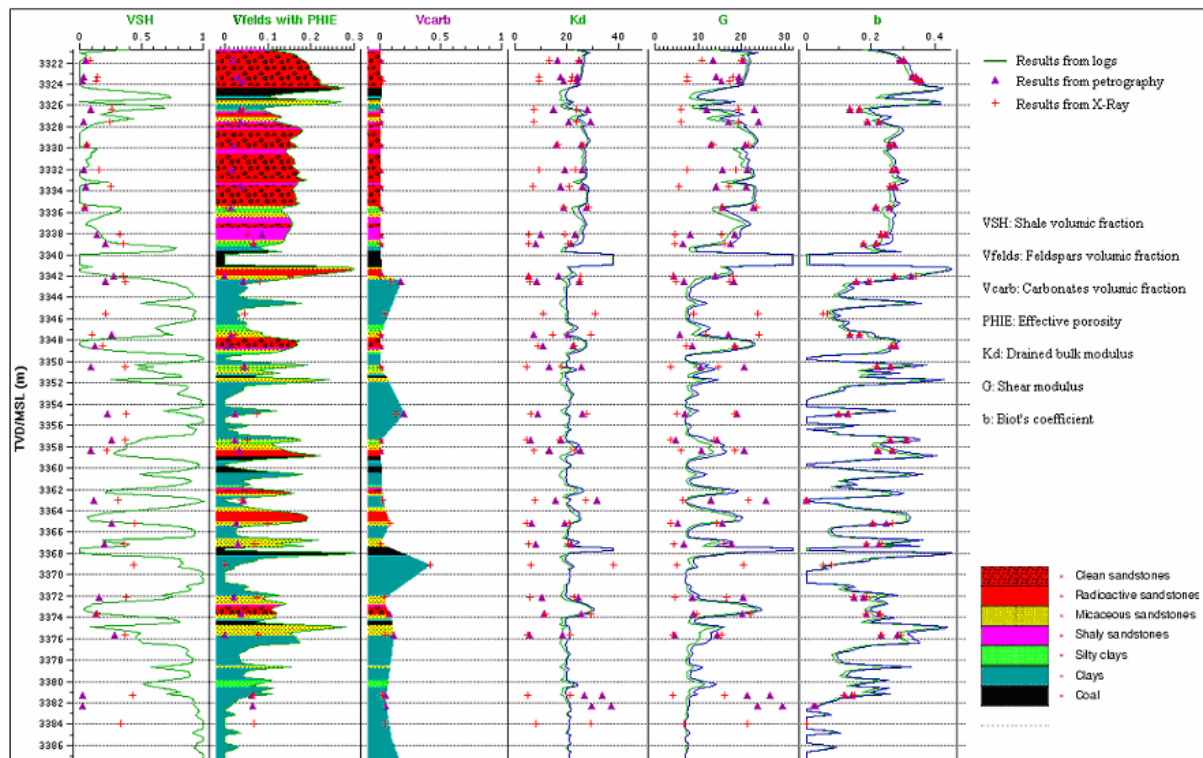


Fig. 1. A reservoir part with lithologies, petrophysical properties and estimated bounds on rock moduli

2.2. Analysis of results

The comparison of the bounds obtained for rock mechanical properties K_d , G and b (blue and green continuous curves for the log input data, triangles and diamonds respectively for the

petrography and X-Ray input data on Fig. 1) underlines the following points. First, the bounds deduced from the log interpretation are very narrow by comparison with those derived from petrography or X-Ray analysis: this is due to the fact that the log interpretation is based on a 2-phase system for the matrix (quartz and shale), and thus neglects secondary minerals like calcite and feldspars which have mechanical moduli with strong contrasts. Thus, these bounds are not realistic and are over-optimistic in terms of the uncertainties attached to the rock moduli. Second, the bounds deduced either from X-Ray analysis or petrography are very consistent. Last, the ranges of uncertainties attached to K_d and G are very similar whereas the range of uncertainties on Biot's coefficient is smaller. The silty clays and micaceous sandstones are the lithologies showing the larger uncertainties on the three parameters.

