Permeability and Tortuosity Variations in Naturally Fractured Carbonate Reservoir*

Adenike Tokan-Lawal[1], Maša Prodanović[2], and Peter Eichhubl[1]

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[1]Bureau of Economic Geology, The University of Texas at Austin, TX (adenike.tokanlawal@gmail.com)
[2]Petroleum and Geosystems Engineering, The University of Texas at Austin, TX

Abstract

Natural fractures provide preferential pathways for fluids in otherwise low porosity hydrocarbon reservoirs. These fractures are usually lined or filled with mineral cements formed from the crystallization of minerals in the fracture pores. The presence of mineral cements adversely affects the quality of the reservoir. Cementation along the fracture reduces hydraulic fracture aperture and fracture porosity and results in more tortuous flow paths. The presence of cements in the fracture pores causes a decrease in the absolute permeability of the fluids; however, the influence of cements on the relative permeability of fluids is not explicit.

In order to accurately predict fluid transport in carbonate reservoirs, we study the influence of diagenesis, partial cementation and resulting roughness on flow in the naturally fractured Niobrara and Monterey formations. We compare the variation of permeability and relative permeability in a Niobrara outcrop to that of a core sample. We also compare permeability and tortuosity variation in the Niobrara and Monterey formations. In addition, we study the influence of numerical cementation on the Niobrara outcrop sample. Fracture geometries were acquired from x-ray microtomography (μCT) scans. The permeability and tortuosity of the fracture (pore) space were determined from simulations of fluid flow through these geometries with impermeable fracture walls.

A combination of the Level-set-method-based-progressive-quasistatic algorithm (LSMPQS software) and Lattice Boltzmann simulation were used to characterize the capillary dominated properties and the relative permeability of the naturally cemented fractures from the studied formations. Finally, we numerically investigate the effect of uniform cementation on the fracture permeability as well as the tortuosity of the pore space and the capillary pressure-water saturation (P_c-S_w) relationship in the Niobrara.

The tortuosity and capillary pressure (Figure 1) of the pore space both increase while aperture (Figure 2) decreases with increasing cement thickness. Although this behavior is qualitatively similar to the effect of pore cementation on fluid flow through the matrix of sandstones, we see a more abrupt behavior in the studied carbonate formations. Relative permeability (Figure 3) of flow within the fracture is not only a function of water saturation but of the cement mineral composition, degree of cementation, fracture roughness, and depth, and is thus reservoir specific.

