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Stochastic computational modelling of highly heterogeneous poroelastic media with long-range correlations

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SUMMARY

The compaction of highly heterogeneous poroelastic reservoirs with the geology characterized by long-range correlations displaying fractal character is investigated within the framework of the stochastic computational modelling. The influence of reservoir heterogeneity upon the magnitude of the stresses induced in the porous matrix during fluid withdrawal and rock consolidation is analysed by performing ensemble averages over realizations of a log-normally distributed stationary random hydraulic conductivity field. Considering the statistical distribution of this parameter characterized by a coefficient of variation governing the magnitude of heterogeneity and a correlation function which decays with a power-law scaling behaviour we show that the combination of these two effects result in an increase in the magnitude of effective stresses of the rock during reservoir depletion. Further, within the framework of a perturbation analysis we show that the randomness in the hydraulic conductivity gives rise to non-linear corrections in the upscaled poroelastic equations. These corrections are illustrated by a self-consistent recursive hierarchy of solutions of the stochastic poroelastic equations parametrized by a scale parameter representing the fluctuating log-conductivity standard deviation. A classical example of land subsidence caused by fluid extraction of a weak reservoir is numerically simulated by performing Monte Carlo simulations in conjunction with finite elements discretizations of the poroelastic equations associated with an ensemble of geologies. Numerical results illustrate the effects of the spatial variability and fractal character of the permeability distribution upon the evolution of the Mohr–Coulomb function of the rock.
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KEY WORDS: reservoir compaction; poroelasticity; finite elements; heterogeneity; stochastic modelling; random permeability; Monte Carlo simulations; long-correlations; fractals; Hurst exponent; multiscale systems; perturbation

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