26 Microbially Induced Carbonate Precipitation in the Subsurface

Fundamental Reactions and Transport Processes

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26.1 INTRODUCTION

Many microorganisms are capable of inducing carbonate mineral precipitation under certain conditions. Not to be confused with structured biomineralization in eukaryotes for bones and shells, bacteria can indirectly cause precipitation, being a by-product of alkalinity increasing metabolisms, such as photosynthesis, urea hydrolysis, sulfate reduction, nitrate reduction, and iron reduction. The geologic record holds many examples of microbially produced carbonates, and presently the process is being utilized to manipulate porous media properties (De Muynck et al., 2010; Riding, 2000). Applications in porous media are numerous but can generally be divided into either increasing the material strength or reducing permeability (Phillips et al., 2013). The microbiology of such systems will be discussed including metabolisms, biofilm concepts, and biological reaction rates, followed by mineral precipitation fundamentals and reactive transport modeling approaches.

Microbial activity can induce a cascade of physical and chemical changes, which can include the shift of carbonate equilibrium chemistry, precipitation, and changes to system hydrodynamics. Changes in hydrodynamics in turn can change the reaction and transport in biofilm- and mineral-affected porous media. Both Darcy-scale and pore-scale reactive transport concepts will be discussed, and classical porous media methodology will be applied to microbially induced carbonate precipitation (MICP) systems.

In the subsurface, microorganisms have a close association with the surfaces of the porous medium they live in making them potentially sensitive to changes to those porous media surfaces. Precipitation can cause physical and chemical changes to the surfaces the microbes are attached to and, as a result, can change the reactive transport behavior in the porous medium. Additionally, precipitation can change the local physical and chemical environments thus altering microbial activity and in mixed microbial communities potentially shifting local populations. As shown in Figure 26.1, many processes can occur during MICP and affect reactive transport, porous media morphology, and biogeochemical conditions. Before precipitation, attached microorganisms can affect flow by the formation of biofilm. Once precipitation commences, additional pore space reduction can occur along with the potential for inactivation of biomass through encapsulation in the precipitate (Al Qabany et al., 2012; Cuthbert et al., 2012; Schultz et al., 2011). Planktonic and attached microbes have the potential to cause precipitation in the bulk fluid. These precipitates can be deposited downstream and cause an additional reduction in porosity and permeability.

The aim of this chapter is to describe the major pore-scale processes associated with MICP and put them in the context of porous media reactive transport modeling approaches. First, MICP is divided into biological, physical, and geochemical subprocesses; their interactions are discussed at the pore scale, and finally it is discussed how these processes and interactions affect local and system-wide reactive transport. The chapter as a whole is intended to serve as an

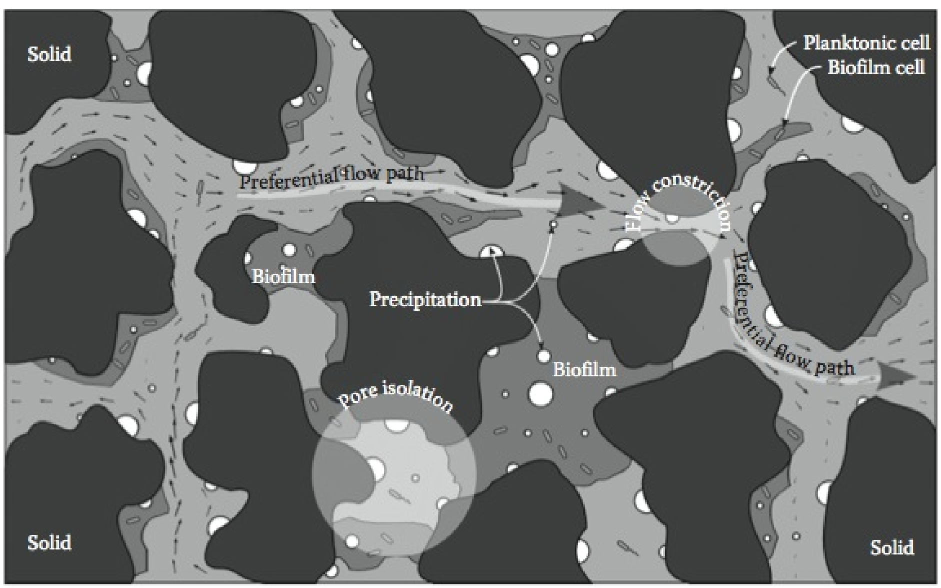

FIGURE 26.1 Fluid flow and reactive processes affecting MICP at the pore network scale. Microbial cells exist either in a freely floating planktonic state or in a biofilm. Precipitation can occur in suspension, in the biofilm or on solid surfaces. Biofilm and precipitates affect local hydrodynamics if they are present in sufficient quantities by blocking pore throats, isolating pores, and constricting flow. Stagnant zones and preferential flow pathways develop leading to pore-scale chemical, physical, and potentially biological heterogeneity.