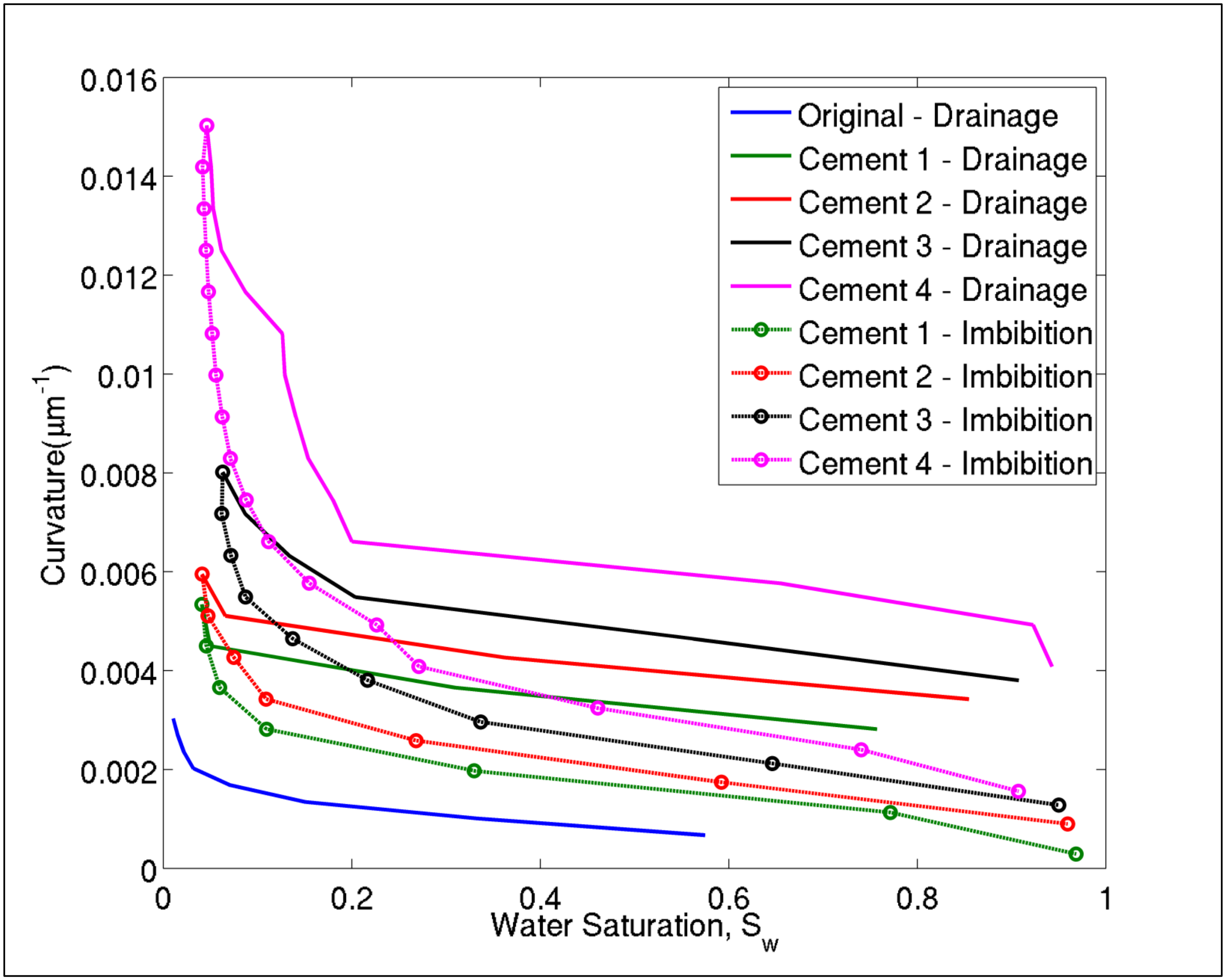


Figure 1. Influence of cementation on the Niobrara outcrop fractures. As the amount of numerical cement increases, the fracture pore space reduces causing a higher interfacial tension between the wetting and non-wetting fluids. Thus, as cement increases a higher capillary pressure will be required for the fluid to move through the fractured pore spaces. Cement 1, Cement 2, Cement 3 and Cement 4 represent steps with numerically added cement of thicknesses: 0.3 mm, 0.5 mm, 0.7 mm and 0.9 mm respectively. Original is the imaged Niobrara outcrop.

