The elastic tensor of monoclinic alkali feldspars

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ABSTRACT

The full elastic tensors of two K-rich monoclinic alkali feldspars, Or83Ab15 sanidine and Or85Ab7 orthoclase, have been determined by using the Impulse Stimulated Light Scattering technique to measure surface acoustic wave velocities. The new data confirm that alkali feldspars exhibit extreme elastic anisotropy, so the bounds of their isotropic average properties span a wide range. The measured adiabatic moduli are, for Or83Ab15 and Or85Ab7, respectively, KReuss = 54.7(7), 54.5(5) GPa; KVogt = 62.9(1.1), 64.4(0.6) GPa; GReuss = 24.1(1), 24.5(1) GPa; and GVogt = 36.1(5), 36.1(7) GPa. The small differences in moduli between the samples suggests that variations in composition and in state of Al, Si order only have minor effects on the average elastic properties of K-rich feldspars. The new measurements confirm that the earliest determinations of elastic wave velocities of alkali feldspars, widely used to calculate wave velocities in rocks, resulted in velocities systematically and significantly too slow by 10% or more.

Keywords: Alkali feldspar, elastic tensor, impulse stimulated light scattering

INTRODUCTION

To be able to understand and interpret the seismic signal from the Earth in terms of phase stabilities and to obtain information about fabric, texture, and mineralogy from seismic wave speeds, full knowledge of the anisotropic elastic properties of minerals is required. From these, the wave velocities can be determined. For example p-wave velocities are equal to (c/r)p where c’ is the compressional modulus in the wave propagation direction and r the density. Full elastic tensors are also required to interpret diffusion in feldspars (e.g., Schäffer et al. 2014), the morphology of microstructures such as perthite exsolution in feldspars (e.g., Williame and Brown 1974) or the orientation and properties of twin walls (e.g., Salje 2015). Elastic properties are also estimated to contribute to about 50% of the free energy change of displacive structural phase transitions in feldspars (Carpenter and Salje 1994, 1998). An invariant of the full elastic tensor is the bulk modulus, required to define the volume variation with pressure and thus the thermodynamic stability of minerals.

Feldspars constitute the most volumetrically important constituent of the Earth’s crust, and alkali feldspars are important in deep subduction and high-pressure metamorphism. Yet, the most widely used elastic data for K-rich alkali feldspars continues to be that of Ryzhova and Aleksandrov (1965), obtained by measurements of ultrasonic wave velocities in pseudo-single-crystals of perthites, an intergrowth of albite and K-feldspar, at room conditions. Not only are these velocity data therefore not representative of a single-phase K-rich feldspar, but in situ high-pressure wave velocity measurements on similar feldspars showed that the room-pressure measurements of Ryzhova and Aleksandrov (1965) yielded p-wave velocities that are systematically slow by between 10 and 30% (Simmons 1964; Christensen 1966). This discrepancy was attributed to the crystals containing cleavage partings and other defects, which are open at room pressure and only closed under several kilobars of external pressure. This was confirmed by the determination of the full elastic tensor of a gem-quality crystal of monoclinic Or83Ab15 sanidine by ultrasonic resonance measurements (Hausühl 1993), which yielded significantly stiffer values of the individual moduli than those of Ryzhova and Aleksandrov (1965), corresponding to higher wave velocities. Furthermore, the compliances eij of Hausühl (1993) yield a value of the Reuss bulk modulus KReuss = 55.7 GPa in reasonable agreement with values of 52(1) and 57(1) GPa determined from two K-rich sanidines by single-crystal diffraction (Angel 1994), and significantly higher than the range of KReuss = 39 to 51 GPa from Ryzhova and Aleksandrov (1965). The single-crystal elastic moduli of albite reported by Ryzhova and Aleksandrov (1965) were also shown to be too soft by Brown et al. (2006), who also demonstrated that their data acquisition scheme was actually insufficient to determine all 13 independent elastic tensor components of monoclinic crystals.

Thus, the only previously published data for the full elastic tensor of K-rich feldspars that is not known to be problematic is the determination by Hausühl (1993). We have, therefore, undertaken a determination of the full elastic tensors of two additional well-characterized monoclinic K-rich feldspars with differing states of Al, Si order and differing compositions. Together with the results from Hausühl (1993) they provide a first indication of the possible effects of composition and state of order on the elastic properties of K-rich feldspars and, in combination with the elastic tensor