Lattice-shear-induced metastable formation of high-pressure silicates in shocked meteorites

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Heavily shocked meteorites contain various types of high-pressure polymorphs of silicate minerals. These high-pressure minerals are micron to submicron sized and occurred within and in the vicinity of shock-induced melt in stony meteorites. Their occurrence suggests two types of formation mechanisms: (1) solid-state high-pressure transformation of the host-rock minerals into monomineralic polycrystalline aggregates, and (2) crystallization of chondritic or monomineralic melts under high pressure [1]. In some cases of the former process, high-pressure minerals occur as coherent lamellae within grains of the host low-pressure minerals. A typical example is the $(Mg,Fe)SiO_3$pyroxene-akimotoite intergrowth in the Tenham meteorite [2]. The akimotoite has relatively high Fe content [Fe/(Mg+Fe)=0.21] but does not have its stability field at any P-T conditions [3]. Therefore, the akimotoite would have been formed metastably due to a rapidly-changing P-T history in the shock event. As another example, a new high-pressure polymorph of olivine, which has been defined as “ε-phase” with a spinelloid structure, was recently discovered as nano-scale lamellae in ringwoodite [$(Mg,Fe)_2SiO_4$-spinel] and wadsleyite [$(Mg,Fe)_2SiO_4$ -spinelloid] grains in Tenham and Miami meteorites, respectively [4]. The phase has never been observed in previous phase equilibrium studies. Both pyroxene-akimotoite and ringwoodite/wadsleyite-ε-phase intergrowths have topotaxy with preserving close-packed oxygen layers for their respective structures. The crystallographic relationships between these host and the product phases suggest that these polymorphic phase transformations are promoted by shear mechanism [5]. This process is achieved by shear deformation of oxygen sublattice associating movements of interstitial cations within single unit-cell dimension. Therefore, shear mechanism is considered to be a favorable mechanism under high differential stress, or under relatively low-temperatures, where atomic diffusion is kinetically hindered. Future experimental studies, which include ultrafast in-situ X-ray diffraction under laser shock compression, and high-resolution electron microscopy on recovered specimens of static high-pressure experiments, would contribute to better understanding of detailed structural changes in naturally shocked samples.

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