2.3. Representation of uncertainties attached to the rock mechanical properties

From the previous analyses, it has been decided to characterize each lithology by a specific uniform law with minimum and maximum values deduced from the minima and maxima observed on both petrographic and X-Ray analyses. Since a strong correlation (Fig. 2, correlation coefficient of 0.88) is observed between K_d and G given all lithologies, uniform laws are only modelled for K_d and the Biot's coefficient b (Tab. 1), these two parameters showing evidence of statistical independence (Fig. 2). Thus, the uncertainty on the rock properties will be accounted for by randomly sampling the uniform laws for K_d and b associated with the lithology at the considered depth, and deducing G from K_d with a linear regression model.

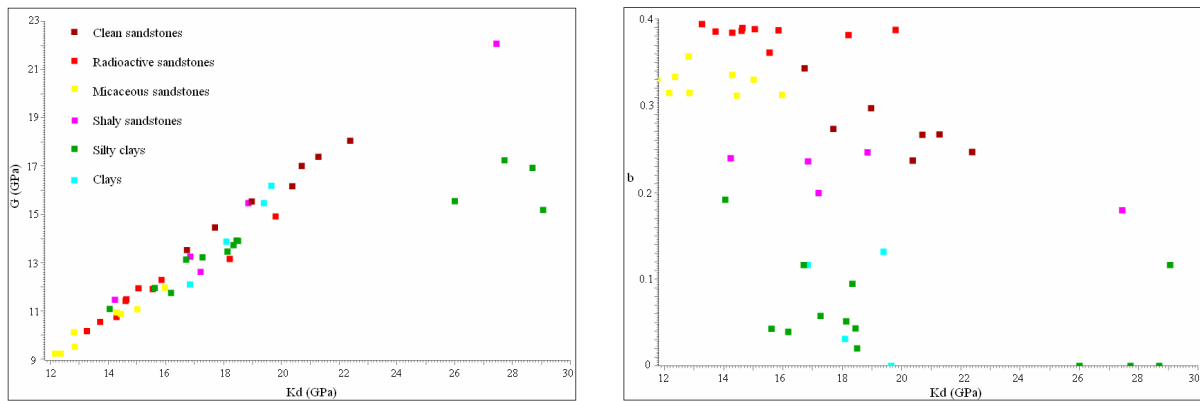


Fig. 2. Cross-plots G vs. K_d and b vs. K_d color-coded with lithologies

Lithology	K_d (GPa) : minimum and maximum values	b : minimum and maximum values
<i>Clean sandstones</i>	8.3 – 28.7	0.23 – 0.35
<i>Radioactive sandstones</i>	5.6 – 26.4	0.35 – 0.41
<i>Micaceous sandstones</i>	3.7 – 24.9	0.28 – 0.37
<i>Shaly sandstones</i>	3.8 – 31.8	0.16 – 0.26
<i>Silty clays</i>	3.7 – 52.2	0.00 – 0.21
<i>Clays</i>	4.9 – 33.8	0.00 – 0.15
<i>Coals</i>	4.9 – 33.8	0.00 – 0.15

Tab. 1. Parameters of the uniform laws for K_d and b per lithology

3. Mechanical modelling

3.1. Principles

For a 1D poro-elastic mechanical model under oedometric conditions, the variations of effective stresses $\Delta\sigma'_v$ and $\Delta\sigma'_H$ respectively along the vertical direction and in the horizontal plane, the associated vertical strains $\Delta\varepsilon_v$ and total vertical displacement S due to the pore pressure drawdown Δp within the reservoir are simply computed with the following equations, in which the sign convention of geomechanics is used (the compressions are considered positive):

$$\Delta\sigma'_v = b\Delta p \quad (1)$$

$$\Delta\sigma'_H = \left(K_d - \frac{2G}{3} \right) \frac{b\Delta p}{K_d + 4G/3} \quad (2)$$

$$\Delta\varepsilon_v = \frac{b\Delta p}{K_d + 4G/3} \quad (3)$$

$$S = \int_{u_{\min}}^{u_{\max}} \Delta\varepsilon_v du \quad (4)$$

The reference computation for subsidence evaluation is taken at the reservoir top for a pressure drawdown of 10 MPa and is evaluated on the lithological column of the reference well, with rock mechanical property values taken as the means of modelled K_d , G and b per lithology. This reference computation leads to $S = 0.019$ m, $\Delta\sigma'_v = 3.8$ MPa and $\Delta\sigma'_H = 0.9$ MPa.

