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Evolution of Zakłodzie enstatite meteorite – insight from TEM analyses

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1. Introduction

The Zakłodzie meteorite is an achondritic-like rock with enstatite chondrite parentage [1,2,3]. Its texture indicative for complicated thermal history and various processes were proposed to account for this [1,2,3]. Based on the mineral composition it was concluded that the rock represents EL7 enstatite chondrite [1]. Twinned enstatite and zonal feldspar crystals in Zakłodzie were interpreted as formed by impact melting and rapid crystallization [2]. On the other hand, cumulate structure was considered to result from igneous processes and slow cooling of the meteorite [3]. The aim of presented study was to define whether Zakłodzie formed by shock event on chondritic parent body or by slow cooling from high temperatures typical for achondritic meteorites.

2. Samples and methods

The FIB-TEM measurements were performed on twinned pyroxene crystals from achondritic-like Zakłodzie meteorite. Several striated low-Ca pyroxene crystals were examined by Tecnai F20x-twin transmission electron microscope in GFZ, with a field emission gun electron source, operating at 200 kV.

3. Results

Analysis of thin foils reveals that the pyroxene has striated structure and consists of disordered mixture of both orthorhombic and monoclinic polymorphs. In high resolution images (Fig. 1) the polymorphs are heterogeneously distributed. Domains of monoclinic pyroxene are relatively broad (up to 40 nm in size i.e., they consist of more than 40 unit cells of cpx). The thickness of cpx domains is highly heterogeneous, and in some parts very thin lamella of cpx overgrown with opx are also abundant. Orthorhombic polymorph of pyroxene is minor. It forms usually very thin lamella, only limited number of lamella up to 20 nm in width was observed.

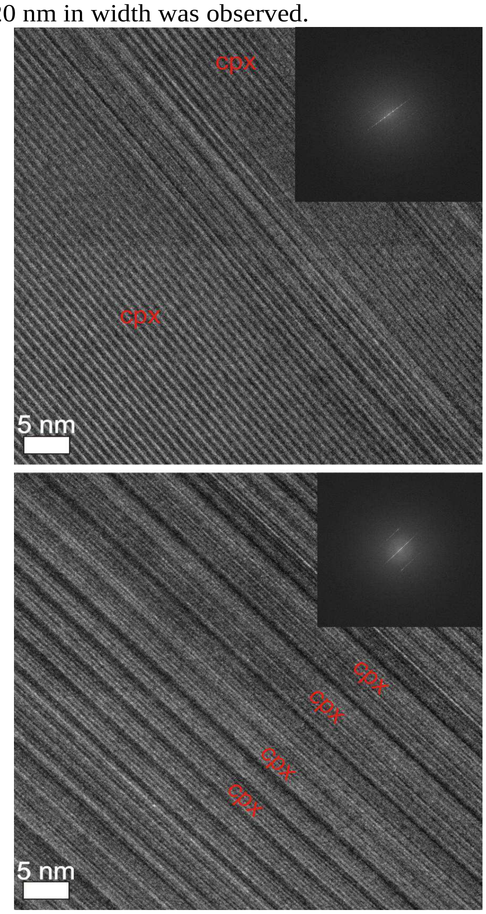

Figure 1: HR-TEM images and SADP of Zakłodzie meteorite showing high heterogeneity of clinopyroxene (cpx) and orthopyroxene (opx) distribution with dominance of cpx.

Electron diffraction patterns (Fig. 1) show strong streaking, confirming high degree of disorder of pyroxene. Streaking observed in diffraction patterns is most probably the result of the stacking disorder produced by the coherent interleaving of blocks of ortho- and clinoenstatite. However, strong diffraction maxima at 9Å are observed, characteristic of the domination of clinopyroxene (Fig. 1).

In regions of strong striation, pyroxene reveals additional diffraction contrast, manifesting in presence of short, up to 200 nm, domains located along individual lamella (Fig. 2a). Presence of such heterogeneously distributed domains is interpreted here as a result of kinking.

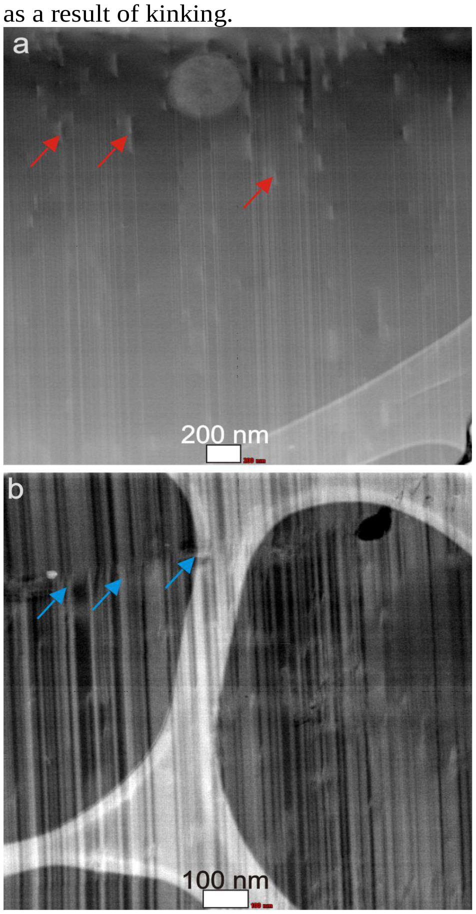

Figure 2: STEM images of Zakłodzie meteorite. a. Kinked lamella of pyroxene. b. Annealed crack.

In spite of being sheared and kinked, lamella are also cracked. In many cracks, traces of recrystallization and annealing are observed (Fig. 2b).

4. Discussion

Intergrowths of ortho- and clino- polymorphs of pyroxene can develop by a number of different mechanisms. They may form in response to high-temperature inversion from protoenstatite during cooling [4,5] or may result from annealing of clinopyroxene within orthopyroxene stability field, or in opposite conditions [4]. Additionally, intergrowths may form in sustained shearing, either homogeneous or heterogeneous (i.e., shock-related) [6].

Nanostructure of the rock-forming pyroxene in Zakłodzie i.e., heterogeneous distribution of orthorombic and monoclinic polymorhps, domination of clinopyroxene and large thickness of its domains (Fig. 1) are suggestive of pyroxene inversion due to shearing and shock [6]. Kinking of lamella (Fig. 2a) is in good agreement with such model of formation. Thus, the results suggest that Zakłodzie meteorite experienced severe shock event on the parent body, which was main event in its evolution. However, shock event itself is not sufficient to cause strong annealing observed in pyroxene of Zakłodzie (Fig. 2b). We suggest that after the shock event, the meteorite was buried in deep part of warm ejecta and thermally annealed. The temperatures attained for pyroxene annealing might have been sufficient to cause partial melting of plagioclase, observed in meteorite by [2,3]. Presented results demonstrate that the Zakłodzie meteorite is most probably genetically related to enstatite chondrites rather than to aubrites or primitive achondrites, despite of its achondritic-like texture.

Acknowledgements

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