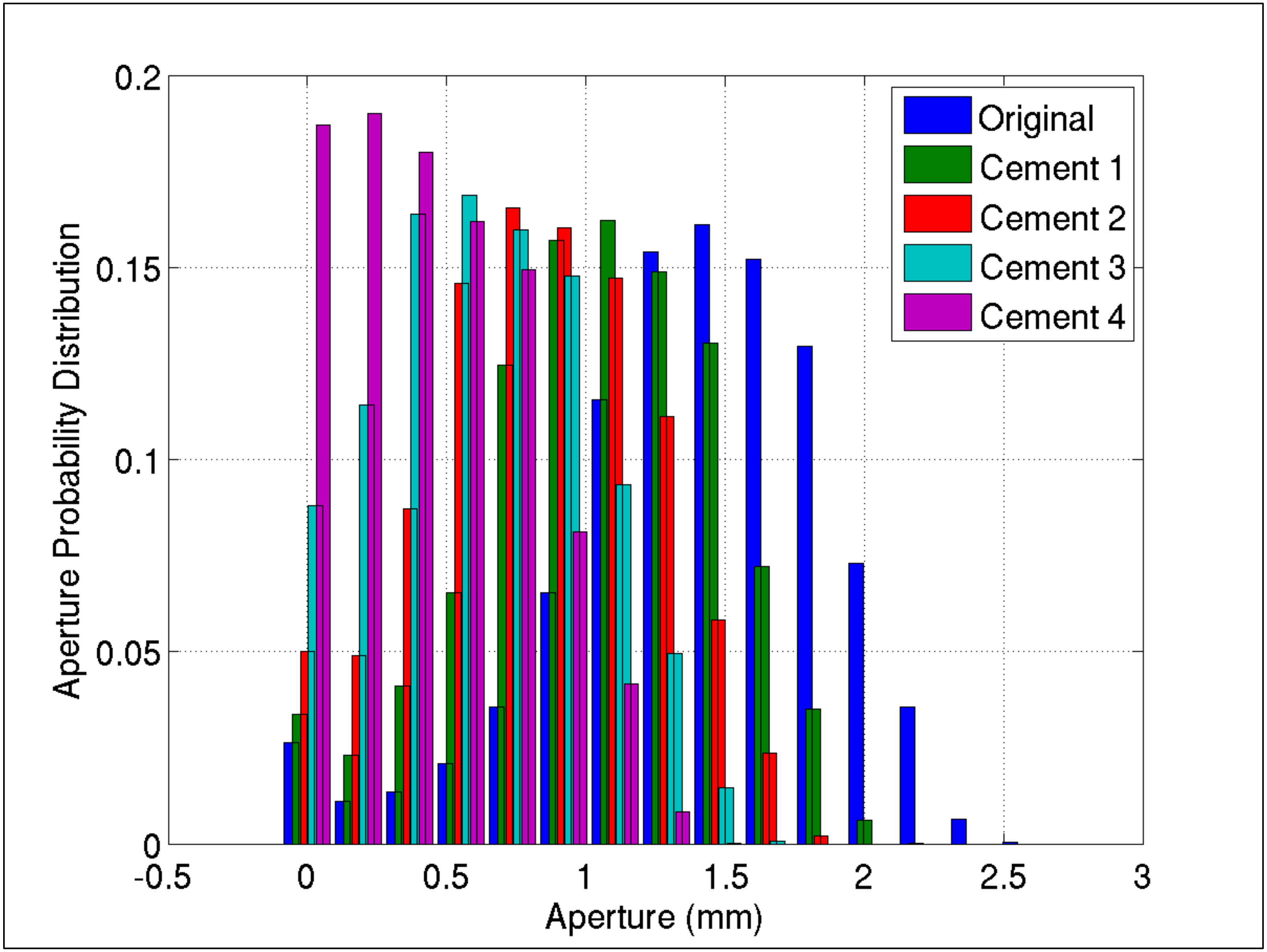


Figure 2. Probability Density Function (PDF) of z-direction aperture for the original and cemented samples. PDF shows that the aperture distribution in the Niobrara shifts to the left after cementation. Cement 1, Cement 2, Cement 3 and Cement 4 represent steps with numerically added cement of thicknesses: 0.3 mm, 0.5 mm, 0.7 mm and 0.9 mm respectively. Original is the imaged Niobrara outcrop.

