Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

journal homepage: www.elsevier.com/locate/petrol

Upscaling digital outcrop models to infer well connectivity in carbonates with karstic features

Iury Coimbra [a], Yoe A.R. Perez [b], Marcio A. Murad [a,*], Fabio L. Custodio [a], Caroline L. Cazarin [c], Patricia A. Pereira [a], Tuane V. Lopes [a], Josue dos S. Barroso [a], Francisco P. Lima-Filho [b]

[a] Laboratório Nacional de Computação Científica (LNCC-MCT), Brazil
[b] Universidade Federal do Rio Grande do Norte (UFRN), Brazil
[c] Petrobras' Research and Development Center (CENPES-PETROBRAS), Brazil

ARTICLE INFO

Keywords:
Karstified carbonates
Caves
Super-K
Multi-well productivity index
GPR
Digital outcrop models
Style transfer metamodels
Hydrodynamics

ABSTRACT

We construct an innovative static–dynamic integrated workflow capable of bridging the gap between input geological data, inherent to a lacustrine carbonate outcrop containing karst geobodies, and the description of the flow patterns and quantification of the multi-well productivity index (MWPI) for a particular well configuration in the outcrop. The workflow incorporates additional features stemming from the use of Machine Learning-based methods to mitigate lack of data in the locations away from the sections of input signals, along with the construction of new upscaling methods to assess the MWPI matrix. The ML-enhanced geostatic model hinges upon shallow surface geophysical data collected using Ground-Penetrating Radar (GPR) techniques. Furthermore, by discretizing the flow equations and adopting a flow-based upscaling method, we construct correlations between well flow rates and pressure drawdown in a typical five-spot well configuration. In this setting, we analyze the sensitivity of each well productivity with respect to heterogeneity distribution and correlations in the karst system within the outcrop. Computational simulations illustrate the ability of the integrated workflow proposed herein to improve prediction of hydraulic-connectivity between well pairs, which appear manifested in the entries of the MWPI matrix, whose magnitude aims at quantifying the effects of the karst geobodies upon geofluid production.

1. Introduction

Carbonate reservoirs exhibit particular challenging and complex issues which stem from the high degree of depositional geological and petrophysical heterogeneity (Lucia et al., 2003). Such formations commonly exhibit pore spaces with different sizes and geometries of high complexity to characterize and predict in the subsurface. Recently, improved methodologies have emerged showing additional capabilities to characterize and predict flow patterns in kastified carbonate reservoirs (see e.g. Lopes et al., 2020; Ferraz et al., 2021; Murad et al., 2020; Fischer et al., 2018). Unlike siliciclastic, the reliability of static and dynamic models for characterizing and performing flow simulations strongly depends on additional information, particularly at the missing scales between well logs and seismic (Stright and Caers, 2005). In this setting, analog data play a key role in improving knowledge of the underlying geological processes in order to attain a 3D description of depositional heterogeneities along with their geometry, dimensions and spatial distribution (Howell et al., 2014; Bisdom et al., 2017b; Marques et al., 2020).

Within the above-mentioned uncertain and highly challenging scenario, in the current work, we are particularly interested in exploring a wide diversity of methodologies to improve our knowledge on the description of Lower Cretaceous Pre-Salt lacustrine carbonates in South Atlantic rift basins (Borghi and Corbett, 2013; Boyd et al., 2015; Muniz and Bosence, 2015) and analyze their impact on flow, streamline patterns and correlated geofluid production in the scenario of multiple wells producing within a sealed rectangular reservoir. The underlying geological setting displays a signature dominated by the presence of highly irregular dissolution structures, commonly referred to as karst systems (Annable, 2003; Goldscheider and Drew, 2014; Klimchouk et al., 2016). Karstification occurs during infiltration of aggressive fluids that dissolve the host rock along pre-existing fractures

* Corresponding author.
E-mail addresses: coimbra@lncc.br (I. Coimbra), yoe.perez@carmoenergy.com (Y.A.R. Perez), murad@lncc.br (M.A. Murad), flc@lncc.br (F.L. Custodio), cazarin@petrobras.com.br (C.L. Cazarin), patricia@lncc.br (P.A. Pereira), tuane@lncc.br (T.V. Lopes), jsantos@lncc.br (J.d.S. Barroso), pinheiro.lima@ufrn.br (F.P. Lima-Filho).

https://doi.org/10.1016/j.petrol.2022.110606
Received 3 March 2022; Received in revised form 26 April 2022; Accepted 3 May 2022