3.2. Impact of the uncertainties on the mechanical properties

This impact is studied by carrying out 100 1D random simulations of the set of mechanical parameters, the lithological column being kept constant (lithologies of the reference well). The variations of the effective stress and strain profiles along the well are computed as well as the subsidence S for each random simulation. The histograms of the subsidence at the top reservoir and associated variations of vertical and horizontal effective stresses (Fig. 3) pinpoint the small impact of the uncertainties on the subsidence S (variation coefficient close to 2%) and on the vertical stress variations (variation coefficient close to 5%) but a larger effect on the horizontal stress variations (variation coefficient close to 24%).

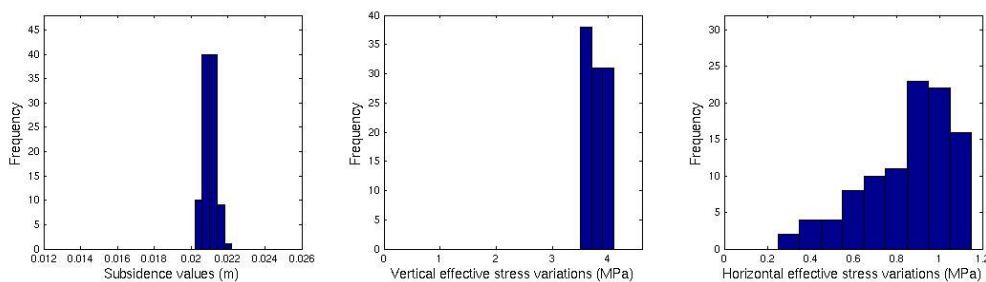


Fig. 3. Histograms of subsidence and variations of effective stresses with uncertain mechanical properties but fixed lithologies

3.3. Impact of uncertainties on the reservoir lithology

Far from wells, another source of uncertainty is the lithology, which is usually poorly controlled particularly in such fluvio-deltaic environment. This impact is analysed by carrying out stochastic simulations of lithology (conditional sequential indicator simulations, Deutsch and Journel, 1992) preliminary to the random simulation of rock mechanical properties. Thus, the mechanical computation leads to subsidence and stress variations accounting for both uncertainties on lithology and rock parameters. The results (Fig. 4) now show a larger impact on both subsidence and stresses, with coefficients of variation of 13% for the subsidence and respectively 52% and 55% for the vertical and horizontal stress variations.

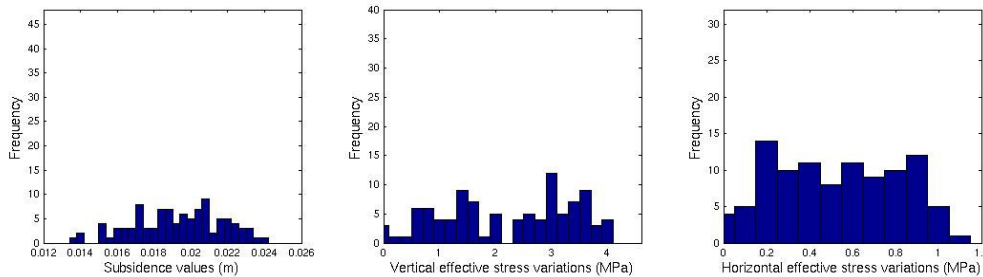


Fig. 4. Histograms of subsidence and variations of effective stresses with uncertain mechanical properties and lithologies

4. Conclusion

Simple 1D oedometric mechanical modelling is very important as a first order risk assessment since it provides conservative values for the estimation of possible subsidence and stress variations induced by the pore pressure decrease during production. Based on this fast computation, it could be decided or not to undertake a detailed coupled 3D hydro-mechanical model. It is also well established that in any mechanical model, there are large uncertainties on the rock properties filling the model, due to the presence of heterogeneities within the reservoir and its overburden, in conjunction with limited well control and few laboratory rock property measurements. A methodology based on embedded stochastic simulations of lithology and associated mechanical properties is demonstrated. It allows to efficiently propagate the uncertainties on the input data down to the final mechanical quantities which are critical for the subsidence risk evaluation. This approach is currently being extended to 3D hydro-mechanical modelling of heterogeneous reservoirs and their surrounding formations when there are significant uncertainties on the heterogeneity spatial distributions. Another extension could be, based on the computed effective stress variations, to find the reservoir points which could encounter the failure criterion.

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