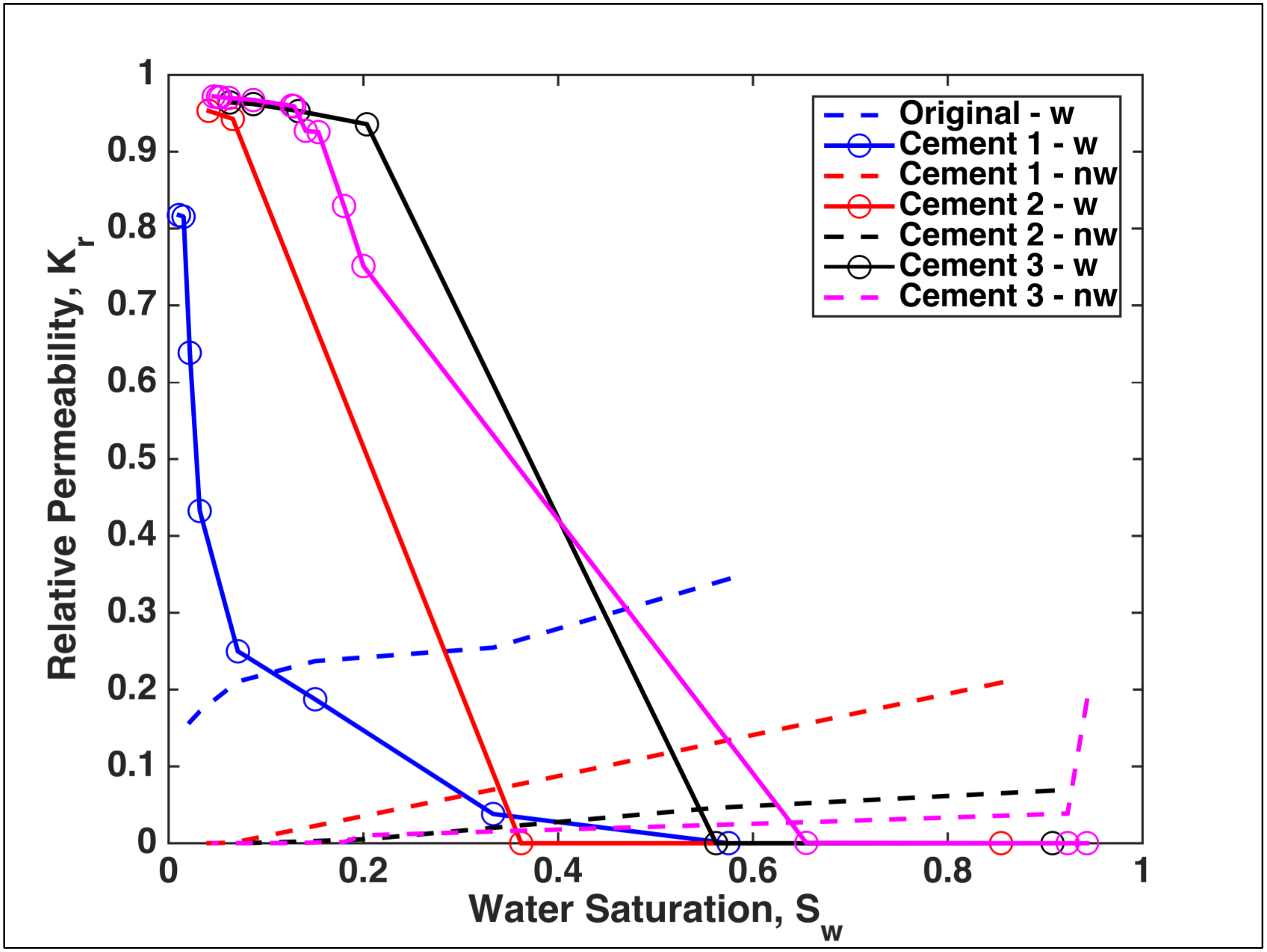
