

From outcrop analogue to flow simulation: Understanding the impact of geologic heterogeneity on hydrocarbon production*

Matthew D. Jackson¹

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¹ (m.d.jackson@imperial.ac.uk)

Hydrocarbon reservoirs are geologically heterogeneous over a wide range of lengthscales. This heterogeneity is a key control on fluid flow during hydrocarbon production, because geological (sedimentary, structural and diagenetic) processes dictate the spatial distribution of petrophysical properties such as porosity, permeability, relative permeability and capillary pressure. These properties control the flow of oil, water and gas. Consequently, to understand, model and predict fluid flow, it is essential to understand and model geological heterogeneity. This is challenging for two reasons. The first is that geological heterogeneity is complex, ranging from the scale of individual pores (c. microns in length) to the scale of the entire reservoir (c. kilometres). The second is that subsurface data is limited. Well data has high spatial resolution but is sparsely distributed; seismic data is extensive but has low spatial resolution. Poor understanding of geological heterogeneity leads to increased uncertainty in predictions of hydrocarbon recovery, and increases the risk associated with hydrocarbon extraction.

Recognizing that a reservoir model cannot represent explicitly every type and scale of heterogeneity raises a number of persistent questions. What are the key types and scales of heterogeneity that models should capture? Are these key heterogeneities the same for all reservoir and hydrocarbon types, and all recovery processes? What is the minimum level of model resolution/complexity required to make recovery predictions that are ‘good enough’? How should models best capture these key heterogeneities? To answer these questions requires the development of models based on rich datasets which capture heterogeneity at a high level of detail. Such models can be constructed using analogue outcrops. This presentation describes ongoing research to develop and apply outcrop analogue models, emphasizing the use of novel surface-based modelling techniques in conjunction with adaptive gridding/meshing for flow simulation, and the insight gained into the impact of geologic heterogeneity on flow.

The approach is illustrated using examples of shallow-marine sandstone reservoir analogues from three contrasting depositional environments across a hierarchy of lengthscales. The environments represented by the analogues comprise (1) a single, wave-dominated shoreface-shelf parasequence, (2) two stacked, fluvial-dominated deltaic parasequence sets and (3) multiple stacked, tide-dominated channel belts and tidal heteroliths. The datasets were obtained from well-exposed outcrops in Utah, USA, the Western Desert, Egypt and the Isle of Wight, UK; they describe reservoir architecture in generic analogues for many shallow-marine

reservoirs. The model results demonstrate that subtle aspects of reservoir architecture, which are typically neglected in subsurface models, can have a significant impact on flow and hydrocarbon recovery. Conversely, features which are routinely included because they are easy to model may be unimportant to flow. New reservoir modelling methods are required to capture subtle, yet important, geological heterogeneities. The methods developed here to handle outcrop datasets are equally applicable to subsurface reservoirs. They rely less on grid- or pixel-based methods, and integrate better with a new generation of reservoir simulators.