The Effect of Fracture-Controlled Cementation on Fluid Flow in Carbonate Reservoirs*

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Abstract

Characterization of fluid flow in fractured carbonate reservoirs is generally idealized using the traditional “floating sugar cube” concept of Warren and Root (1963). Carbonate rocks are in general very reactive, however, and diagenetic processes, where the reactive fluids are controlled by fractures¸ can greatly alter static and dynamic properties of both fractures and matrix. Reservoir properties can be enhanced by leaching or destroyed by cementation. Furthermore, field and core observations suggest that the fracture-controlled diagenesis increases the heterogeneity of carbonate reservoirs. This heterogeneity occurs at a wide range of scales, from large (e.g. fault-related dolomitization) to small (e.g. dissolution/cementation along micro-fractures).

Introduction

Fracture-controlled cementation can affect fracture properties, matrix properties and the exchange of fluid between fracture and matrix. The former has received relatively large attention in the last decades, whereas the two latter, which are the focus of this study, have not been widely examined. Petrographic and porosity analyses have been performed on selected samples using standard transmitted optical microscopy, scanning electron microscope (SEM) in backscatter electron mode (BSE) and micro-CT scan. BSE image analysis captures micro and macro porosity at a resolution of 0.7µm. SEE images on fresh sample surfaces were used to analyze cement distribution and pore connectivity at different distances from the fracture wall. Porosity profiles were generated from the BSE images using an in-house developed MatLab code.

Discussion

An example of porosity distribution close to a fracture is shown in Figure 1. This example is from outcrop of the Shuaiba Formation (Aptian) from Jebel Madar in the Adam Foothills, Oman. A significant drop in matrix porosity is observed from the intact matrix body towards the cemented matrix at the fracture wall. The porosity of the background matrix away from the fracture is 12%, and decreases to a minimum of 0.5% at fracture wall over a distance of 20 mm. Porosity calculated from BSE images of thin sections parallel to the fracture is shown as green circles and match very well with the porosity profile obtained by the two fracture perpendicular thin sections shown in the Figure 1.

Cementation along the fracture reduces hydraulic fracture aperture and fracture porosity, and result in channelized/tortuous rather than parallel plate type of flow (e.g. Chaudhuri et al. 2008). Several efforts have been made in the last decades to understand and simulate the effects of fracture cementation on residual fracture porosity and fluid flow along the irregular and channelized fracture system (e.g. Berkowitz 2002, Gale et al. 2010, Laubach et al. 2010, Ishibashi et al. 2009). However, not much has yet been published on effects of fracture cementation on matrix to fracture fluid exchange and cement distribution on the fracture surface.

Generic single porosity matrix-fracture models, where fractures are explicitly represented, are used in dynamic analyses. Simulations are run for different flow mechanisms: viscous, capillary and gravity driven flow. Two dynamic studies have been performed. Firstly, the effect of cementation on matrix-fracture fluid exchange has been analyzed, where cement is only distributed at the interface between matrix and fracture, with no alteration in matrix or fracture properties. In this case, both microscopic and macroscopic patchy cement distributions have been tested. Secondly, the effect of cemented matrix on fluid dynamics has been analyzed, where cement is only inserted into the matrix pore volume, subsequently affecting matrix porosity and permeability. Preliminary simulation results suggest that the effect of cementation on fluid dynamics depends on the dominating forces in the model and the cement distribution. This effect is, however, difficult to predict and to capture in the model prior to simulation.

Conclusion

Nevertheless, one should be aware of the presence of cement at the interface between matrix and fracture for history matching and up-scaling purposes. Our results suggest that the effects of fracture diagenesis on fluid dynamics can be of great importance in carbonate reservoirs and requires further investigation.