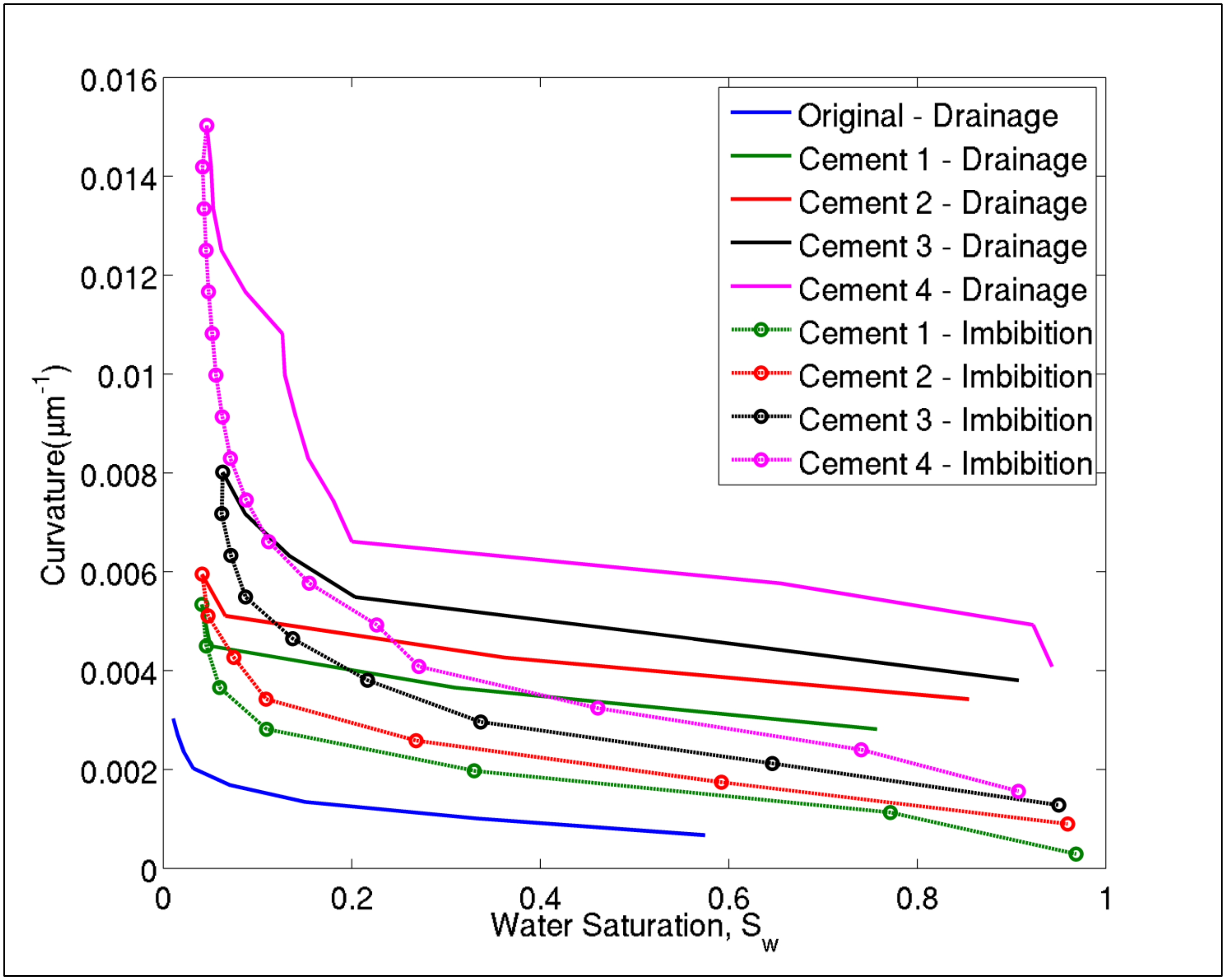


