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Seismic detectability of carbonates in the deep Earth: A nuclear inelastic scattering study

Stella Chariton[1,*], Catherine McCammon[1,†], Denis M. Vasiukov[2], Michal Stekiel[3], Anastasia Kantor[1,4], Valerio Cerantola[4], Ilya Kupenko[5], Timofey Fedotenko[2], Egor Koemets[1], Michael Hanfland[4], Alexandr I. Chumakov[4], and Leonid Dubrovinsky[1]

[1]Bayerisches Geoinstitut, Universität Bayreuth, 95440 Bayreuth, Germany
[2]Laboratory of Crystallography, Universität Bayreuth, 95440 Bayreuth, Germany
[3]Institute of Geosciences, Goethe Universität, 60438 Frankfurt am Main, Germany
[4]ESRF, The European Synchrotron, CS40220, 38043 Grenoble Cedex 9, France
[5]Institute for Mineralogy, Universität Münster, 48149 Münster, Germany

Abstract

Carbonates play an important role in the transport and storage of carbon in the Earth's mantle. However, the abundance of carbon and carbonates in subduction zones is still an unknown quantity. To determine the most abundant accessory phases and how they influence the dynamical processes that operate within the Earth, investigations on the vibrational, elastic, and thermodynamic properties of these phases are crucial for interpreting seismological observations. Recently, the nuclear inelastic scattering (NIS) method has proved to be a useful tool to access information on the lattice dynamics, as well as to determine Debye sound velocities of Fe-bearing materials. Here we derive the acoustic velocities from two carbonate compositions in the $FeCO_3$-$MgCO_3$ binary system up to ~70 GPa using the NIS method. We conclude that more Mg-rich samples, in this case $(Fe_{0.26}Mg_{0.74})CO_3$, have ~19% higher sound velocities than the pure end-member Fe composition. In addition, we observed a significant velocity increase after the Fe^{2+} spin transition was complete. After laser heating of $FeCO_3$ at lower mantle conditions, we observed a dramatic velocity drop, which is probably associated with thermal decomposition to another phase. Parallel to our NIS experiments, we conducted a single-crystal X-ray diffraction (SCXRD) study to derive the equation of states of $FeCO_3$ and $(Fe_{0.26}Mg_{0.74})CO_3$. The combined information from NIS (i.e., Debye velocities) and SCXRD (i.e., densities and bulk moduli) experiments enabled us to derive the primary and shear wave velocities of our samples. Our results are consistent with results obtained by other methods in previous studies, including Brillouin spectroscopy, inelastic X-ray scattering, and DFT calculations, supporting NIS as a reliable alternative method for studying the elastic properties of Fe-bearing systems at high pressures and temperatures. Finally, we discuss the seismic detectability of carbonates. We determine that nearly 22 wt% CO_2 must be present in the subduction slab to detect a 1% shear wave velocity decrease compared to non-carbonated lithologies at the transition zone to lower mantle boundary depths.

Keywords: Nuclear inelastic scattering, Fe-bearing carbonates, high pressure and temperature, spin transition, elastic wave velocities