LETTER

Steinhardtite, a new body-centered-cubic allotropic form of aluminum from the Khatyryka CV3 carbonaceous chondrite

LUCA BINDI1,*, NAN YAO2, CHANEY LIN3, LINCOLN S. HOLLISTER4, GLENN J. MACPHERSON5, GERALD R. POIRIER2†, CHRISTOPHER L. ANDRONICOS6, VADIM V. DISTLER7, MICHAEL P. EDDY8, ALEXANDER KOSTIN9, VALERY KRYACHKO7, WILLIAM M. STEINHARDT10 AND MARINA YUDOVSKAYA7

1Dipartimento di Scienze della Terra, Università di Firenze, Via La Pira 4, I-50121 Florence, Italy
2Princeton Institute for the Science and Technology of Materials, Bowen Hall, Princeton University, Princeton, New Jersey 08544, U.S.A.
3Department of Physics, Jadwin Hall, Princeton University, Princeton, New Jersey 08544, U.S.A.
4Department of Geosciences, Guyot Hall, Princeton University, Princeton, New Jersey 08544, U.S.A.
5Department of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, D.C. 20560, U.S.A.
6Division of Earth and Atmospheric Sciences, Purdue University, West Lafayette, Indiana 47907, U.S.A.
7Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry (IGEM), Russian Academy of Sciences, Starmonometny per. 35, Moscow, 119017 Russia
8Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, U.S.A.
9Geoscience Technology, BHP Billiton, Houston, Texas 77056, U.S.A.
10Department of Earth and Planetary Sciences, Harvard University, 20 Oxford Street, Cambridge, Massachusetts 02138, U.S.A.

ABSTRACT

Steinhardtite is a new mineral from the Khatyryka meteorite; it is a new allotropic form of aluminum. It occurs as rare crystals up to ~10 μm across in meteoritic fragments that contain evidence of a heterogeneous distribution of pressures and temperatures during impact shock, in which some portions of the meteorite reached at least 5 GPa and 1200 °C. The meteorite fragments contain the high-pressure phases ahrensite, coesite, stishovite, and an unnamed spineloid with composition Fe1−xSiOx (x ~ 0.4). Other minerals include trevorite, Ni-Al-Mg-Fe spinel, magnete, diopside, forsterite, clinoenstatite, nepheline, pentlandite, Cu-bearing troilite, icosahedrite, khrytikite, cupalite, taenite, and Al-bearing taenite. Given the exceedingly small grain size of steinhardtite, it was not possible to determine most of the physical properties for the mineral.

A mean of 9 electron microprobe analyses (obtained from two different fragments) gave the formula Al1xNi33,32Fe33,68, on the basis of 1 atom. A combined TEM and single-crystal X-ray diffraction study revealed steinhardtite to be cubic, space group Im3m, with a = 3.0214(8) Å, and \( V = 27.58(2) \text{ Å}^3 \), \( Z = 2 \). In the crystal structure \( [R_2 = 0.0254]\), the three elements are disordered at the origin of the unit cell in a body-centered-cubic packing (α-Fe structure type). The five strongest powder-diffraction lines \([d \text{ in Å} (hkl)]\) are: 2.1355 (100) (110); 1.5100 (15) (200); 1.2329 (25) (211); 0.9550 (10) (310); 0.8071 (30) (321).

The new mineral has been approved by the IMA-NMNC Commission (2014-036) and named in honor of Paul J. Steinhardt, Professor at the Department of Physics of Princeton University, for his extraordinary and enthusiastic dedication to the study of the mineralogy of the Khatyryka meteorite, a unique CV3 carbonaceous chondrite containing the first natural quasicrystalline phase icosahedrite.

The recovery of the polymorph of Al described here that contains essential amounts of Ni and Fe suggests that Al could be a contributing candidate for the anomalously low density of the Earth’s presumed Fe-Ni core.

**Keywords**: Aluminum, chemical composition, TEM, X-ray diffraction, new mineral, steinhardtite.

INTRODUCTION

In the course of a detailed investigation of fragments belonging to the Khatyryka meteorite (Steinhardt and Bindi 2012; MacPherson et al. 2013; Bindi and Steinhardt 2014), we found a metallic AlNiFe mineral (Hollister et al. 2014) that turned out to have the characteristics of a new mineral species.

Here we report the structural and chemical study leading to the description of this new mineral, which was named steinhardtite after Paul J. Steinhardt, Professor at the Department of Physics of Princeton University and Director of the Princeton Center for Theoretical Science, for his extraordinary and enthusiastic dedication to the study of the mineralogy of the Khatyryka meteorite, a unique CV3 carbonaceous chondrite hosting the first natural quasicrystal icosahedrite (Bindi et al. 2009, 2011, 2012). Moreover, decagonal quasicrystalline alloys have been described in the Al-Ni-Fe system (e.g., Lemmerz et al. 1994; Parshin et al. 2009), thus representing an added reason for the dedication: Steinhardt’s pioneering contribution to the theoretical development of quasipe-