Figure 3. Relative permeability drainage plots for the original and cemented fractures. The non-wetting fluid has overall higher relative permeability than the cemented sample for the same saturation. Relative permeabilities are not only a function of wetting (water) phase saturation but of the degree of mineralization and fracture roughness. Cement 1, Cement 2, Cement 3 and Cement 4 represent steps with numerically added cement of thicknesses: 0.3 mm, 0.5 mm, 0.7 mm and 0.9 mm respectively. Original is the imaged Niobrara outcrop. w and nw represent wetting and non-wetting phase respectively.



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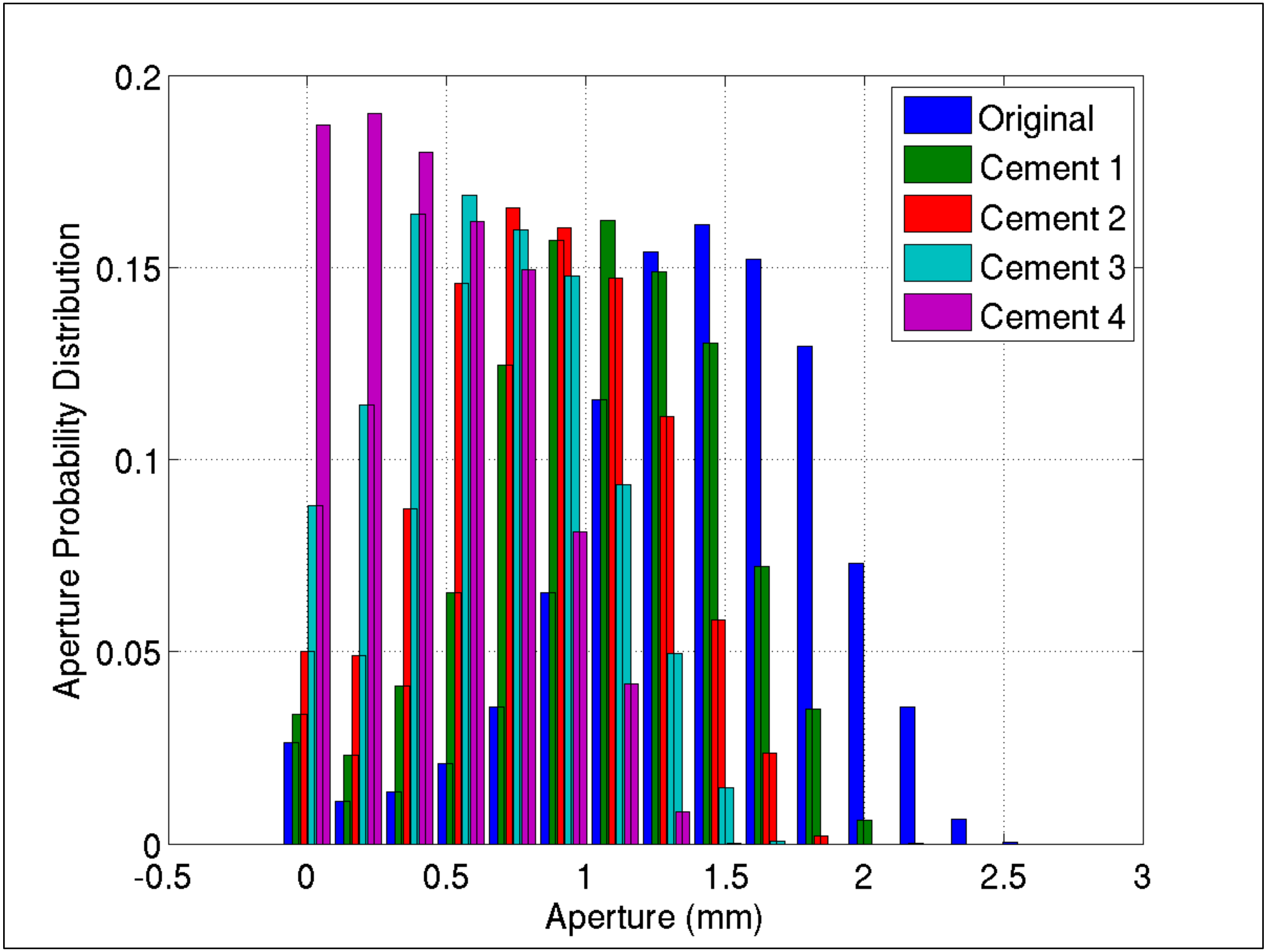

