Computational Geosciences
https://doi.org/10.1007/s10596-019-09894-9

ORIGINAL PAPER

A new computational model for flow in karst-carbonates containing solution-collapse breccias

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Received: 30 October 2018 / Accepted: 30 August 2019

Abstract

We develop a new three-scale (micro/meso/macro) computational model based on a reiterated homogenization procedure to describe flow in carbonate rocks containing complex geological structures, such as fractures and solution-collapse breccias in the sense of Loucks (AAPG Bull. **83**(11), 1795–1834, 1999). In this setting, we construct a hierarchical karst-fracture model wherein the larger geological objects are incorporated explicitly whereas the higher density microscopic structures are homogenized and replaced by equivalent continua with properties computed from self-consistent homogenization schemes. In the upscaling method, we subdivide the different clastic arrangements in the breccia into crackle, mosaic, and chaotic substructures where equivalent permeability and elastic constants are assigned to each layer within the breccia. After reconstructing the mesoscopic coefficients, we adopt a flow-based upscaling to the macroscale, where the characteristic length is associated with a typical coarse grid cell of a reservoir simulator. The mesoscopic flow equations are constructed based on the discrete fracture model (DFM) and discretized by a robust computationally scheme with the ability to handle strong heterogeneity induced by the collapse breccia and pressure jumps across flow barriers. In addition to the scenario wherein the collapse breccia network is composed of disconnected objects (isolated chambers), we also develop a reduced model for the case of connected karst facies playing the role of a network of enlarged fractures. Numerical results, with input data extracted from outcrops drone images, are presented illustrating the influence of different settings on flow patterns and their effect upon the magnitude of macroscopic properties.

Keywords Carbonate reservoir · Collapsed paleocaves · Damage zone · Discrete fracture model · Self-consistent homogenization · Finite element · Outcrop images · Flow-based upscaling

1 Introduction

The computational modeling of karst carbonates is of utmost importance for hydrocarbon production and water resources (see, e.g., [1, 37] for an extensive review). In addition to the network of fractures, several karst facies commonly appear where we may highlight collapse sinkholes, pipe breccias, super-K, network of enlarged fractures, and conduits [26, 30]. Consequently, it becomes essential to capture the features of these complex structures incorporating them in an accurate manner in computational models at different scales.

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The morphology of karstic systems, including geometry and texture of the cave network and the surrounding damage zone [37], consists of essential information which dictates the behavior of the local hydromechanical coupling. In such a context, a distinction between epigenic and hypogenic caves needs to be addressed. The former structure results from the dissolution induced by the percolation of meteoric or surface waters, whereas the latter is formed from ascending hydrothermal fluids such as CO_2 and H_2S with movement ruled by buoyancy forces [19, 35]. The cave network can be totally open or filled with collapse breccias composed of carbonate fragments (clasts) and sediments, such as sand, clay particles, or even cement detached from the limestone due to the cave ceiling collapse. Such geological structures may appear as isolated chambers or highly connected enlarged fractures [26, 30]. The karst network is manifested at the surface through the appearance of collapse sinkholes (dolines) and gives rise to a system

Published online: 19 November 2019