A high-pressure, clinopyroxene-structured polymorph of albite in highly shocked terrestrial and meteoritic rocks

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ABSTRACT

Clinopyroxenes with excess Si have been described in run products from high-pressure experiments and inferred to have existed in nature from retrograde transformation phases. Here, we present the discovery of albitic jadeite, \((\text{Na,Ca,Al}_6\text{Si}_8\text{O}_{20})(\text{Al,Si})\text{Si}_2\text{O}_6\)—the first natural, sodic clinopyroxene with excess Si occupying the octahedral cation site, \(M1\), and a corresponding \(\frac{1}{4}\) vacancy on the \(M2\)-site in the Ries impact structure and in a suite of \(L6\) ordinary chondrites, EET 13014, EET 13052, NWA 1662, and TIL 08001. Garnet compositions in these samples indicate shock pressures of 18–22 GPa. Based on our survey, albitic jadeite is likely to be rather common in terrestrial and meteoritic shock-metamorphic environments. Shock-generated jadeite should be reexamined with respect to excess Si.

Keywords: Albitic jadeite, \((\text{Na,Ca,Al}_6\text{Si}_8\text{O}_{20})(\text{Al,Si})\text{Si}_2\text{O}_6\), high-pressure clinopyroxene, shock-induced phase, Ries impact structure, \(L6\) ordinary chondrites

INTRODUCTION

At low pressures, Si exclusively occupies tetrahedral sites in clinopyroxene. A compositional analysis that indicates more Si than can be accommodated in tetrahedral coordination generally reflects a poor analysis or contamination of the analytical volume by some other phases. However, clinopyroxenes that were synthesized in high-pressure experiments clearly exhibit Si, not only on the tetrahedral but also on the octahedral \(M1\) site. Charge-balancing of excess Si is usually achieved through compensating vacancies on the \(M2\) site (e.g., Angel et al. 1988; Liou et al. 1998), although octahedral vacancies at high pressure can also be mediated by Al (e.g., Wood and Henderson 1978; Ma et al. 2015). Regardless of the actual mechanism, increasing vacancies on the \(M2\) site with increasing depth has been proposed to play an important role in the distribution water in the sublithospheric mantle (e.g., Bell and Rossman 1992; Warren and Hauri 2014).

The presence of octahedral Si in clinopyroxene equilibrated at high pressures is well established by direct observations on synthetic clinopyroxenes (e.g., Angel et al. 1988; Yang et al. 2009). The case for octahedral Si in natural pyroxenes is less direct. There is no evidence, for example, that omphacite, the dominant pyroxene in subducted slabs, contains octahedrally coordinated Si. Omphacite phenocrysts from some exhumed ultrahigh-pressure metamorphic terrains do, however, exhibit oriented lamellae of quartz or coesite, and these lamellae are often interpreted to be the exsolution products of a former excess Si component upon exhumation and indicative of the high-peak pressures experienced by these rocks (e.g., Zhang et al. 2005).

In static high-pressure, high-temperature experiments, albite \((\text{NaAlSi}_3\text{O}_8)\) breaks down to form jadeite \((\text{NaAlSi}_2\text{O}_6)\) and a dense \(\text{SiO}_2\) phase, either coesite or stishovite (e.g., Liu 1978). On Earth, the formation of jadeite \((\text{NaAlSi}_2\text{O}_6)\) through dissociation of albite plagioclase in metapelites or basalt marks the onset of eclogitization in high-pressure metamorphic environments. The same reaction has also been reported from shocked ordinary chondrites (e.g., Tropper et al. 1999; Miyahara et al. 2013). Here, we report a new vacancy-stabilized, high-pressure, high-temperature clinopyroxene with Si on the \(M1\) site and a composition essentially equivalent to that of albitic plagioclase. This clinopyroxene is formed by shock metamorphic transformation of albite in terrestrial impactites and ordinary chondrites. It has not been previously observed or synthesized and, therefore, it provides potential new insights into shock conditions and impact processes.

We examined an amphibolite xenolith from suevite of the Ries impact structure and the \(L6\) ordinary chondrites EET 13014, EET 13052, TIL 08001, and NWA 1662 with advanced electron-beam and synchrotron X-ray techniques and discovered a highly defective, shocked-induced, high-pressure albitic jadeite (Figs. 1–2). The new phase is an Na-analog of tissintite \([(\text{Ca,Na,Al}_6\text{Si}_8\text{O}_{20})\text{Al(Si,Al)}\text{Si}_2\text{O}_6]\) and has a structural formula of \((\text{Na,Ca,Al}_6\text{Si}_8\text{O}_{20})(\text{Al,Si})\text{Si}_2\text{O}_6\). Its composition ranges from \((\text{Na}_{0.67}\text{Ca}_{0.33})(\text{Al}_{0.75}\text{Si}_{0.25})\text{Si}_2\text{O}_6\) to \((\text{Na}_{0.90}\text{Ca}_{0.09}\text{Al}_{0.01}\text{Si}_{0.01})\text{Si}_2\text{O}_6\), which corresponds to plagioclase with An0-An33 compositions. A clinopyroxene with this structure exhibits a high concentration of excess Si on the octahedral cation \(M1\) site and an \(M2\) site with \(\frac{1}{4}\) vacancy. This clinopyroxene is a new high-pressure polymorph of albite.