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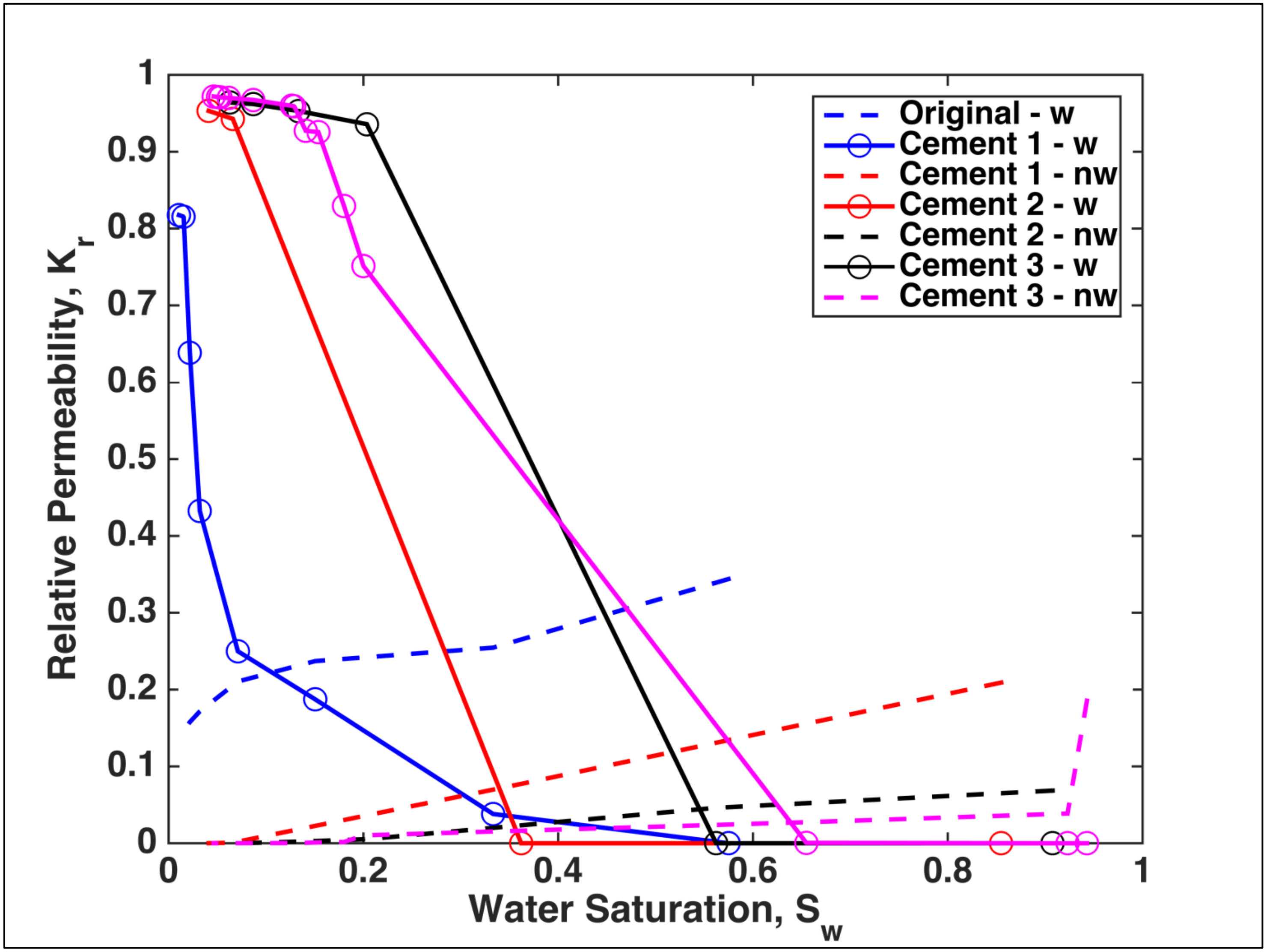

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