Jadeite and related species in shocked meteorites: Limitations on inference of shock conditions

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ABSTRACT

Jadeite is frequently reported in shocked meteorites, displaying a variety of textures and grain sizes that suggest formation by either solid-state transformation or by crystallization from a melt. Sometimes, jadeite has been identified solely on the basis of the Raman spectra. Here we argue that additional characterization is needed to confidently identify jadeite and distinguish it from related species. Based on chemical and spectral analysis of three new occurrences, complemented by first-principles calculations, we show that related pyroxenes in the chemical space (Na)⁶Mg(Al)⁶(Si)⁶O₁₂-(Ca)⁴Mg(Al)⁴(Si)⁴O₁₀ with up to 2.25 atoms Si per formula unit have spectral features similar to jadeite. However, their distinct stability fields (if any) and synthesis pathways, considered together with textural constraints, have different implications for precursor phases and estimates of impactor size, encounter velocity, and crater diameter. A reassessment of reported jadeite occurrences casts a new light on many previous conclusions about the shock histories preserved in particular meteorites.

Keywords: High-pressure polymorphs, spectroscopy, planetary, pyroxenes, chondrites

INTRODUCTION

Plagioclase is common in Earth’s crust and in many differentiated (e.g., shergottites and eucrites) and undifferentiated meteorites. Under the extreme temperature (T) and pressure (P) conditions that are reached during collisions on and among meteorite parent bodies, sodic plagioclase may transform into a variety of high-pressure (HP) forms, including hollandite-structured lingunite (Gillet et al. 2000; Baziotis et al. 2013; Kubo et al. 2017), amorphous maskelynite, jadeite plus a silica phase, or the recently discovered albitic jadeite (Ma et al. 2022). In any closed-system transformation, albite that decomposes to stoichiometric jadeite must also form excess SiO₂ in the form of stishovite, coesite, or an amorphous phase (James 1969; Liu 1978; Yagi et al. 1994; Kubo et al. 2010). The phase of SiO₂ that forms depends on peak pressure as well as kinetic factors (Kubo et al. 2010, 2015; Černok et al. 2017). Another transformation path, however, is from albite to albitic jadeite—a super-silicic, vacancy-rich pyroxene with excess Si occupying octahedral M1 sites (Ma et al. 2022). Tissintnite, the Ca-rich analog of albitic jadeite, forms only from more calcic plagioclase (Rucks et al. 2018); it has been observed so far only in eucrites and Martian meteorites (Pang et al. 2016; Ma et al. 2015).

The presence of true stoichiometric jadeite in a given meteorite suggests that it experienced a given set of P and T conditions, especially when found in combination with a particular high-pressure silica phase, bounded by the thermodynamic equilibrium reaction albite → jadeite + SiO₂. However, it is also possible—due to kinetic reasons—to form jadeite metastably under unknown P-T conditions. In other contexts, meteoritic jadeite may occur without accompanying silica, suggesting either subsolidus recrystallization or growth from a melt. On the other hand, albitic jadeite and other minerals with a related structure have similar physical properties but unknown and presumably different formation conditions. It is therefore critical to ensure that a meteorite contains true jadeite before using its occurrence to constrain shock conditions. It is also an important research goal to experimentally calibrate the shock conditions for the synthesis of albitic jadeite and other forms.

However, distinguishing among jadeite and its relatives is challenging. Several studies have claimed the presence of jadeite on the basis of optical petrography or Raman spectroscopy alone, without confirmation by chemical analysis or a structure-sensitive method such as electron backscatter diffraction (EBSD). One challenge is that the disorder and strain of the crystal due to substitutions and vacancies on certain cation sites can influence the stability of the crystal under irradiation by lasers, X-rays, or high-energy electron beams. Albitic jadeite, for example, is observed to be acutely sensitive to electron beams, becoming