Effect of faceting on olivine wetting properties

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ABSTRACT

Grain-scale pore geometry primarily controls the fluid distribution in rocks, affecting material transport and geophysical response. The dihedral angle (θ) in the olivine-fluid system is a key parameter determining pore fluid geometry in mantle wedges. In the system, curved and faceted olivine-fluid interfaces define θ, resulting in faceted-faceted (FF), faceted-curved (FC), and curved-curved (CC) angles. The effect of faceting on θ under various pressure and temperature (P-T) conditions and fluid compositions, however, has not been constrained, and mineralogical understanding remains unresolved. This study evaluated faceted-bearing θ and their proportions in olivine-multicomponent aqueous fluid systems. Our results show that 1/3 of olivine-fluid θ are faceted-bearing angles, regardless of the P-T conditions and fluid composition. Faceting produces larger dihedral angles than CC angles. The grain boundary plane (GBP) distribution reveals that the GBPs of faceted interfaces at triple junctions have low Miller index faces ({100}, {010}, and {101}). The misorientation angle/axis distributions of adjacent grain pairs are in accord with a theoretical distribution of random olivine aggregate. Moreover, the calculation of the FF angles for adjacent grain pairs with low Miller index GBPs reproduces measured angle values based on the olivine crystal habit. Therefore, our study suggests that the FF angle is strongly affected by olivine crystallography. The presence of faceting increases θ and a critical fluid fraction (φc) for percolation, lowering permeability. In the mantle wedge, where olivine crystallographic preferred orientation (CPO) is expected owing to corner flow, increasing the FF angle proportion with associated changes in fluid pore morphology will lead to permeability anisotropy, and controlling the direction of the fluid flow, and it will result in geophysical anomalies such as seismic wave attenuation and high electrical conductivity.

Keywords: Dihedral angle, faceted plane, Miller index, crystallographic orientation, permeability anisotropy, mantle wedge

INTRODUCTION

Pore geometry significantly controls the distribution of geological fluids (i.e., aqueous fluids and silicate melt) in deep mantle wedges, thereby affecting element cycling and geophysical responses in subduction zones (Watson and Brenan 1987; Hermann et al. 2006; Iwamori 1998; van Keken et al. 2011; Pommier and Evans 2017; Worzewski et al. 2011; Zheng et al. 2016). Although channelized fluid flow has often been inferred from field studies (Angiboust et al. 2014), pervasive grain-scale fluid flow may be the most plausible fluid migration regime at high-pressure (P) and high-temperature (T) conditions where dissolution-precipitation intensively operates and interfacial energy minimization (“textural equilibrium”) is quickly attained. Moreover, the pervasive fluid flow may be suitable for explaining the resistivity anomalies observed at a magnetotelluric (MT) grid scale (commonly >10 km) because it would be required for the channelized flows to be distributed continuously and nearly isotropically over this length scale. In an olivine-dominant mantle rock, the olivine-fluid dihedral angle (θ) is the primary parameter controlling grain-scale fluid connectivity (Toramaru and Fujii 1986; Mibe et al. 1999; Huang et al. 2019, 2020). Therefore, a precise constraint on θ in the olivine-fluid system is important for a complete understanding of the fluid distribution and migration in subduction zones.

The dihedral angle is a consequence of the fluid-mineral interaction, which changes the fluid pore geometry through dissolution and precipitation processes to minimize the interfacial energy in the system. It is defined as the ratio of the grain boundary energy (γs) to the solid-fluid interfacial energy (γsf) (Smith 1948) as follows:

\[ 2\cos(\theta/2) = \frac{\gamma_s}{\gamma_{sf}} \] (1)

In an isotropic system where solid-fluid interfaces are smoothly curved with a constant mean curvature; the equilibrium