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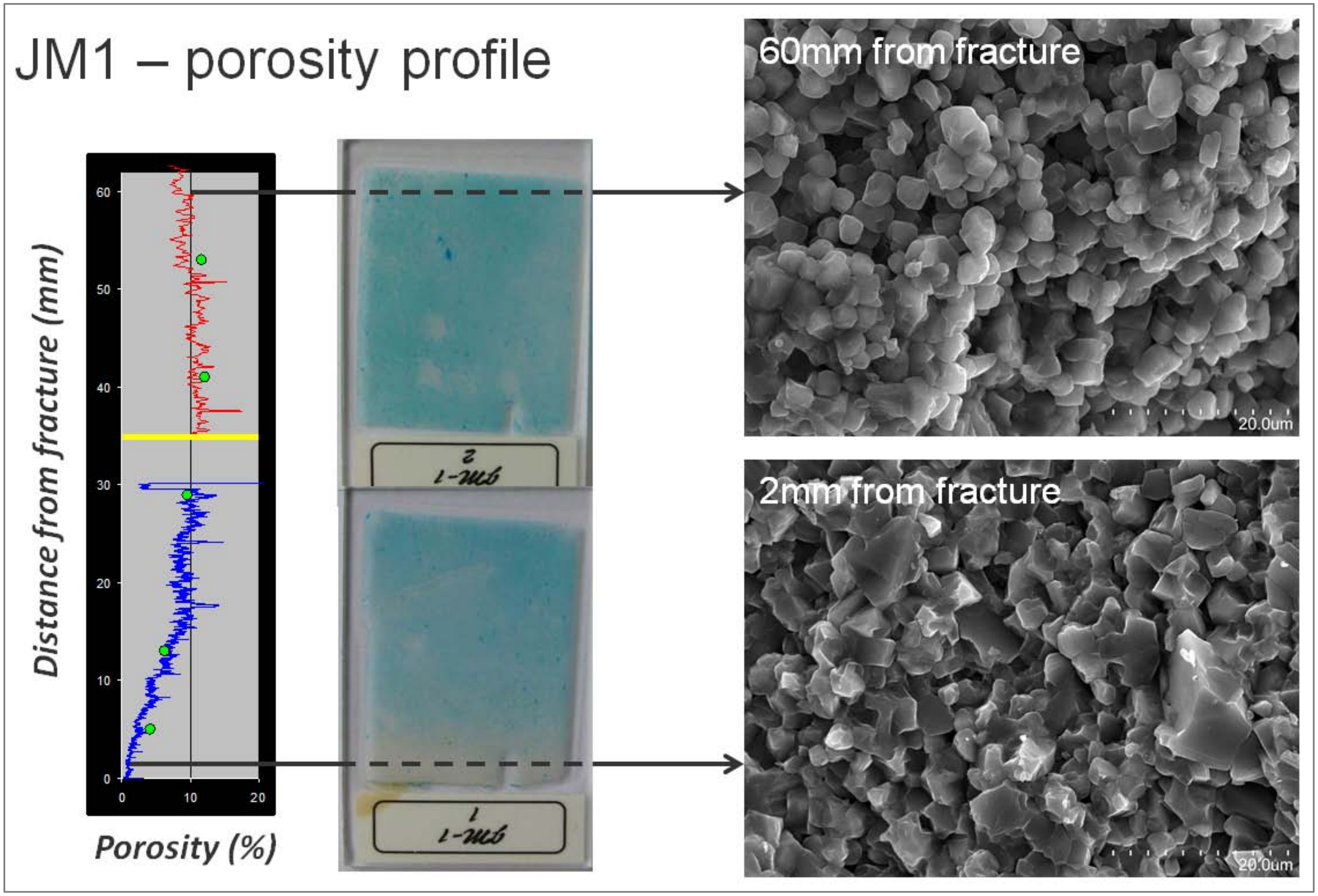

Figure 1. Porosity profile from fracture surface to matrix. The green circles represent porosity from fracture parallel thin sections, blue and red curves represent the two fracture perpendicular thin sections showed next to the profile. See images of two sample chips at 2 and 60 mm from the fracture wall.