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Evaluation of the elasticity normal to the basal plane of non-expandable 2:1 phyllosilicate minerals by nanoindentation

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Abstract

Nanoindentation experiments were conducted to investigate the elasticity normal to the basal plane of six non-expandable, hydrous 2:1 phyllosilicate minerals (pyrophyllite, talc, biotite, two muscovite samples, and margarite) with layer charge z ranging from 0 to 1.823 per $O_{10}(OH)_2$. For the examined indentation depth h of ≤200 nm, the measured Young's modulus E decreases with increasing h. Furthermore, the rate of reduction in the apparent E, in general, decreases with increasing z. The dependence of apparent E on h is attributed to indentation-induced inelastic deformation, particularly the deformation related to the high local stresses beneath the indenter tip, such as kink band formation, layer delamination, void generation, and cracking, which tend to cause damage to the layer structure. To minimize the influence of inelastic deformation on the measurement of E by indentation, the maximum E at small h is proposed to be the truly representative elastic modulus. The stiffest species, margarite, with $z = 1.823$, has a representative E of 165.5 GPa, seven times greater than that of pyrophyllite with $z = 0$ and $E = 23.5$ GPa. A nearly linear correlation between the representative E and the square of the ratio of the surface charge density σ to half of the basal spacing $d(001)$, $[2\sigma/d(001)]^2$, exists. This relationship suggests that the elasticity normal to the basal plane of these phyllosilicates is primarily controlled by the long-range electrostatic attractions between the 2:1 layer and interlayer cations instead of atomic bonds within the 2:1 layer, although other compositional and structural variations also affect the interlayer interactions. This relationship may indicate that the interlayer complexes can be used as the elasticity signatures of phyllosilicate minerals.

Keywords: Elasticity, interlayer interactions, nanoindentation, phyllosilicates, Young's modulus